

# Neural Dynamics For Embodied Cognition: Sequence generation

Gregor Schöner  
Institute for Neural Computation (INI)  
Ruhr-University Bochum

# Survey

## ■ Foundations 1: Neural dynamics [GS]

- Introduction to Cedar/Instabilities in DFT [Stephan Sehring]

## ■ Foundations 2: Dimensions/Binding [GS]

- Cedar architecture: visual search [Raul Grieben]

## ■ Foundations 3: Toward grounded cognition [GS]

- Cedar architecture: relational grounding [Daniel Sabinasz]

## ■ Foundations 4: Sequence generation [GS]

- Cedar architecture sequence generation [Minseok Kang]

- Sequence generation: problem and example
- Condition of satisfaction
- Who to activate next?
- Demonstration of sequence generation

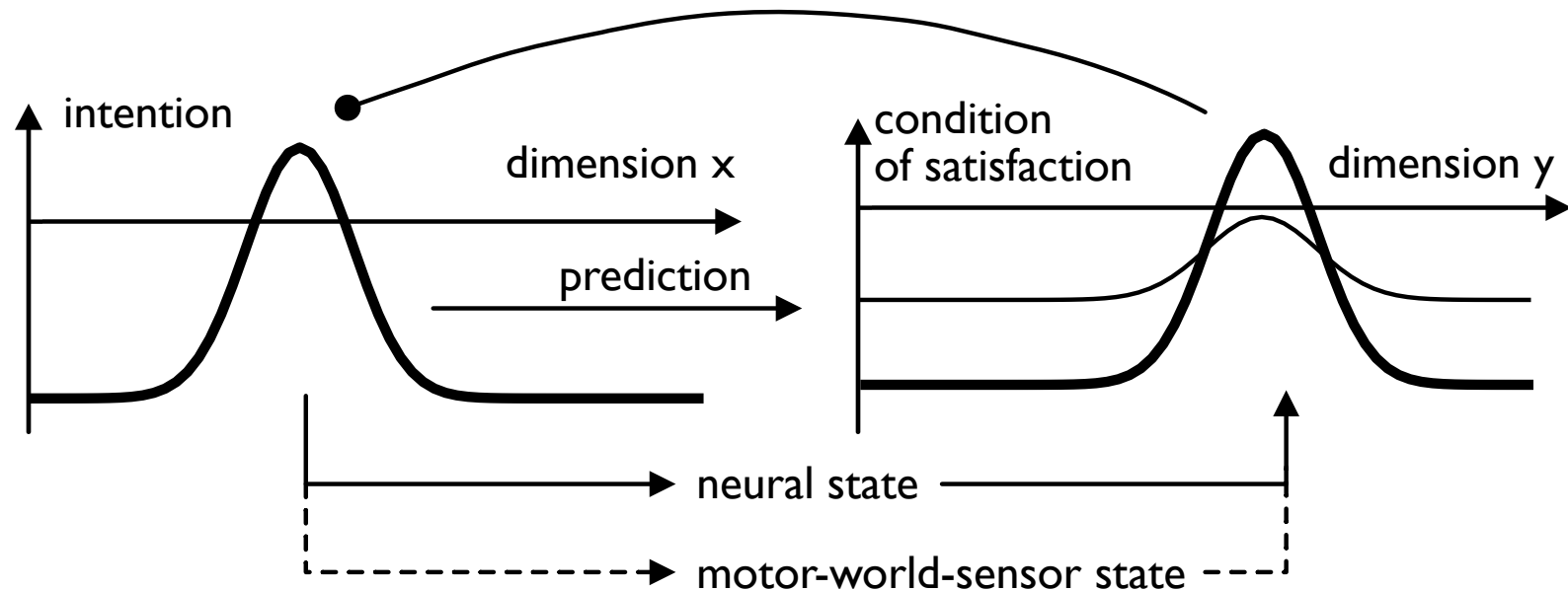
# The problem with sequences

- functionally significant neural states are attractors.. which resist change
- in a sequence of processing steps or actions, individual neural states must be given up ... to enable transition to new neural states...



# Outline of the answer

- the neural attractor = **intention** predicts its **condition of satisfaction**
- matching input detected => **detection instability**
- inhibits intention... => transition



# Sequence of physical acts

■ task: search for objects of a given color in a given order

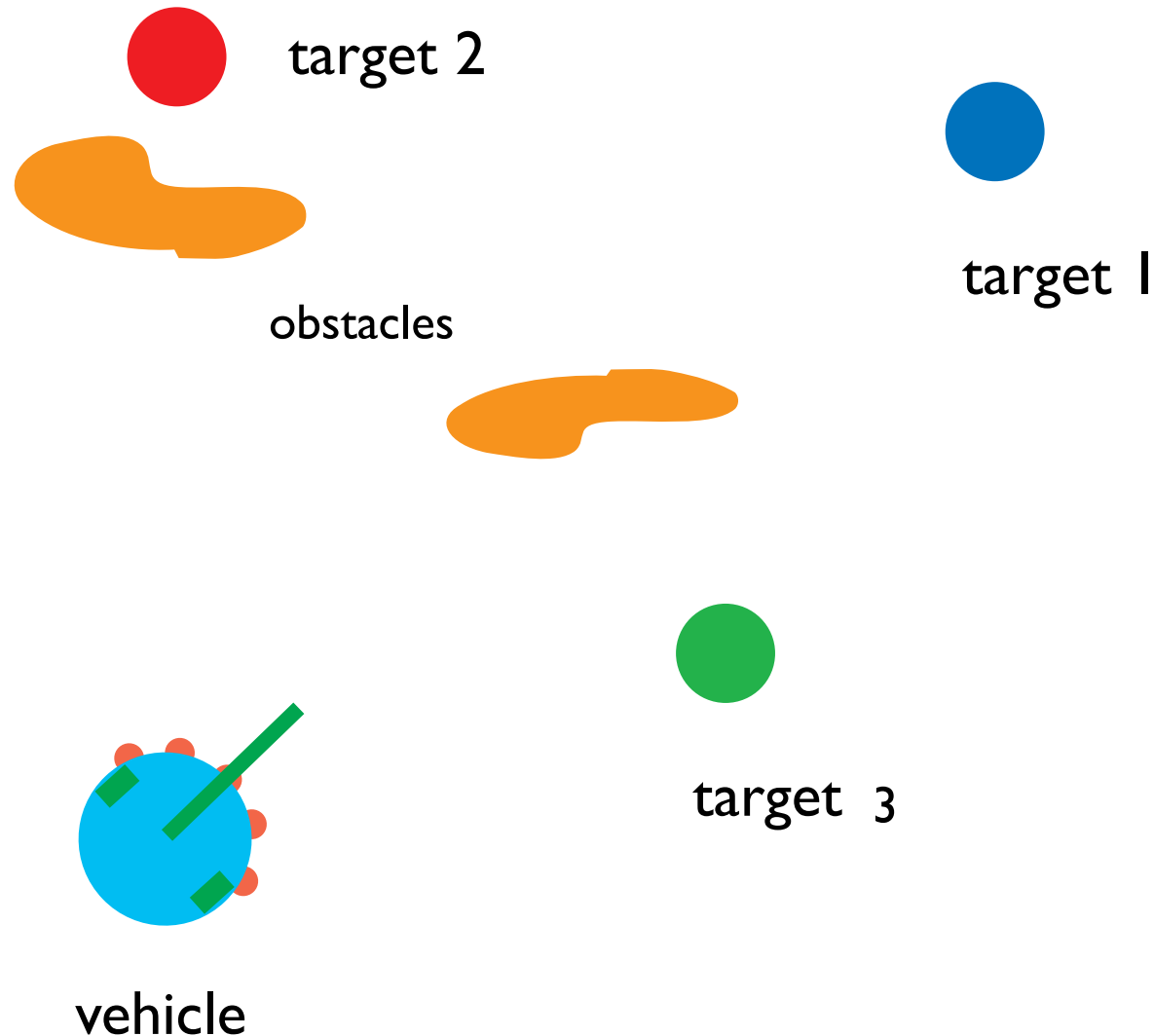
■ 1 blue

■ 2 red

■ green

■ stably couple to objects once they are detected

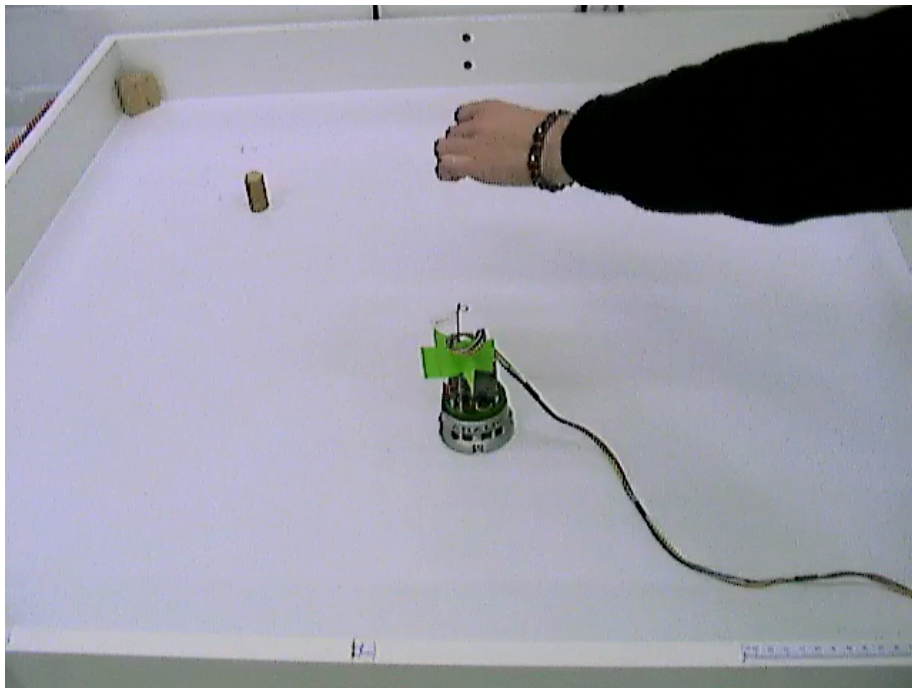
■ ignore objects when their turn has not yet come (distractors)



# Implementation as an imitation task

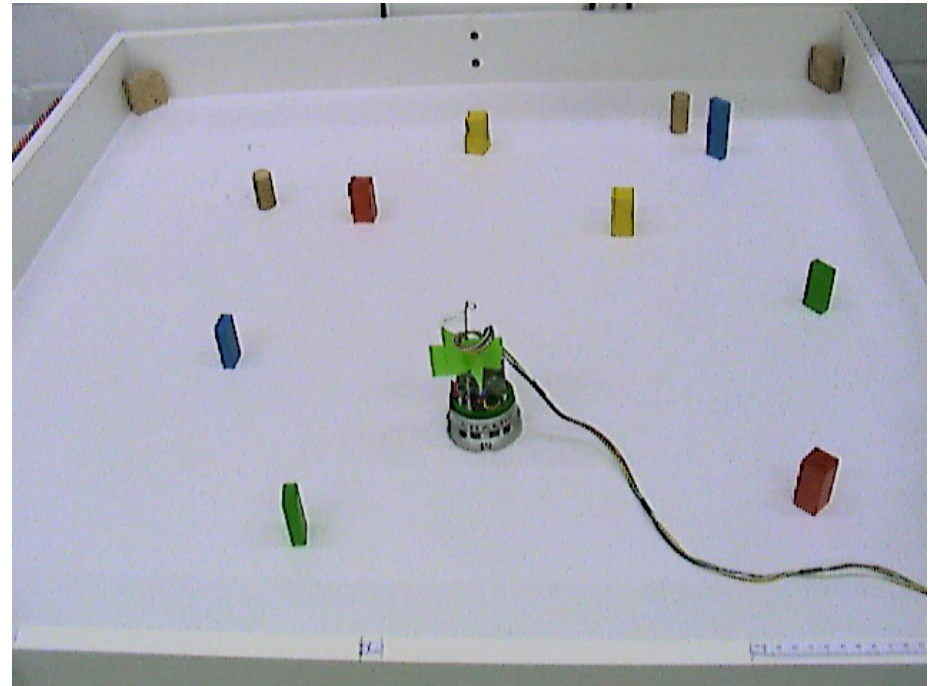
- learn a serially ordered sequence from a single demonstration

yellow-red-green-blue-red

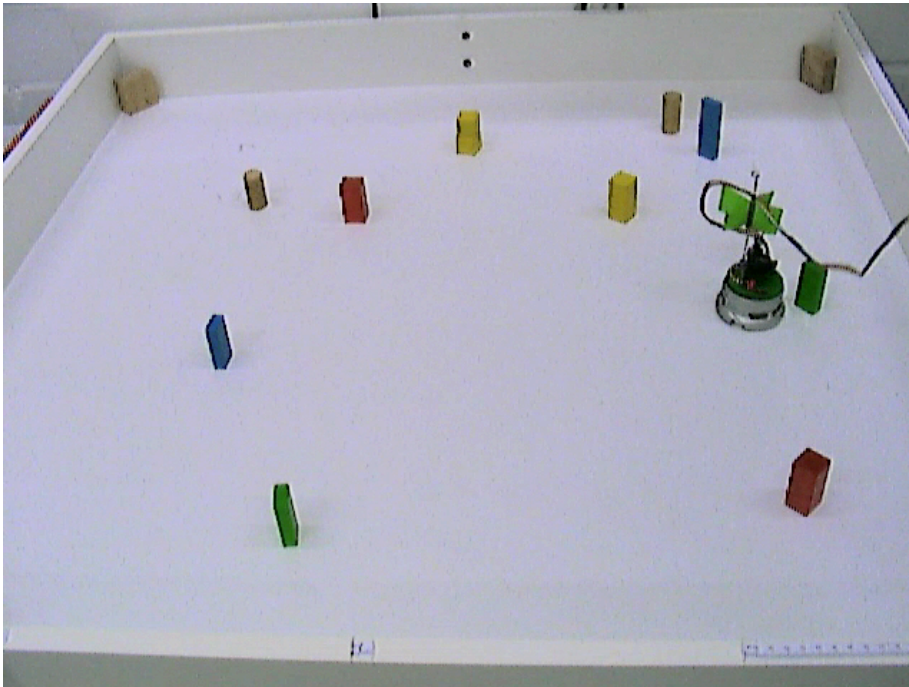


- perform the serially ordered sequence with new timing

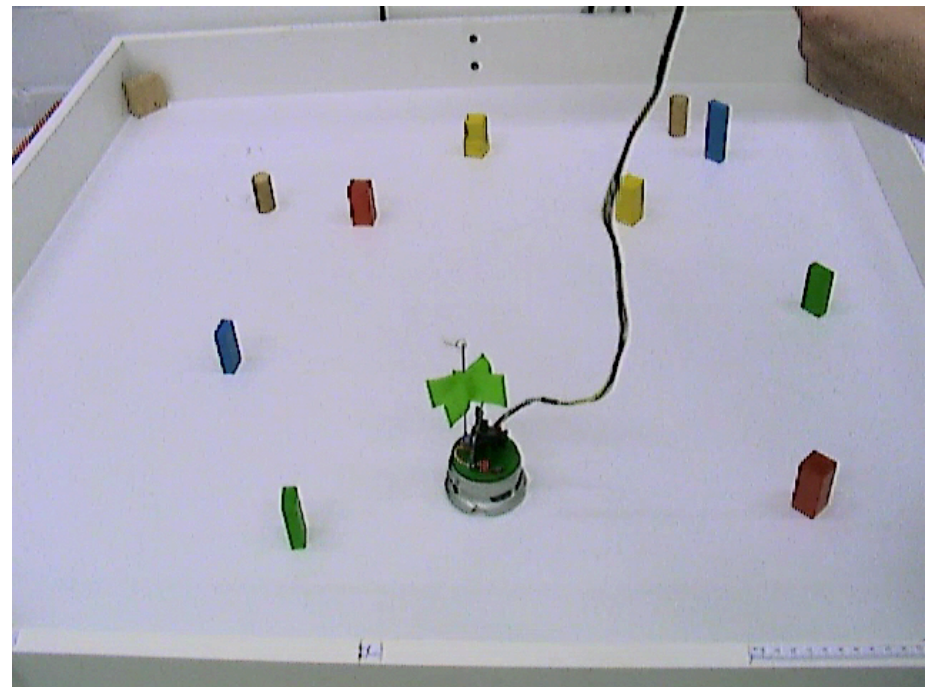
yellow-red-green-blue-red



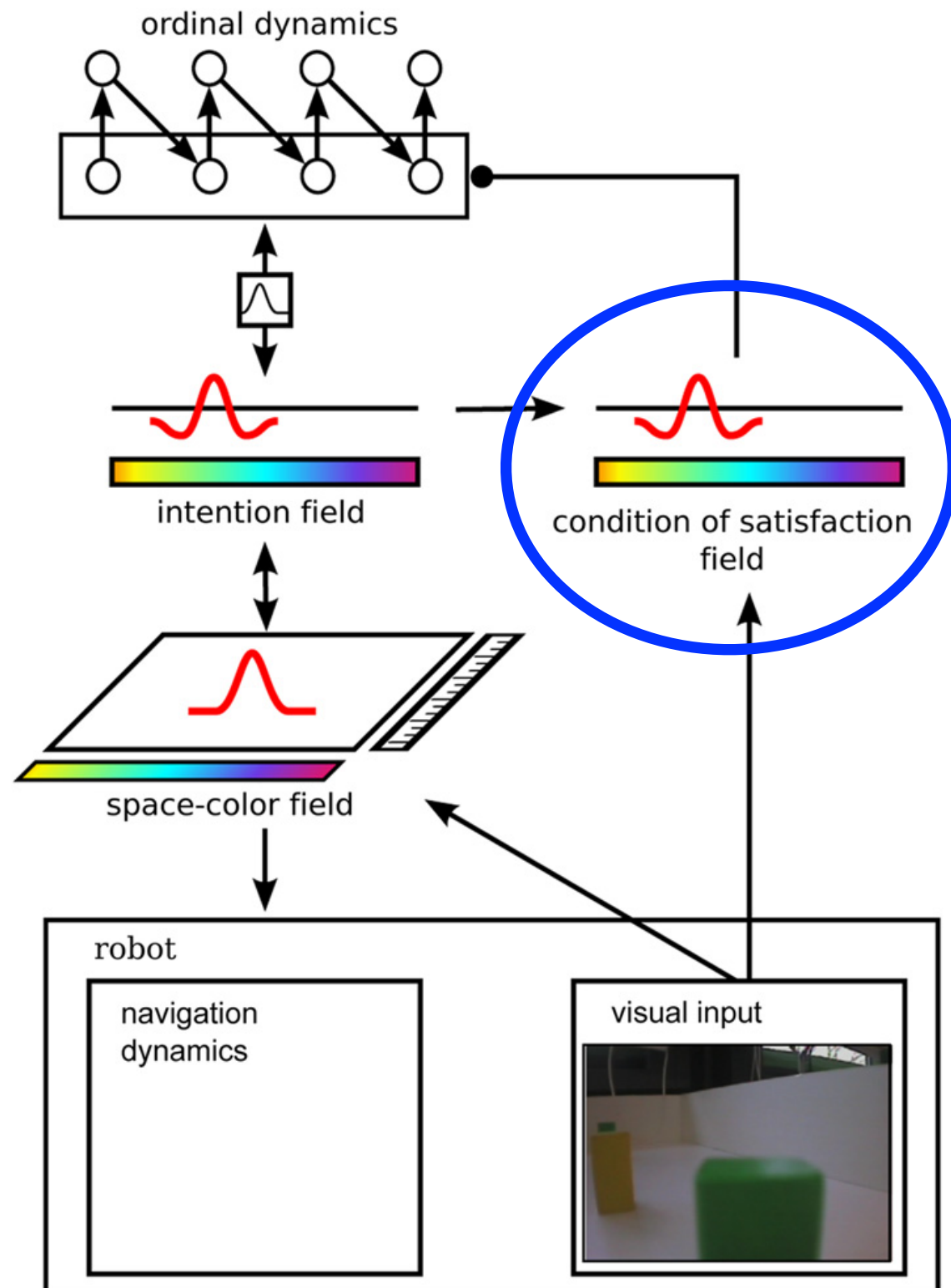
red a distractor



red a target



# Condition of Satisfaction (CoS)



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

# Visual input

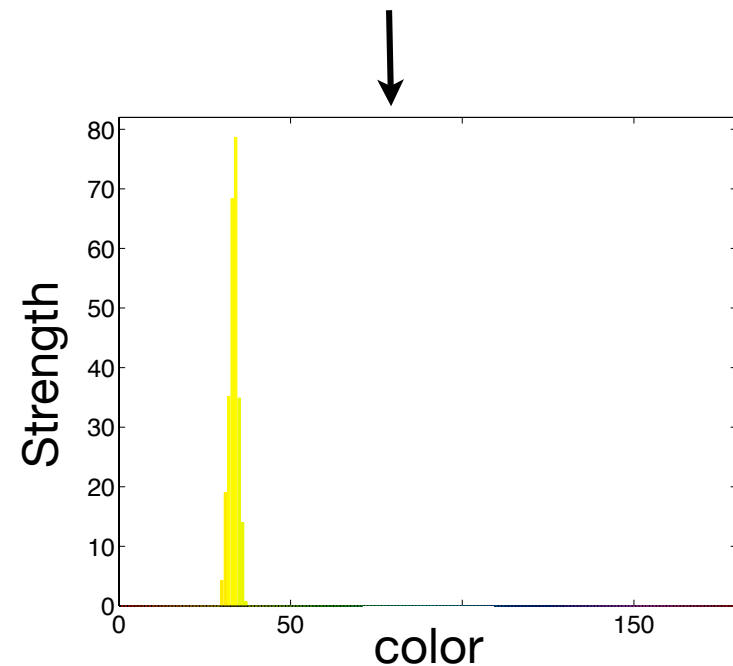
Camera image

■ 2D visual input

■ horizontal space

■ color

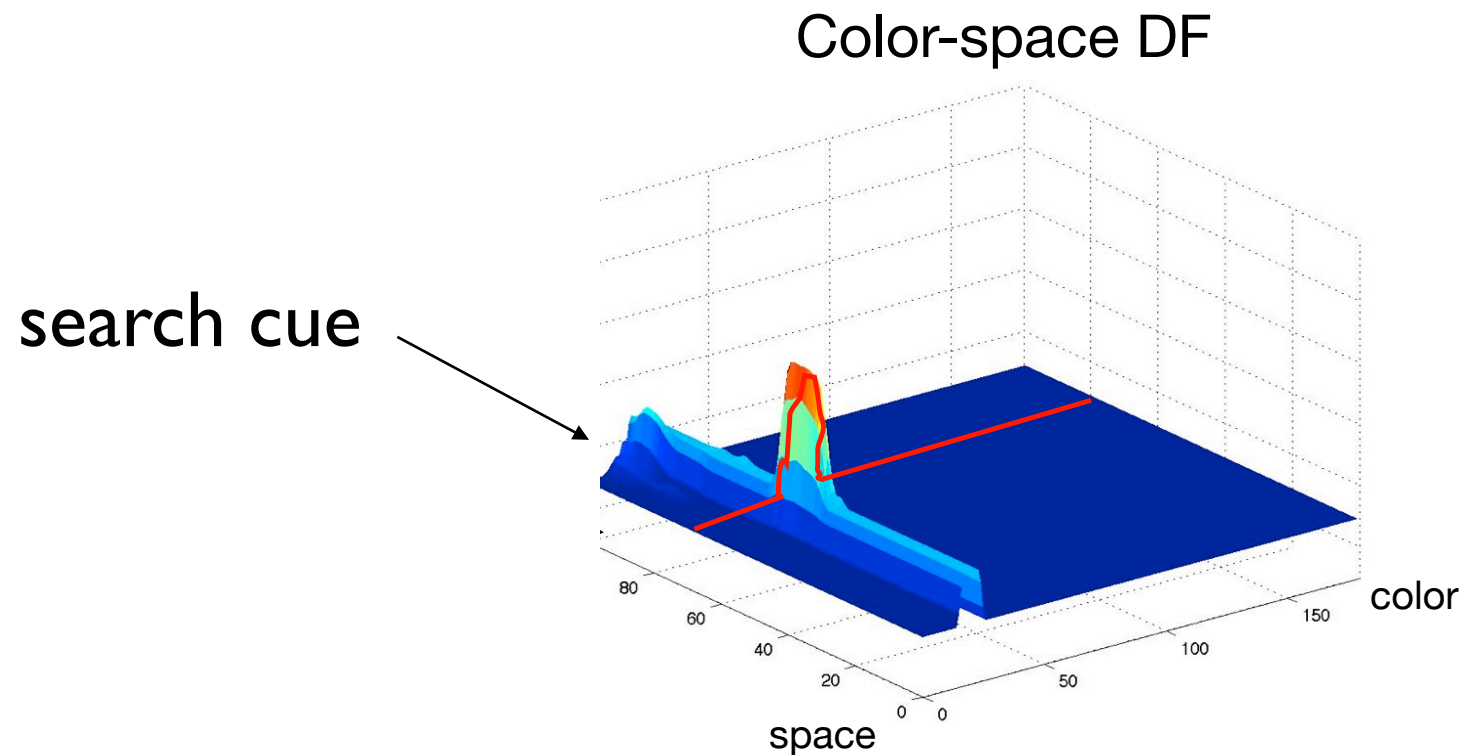
■ “intensity” of 2D input  
from color histogram at  
each horizontal location



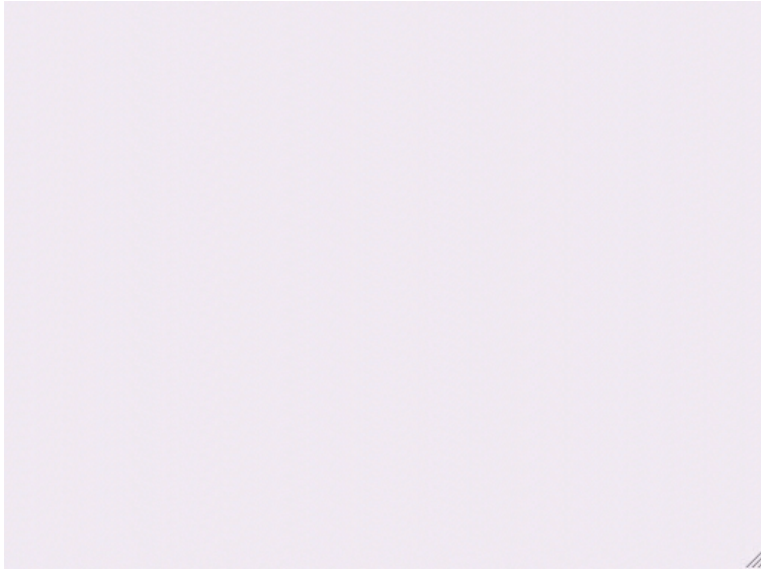


# Visual search

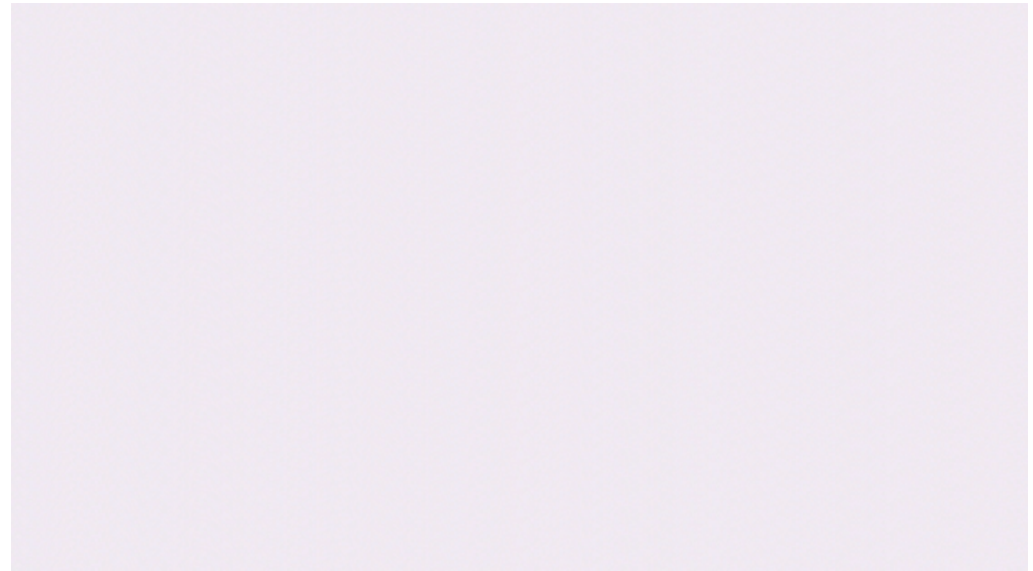
- intention=color cue provides ridge input into space-color field
- when that ridge overlaps with 2D space-color input => peak formed



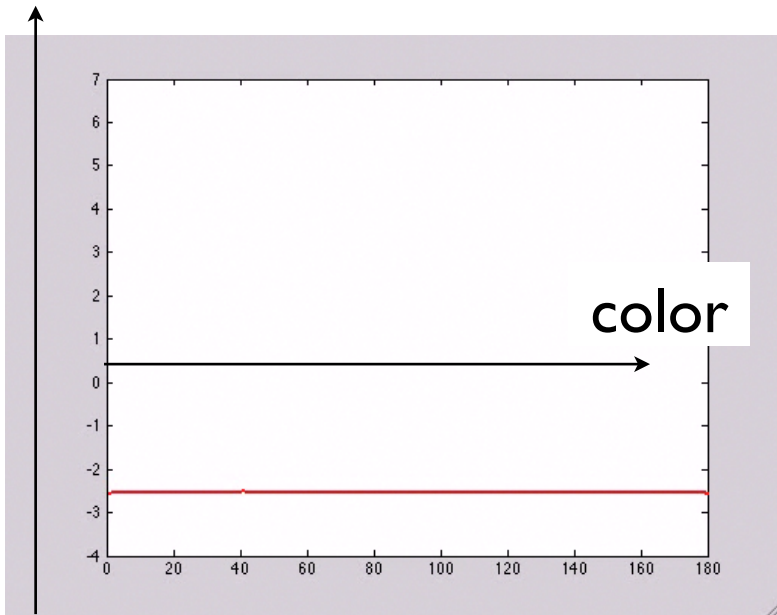
ordinal stack



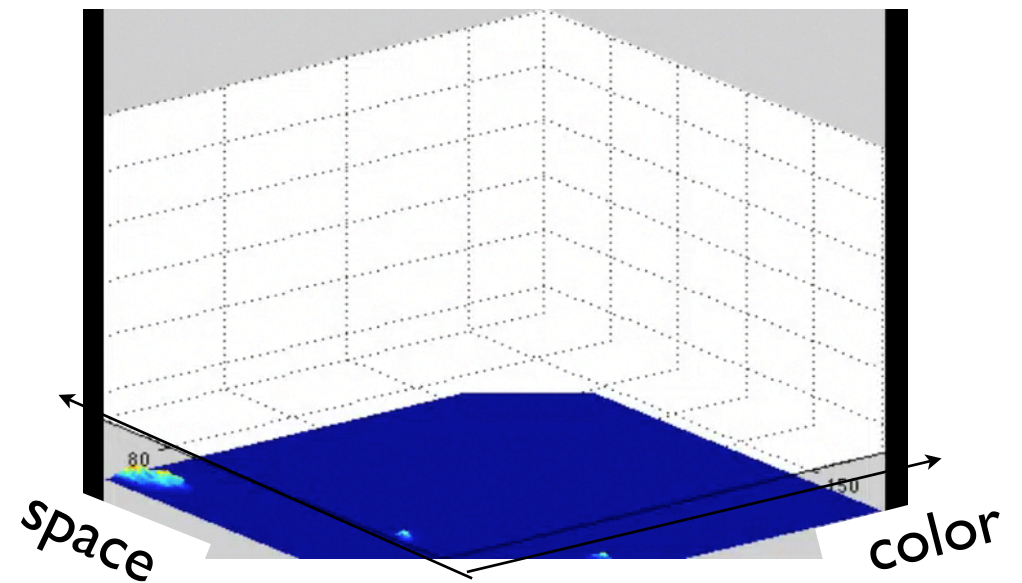
condition of satisfaction (CoS)



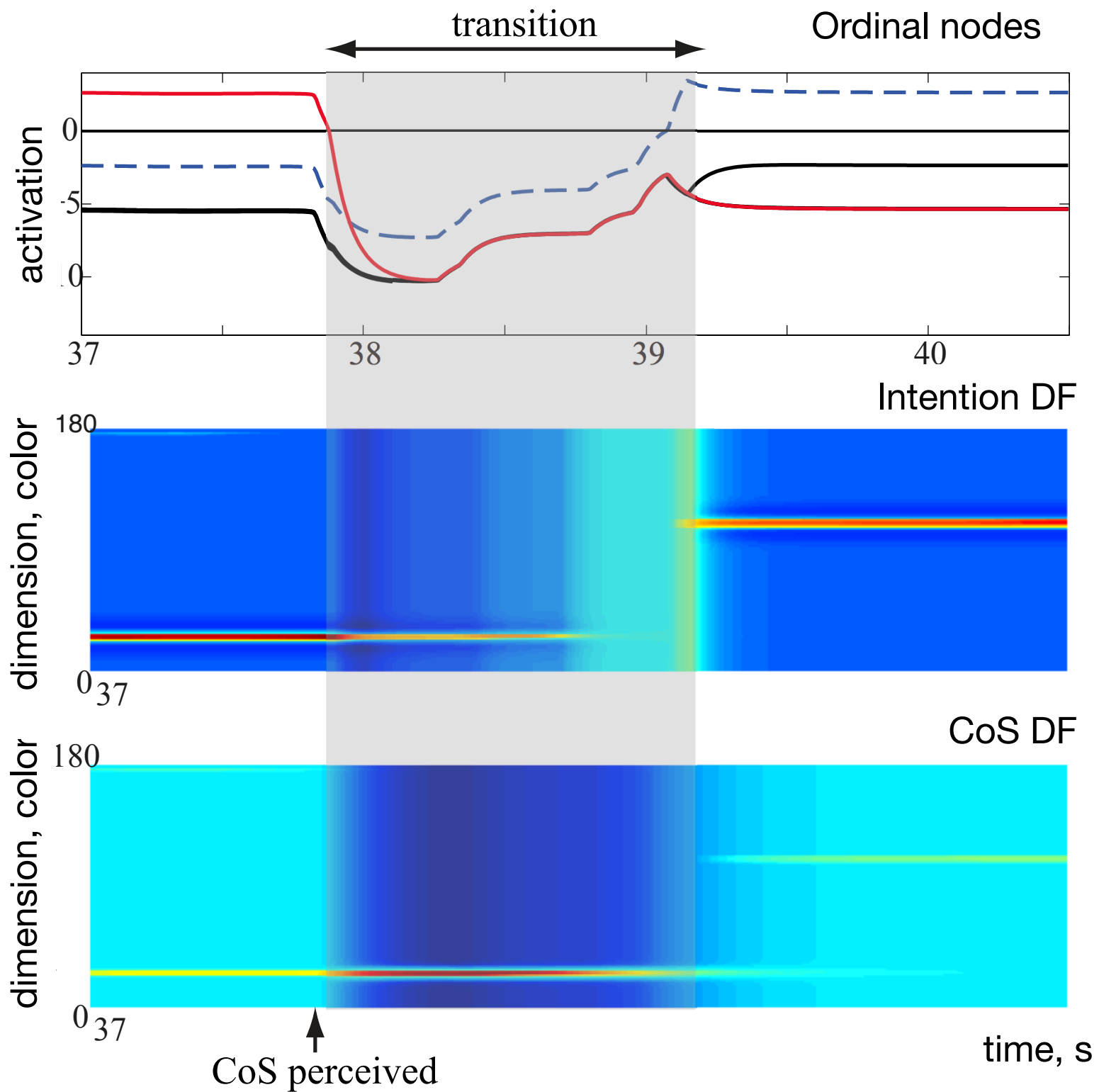
intentional state

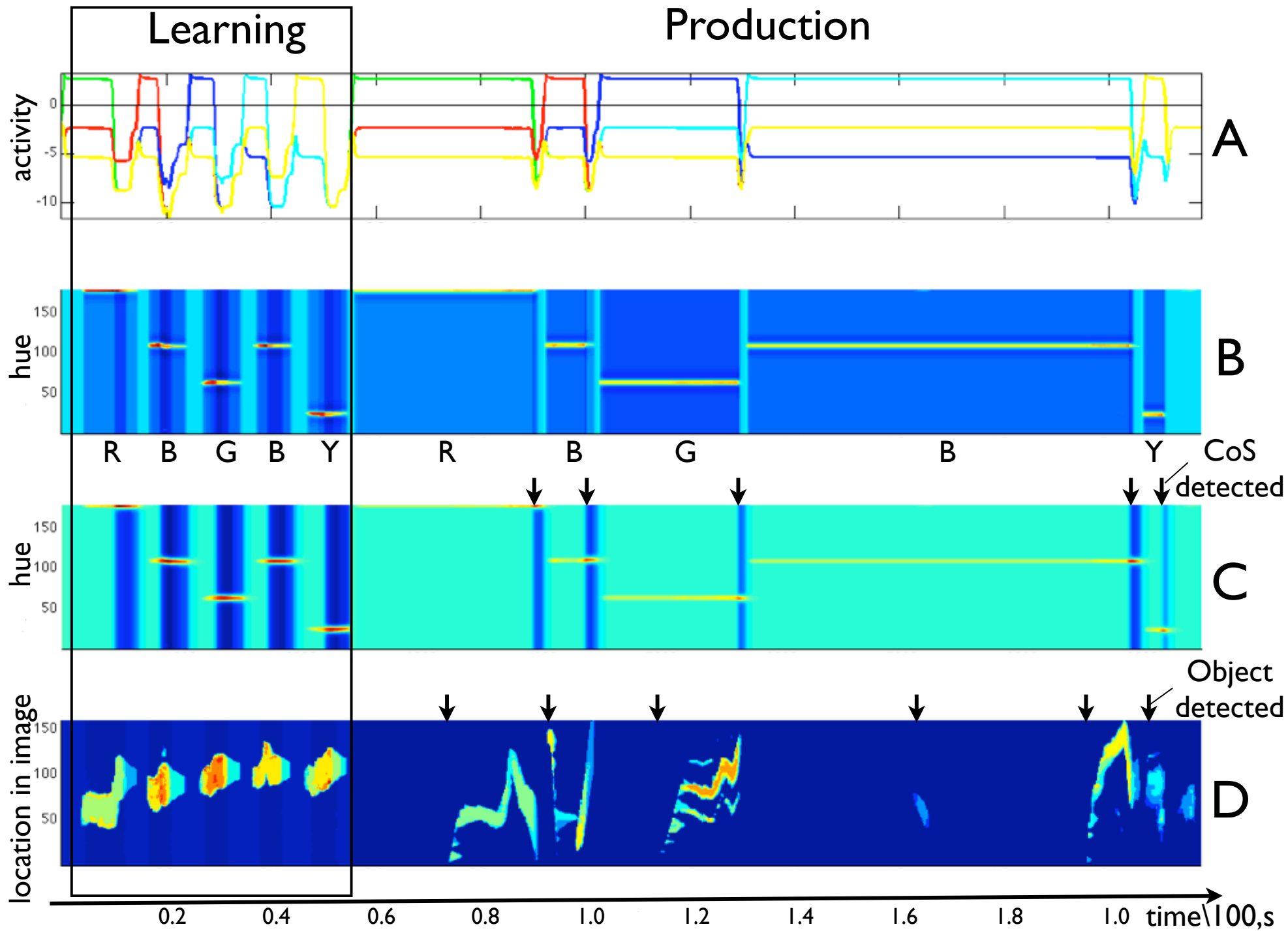


2D color-space field



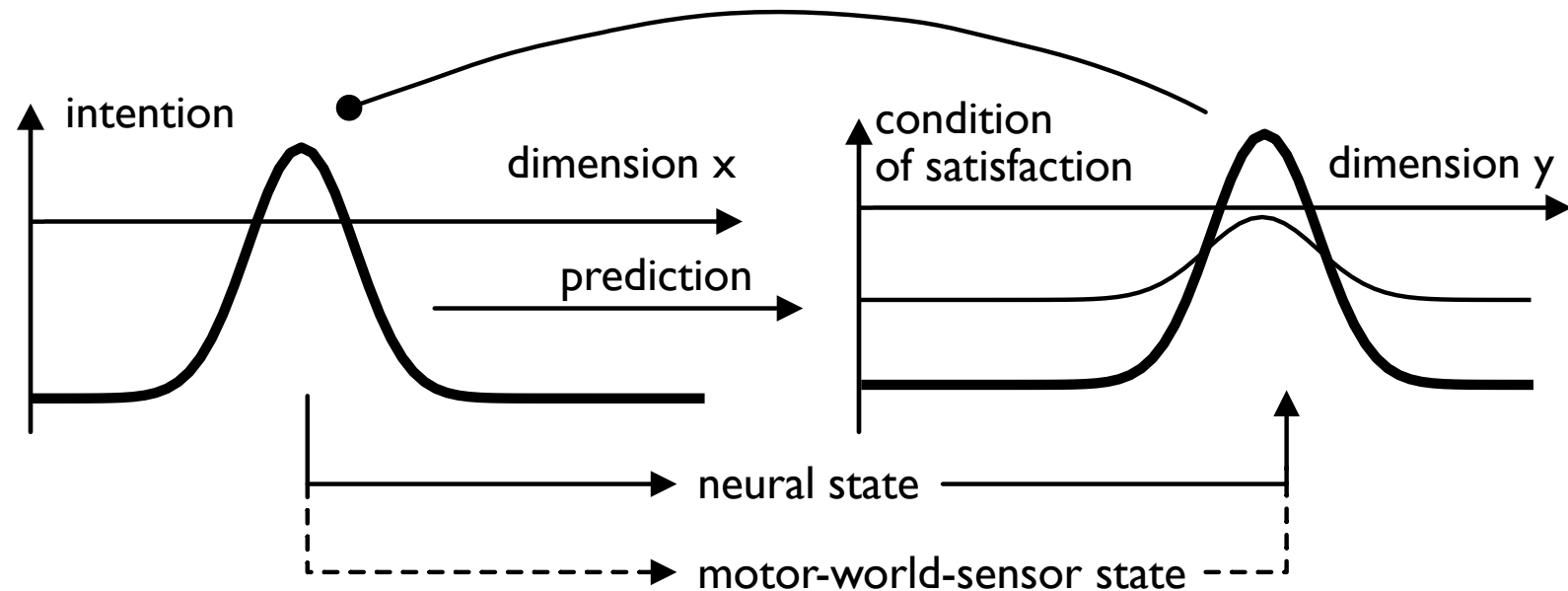




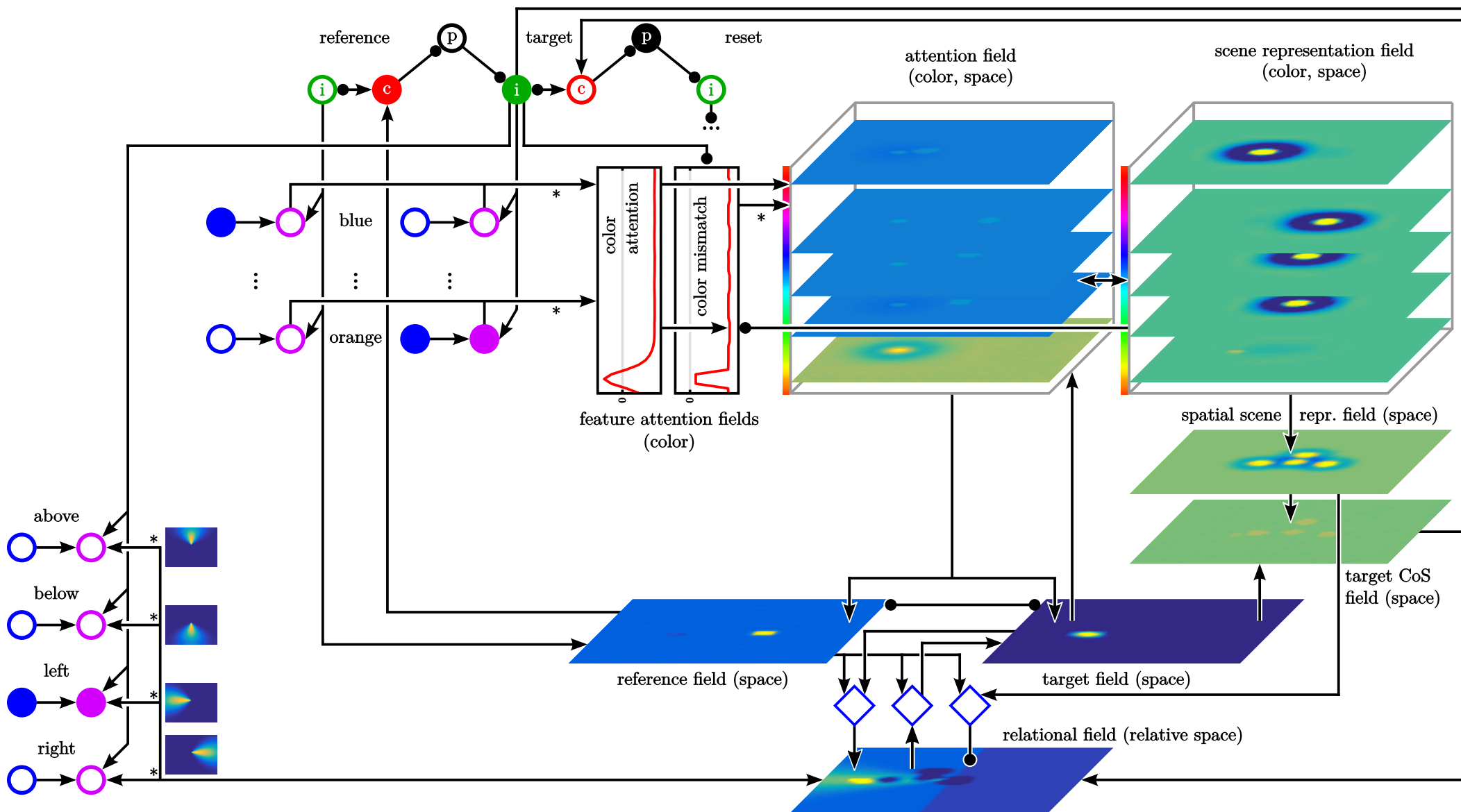


# Sequence of mental acts

- the generation of a neural state inside the architecture is the signal that triggers the CoS

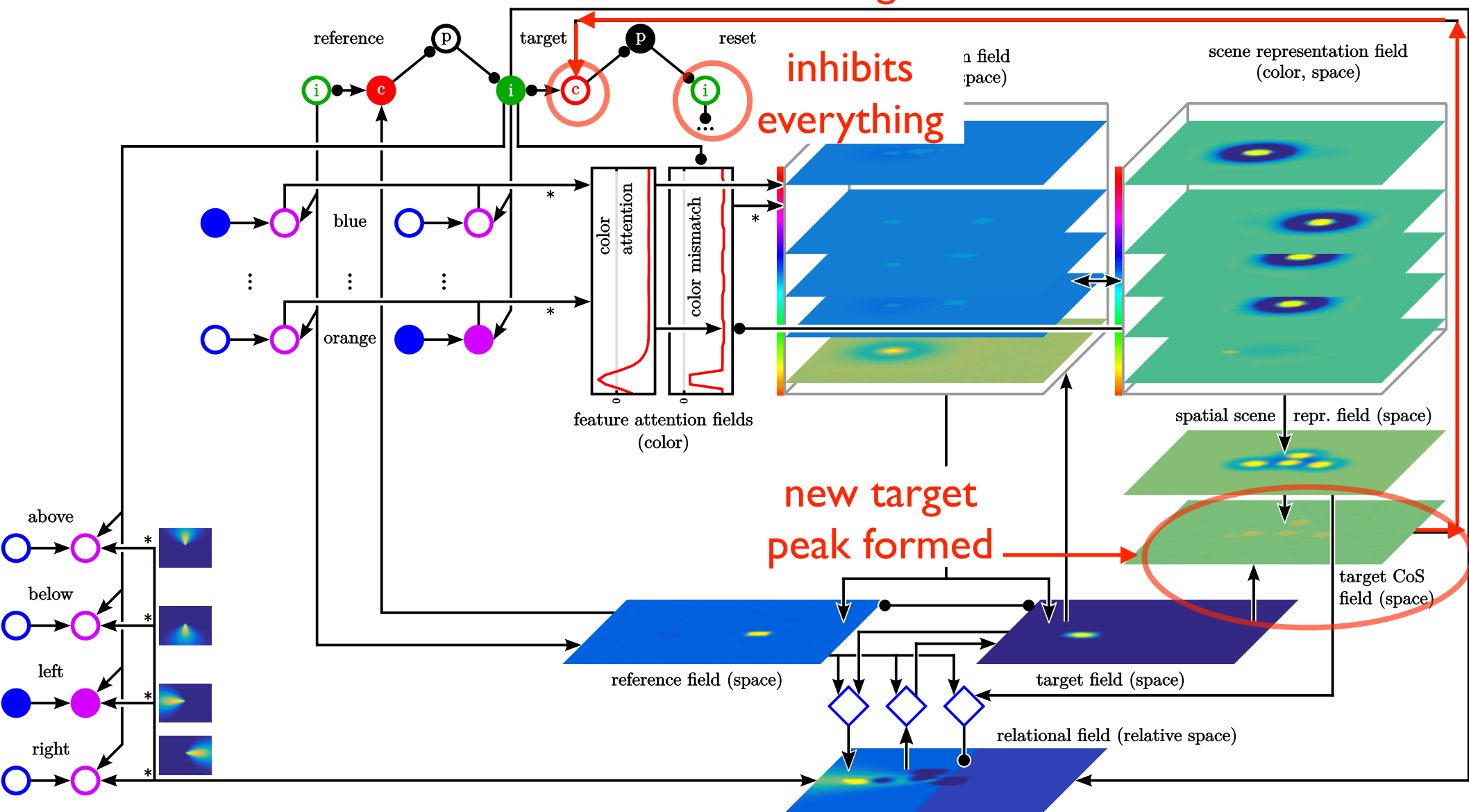


# Example: mental mapping

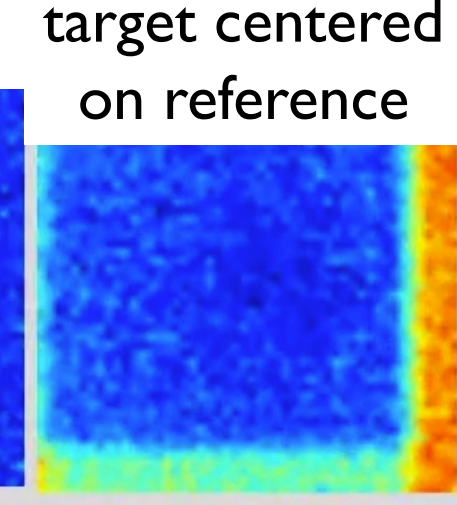
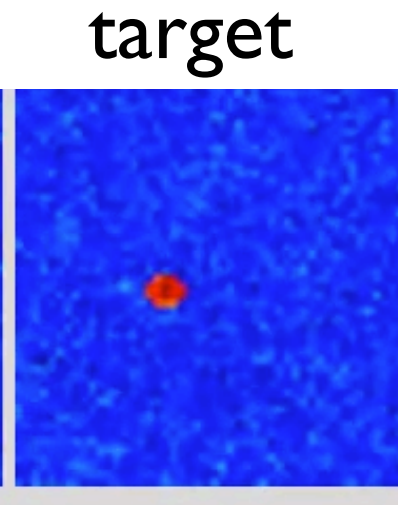
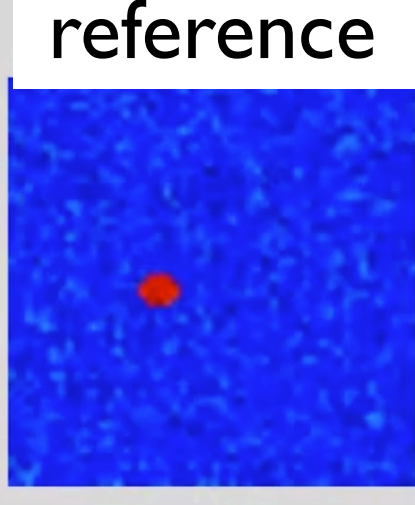
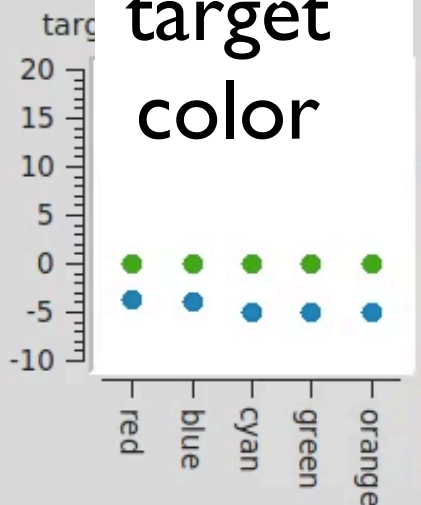
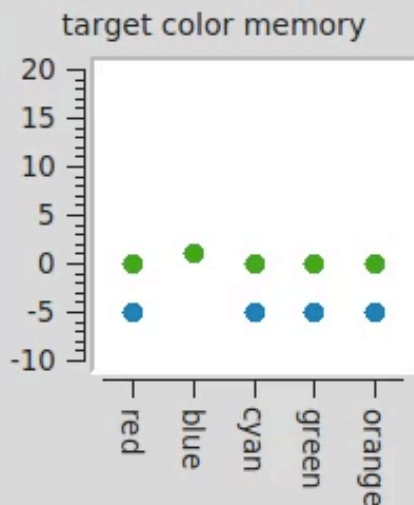
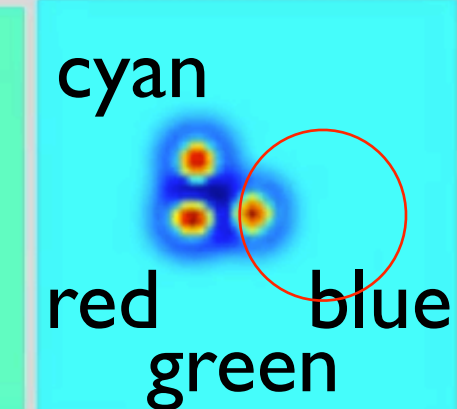
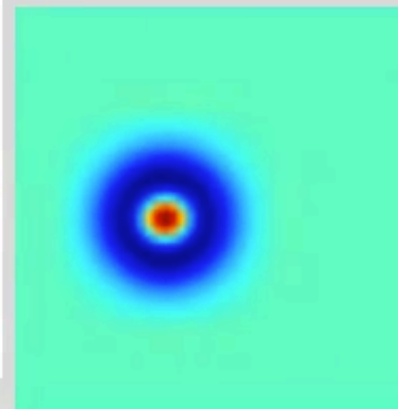
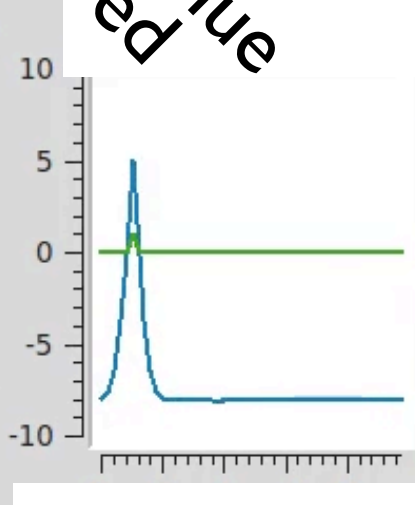
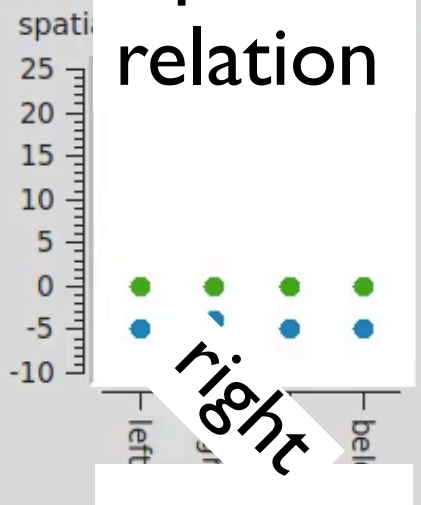
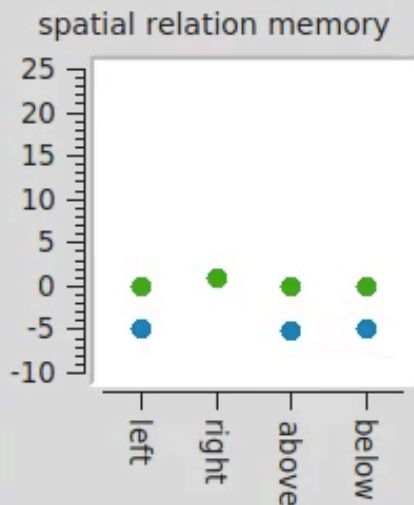
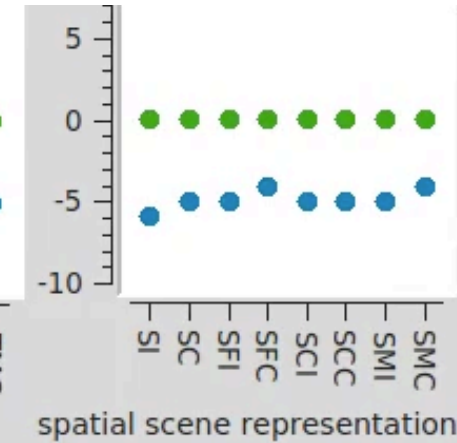
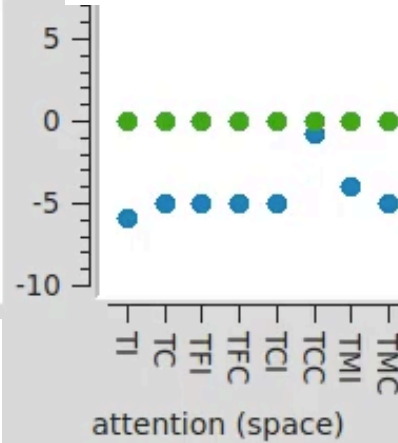
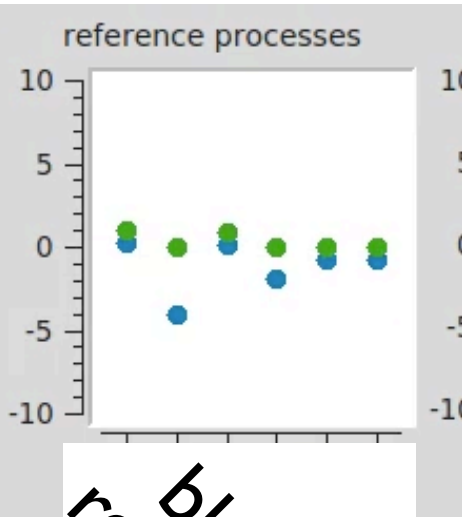
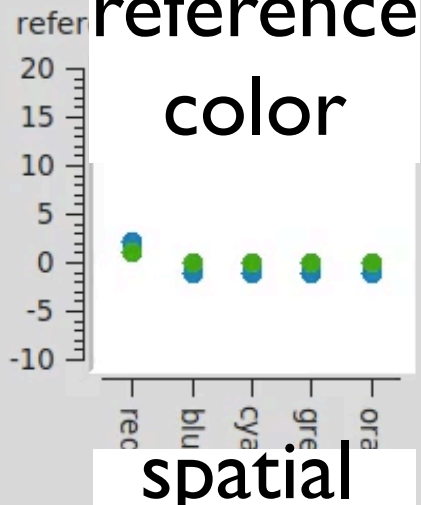
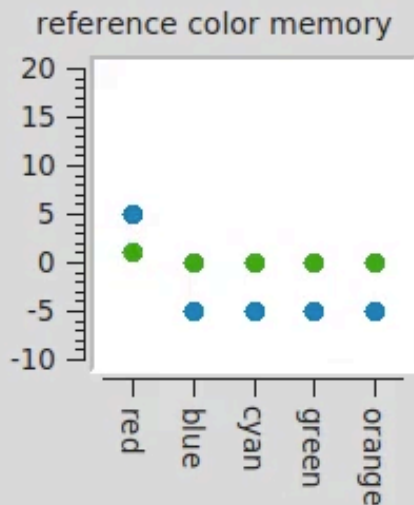


# Example: mental mapping

excites CoS of target role

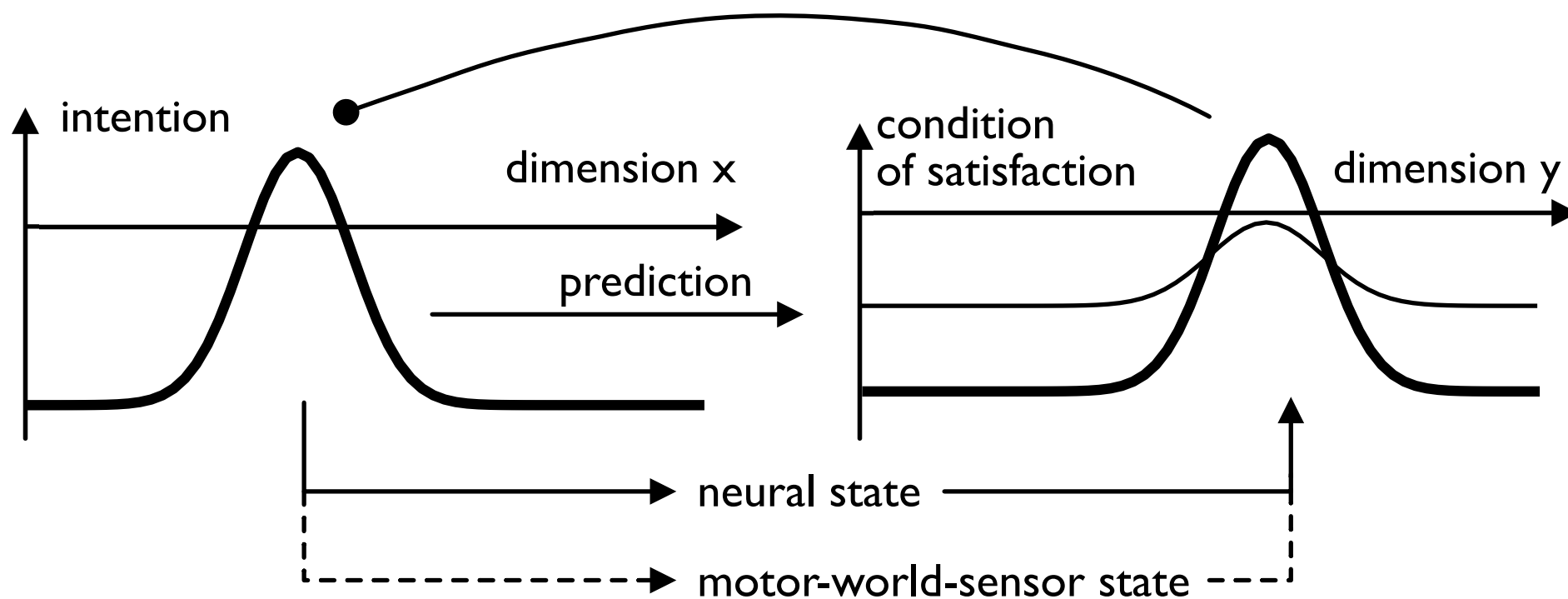


“blue right of red”



- Sequence generation: problem and example
- Condition of satisfaction
- Who to activate next?
- Demonstration of sequence generation

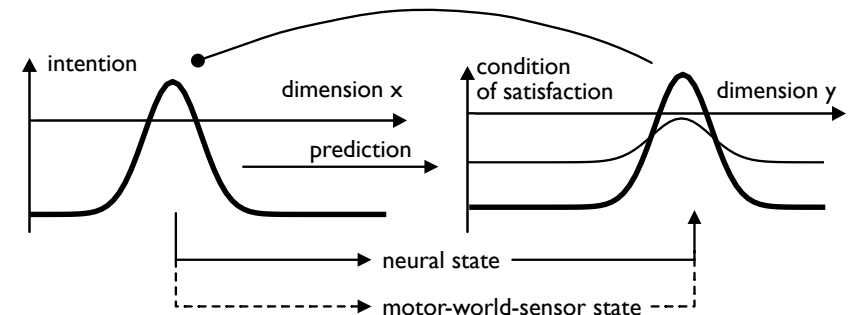
# Mathematical mechanism





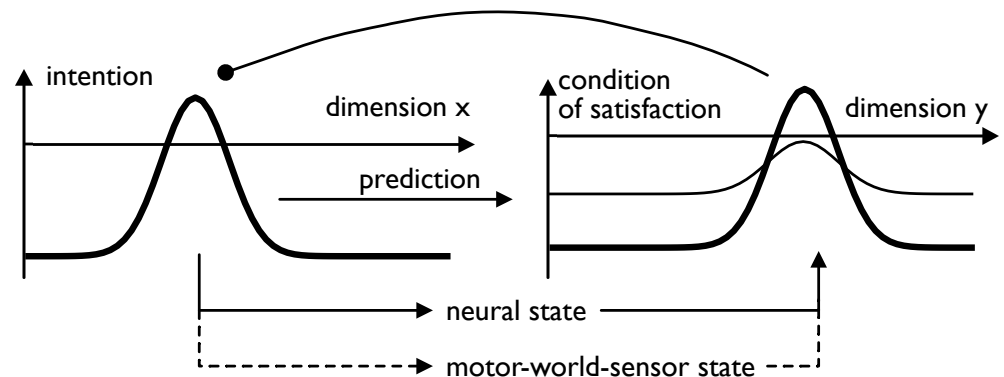
# Sequence of instabilities

- 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



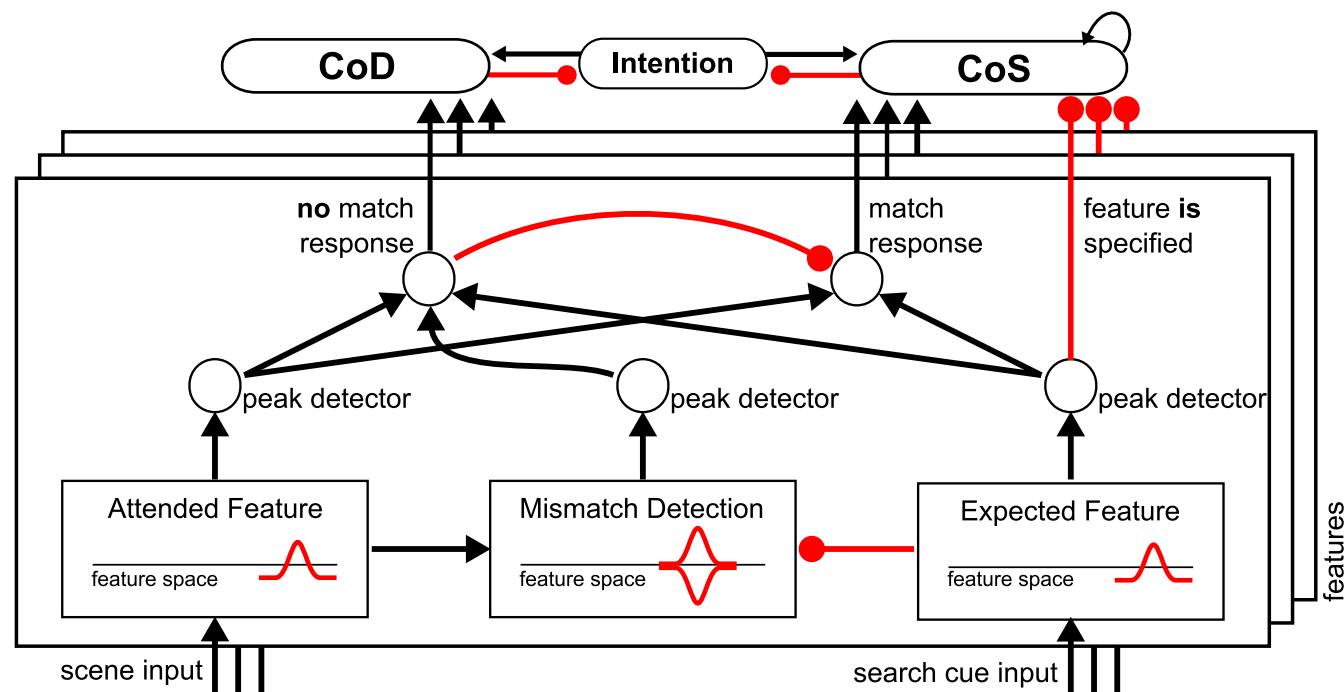
# CoS and efference copy

- 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

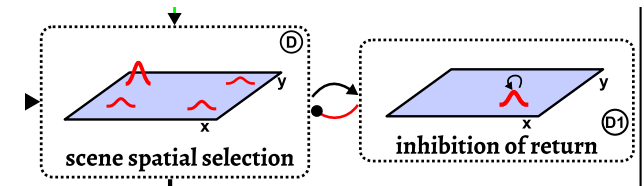
- match-detection  $\Rightarrow$  CoS
- mis-match (or change) detection  $\Rightarrow$  CoD (condition of dissatisfaction)



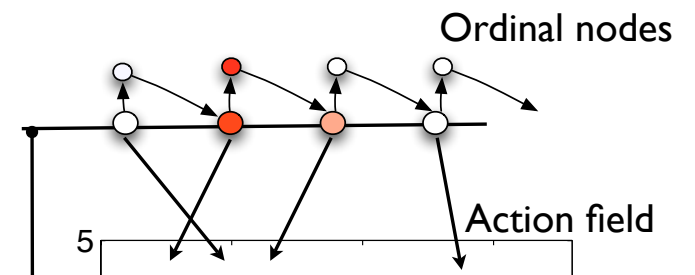
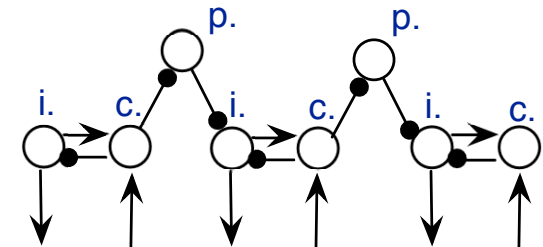
- Sequence generation: problem and example
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# How is the next state selected?

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

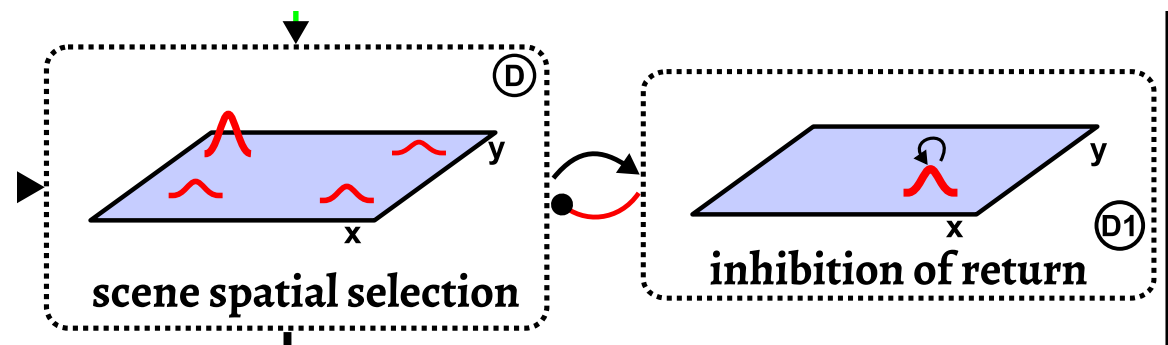


- 1 gradient-based selection
- 2 chaining
- 3 positional representation



# 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



# Gradient-based

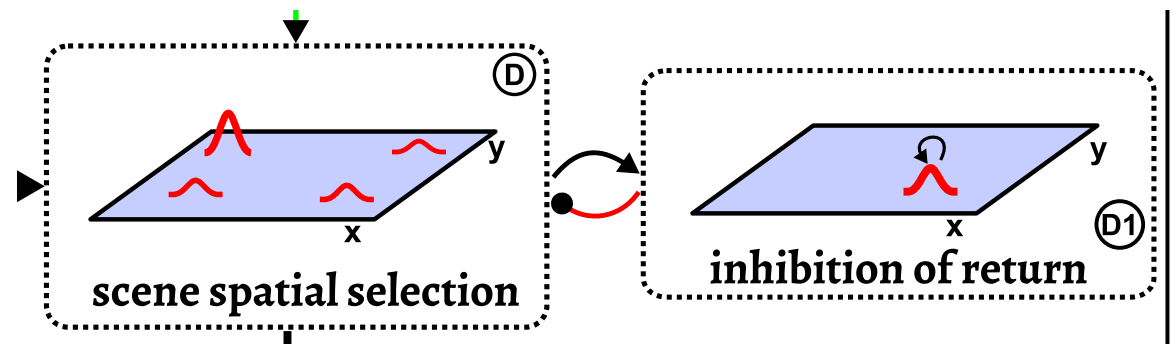
■ this is used in many of the DFT architectures

■ visual search

■ relational grounding

■ mental mapping

[Grieben, Schöner, *CogSci* 2021]



# Chaining

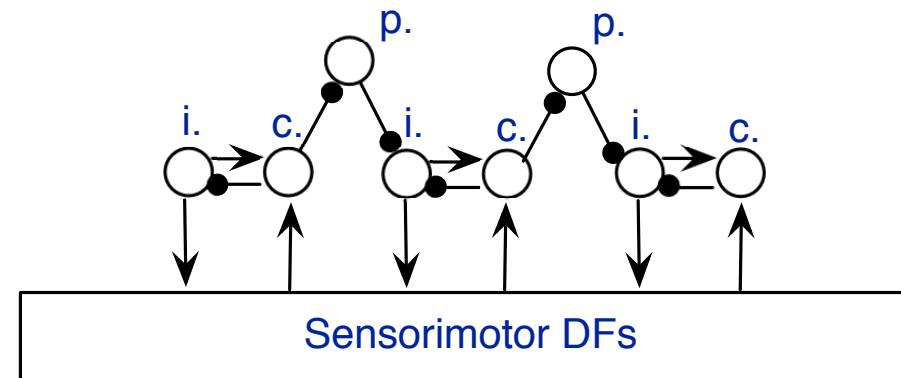
- for fixed sequences...

  - 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)

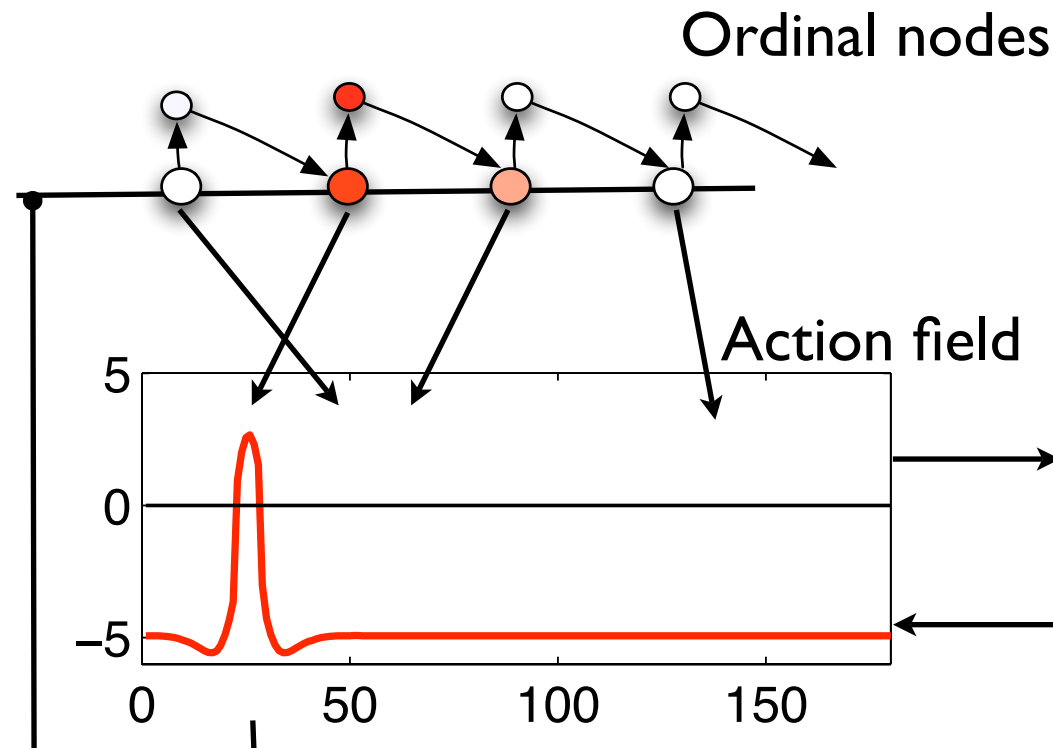
- could be thought to emerge with practice/habit from the positional system





# 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...



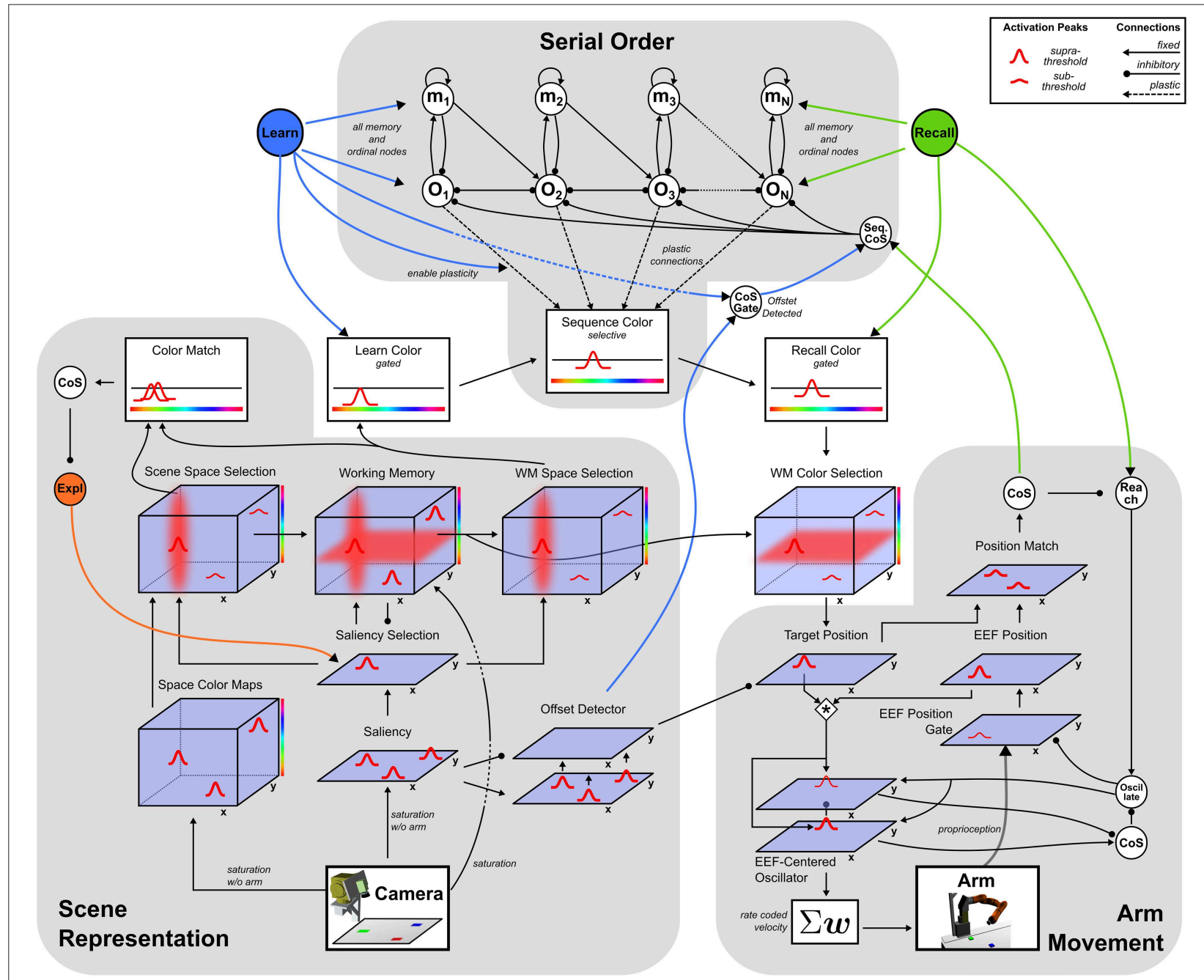


# Positional representation

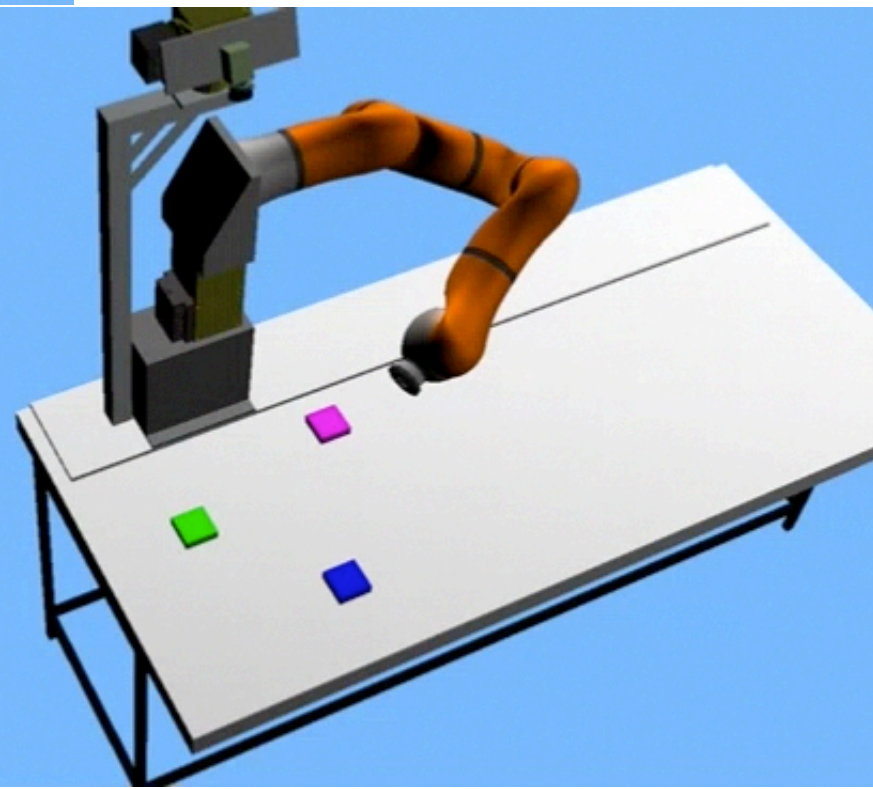
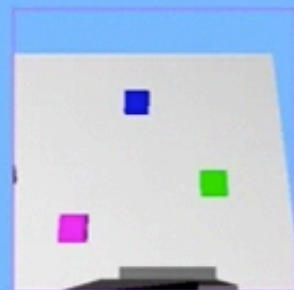
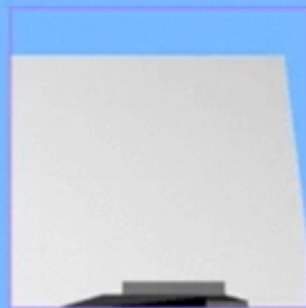
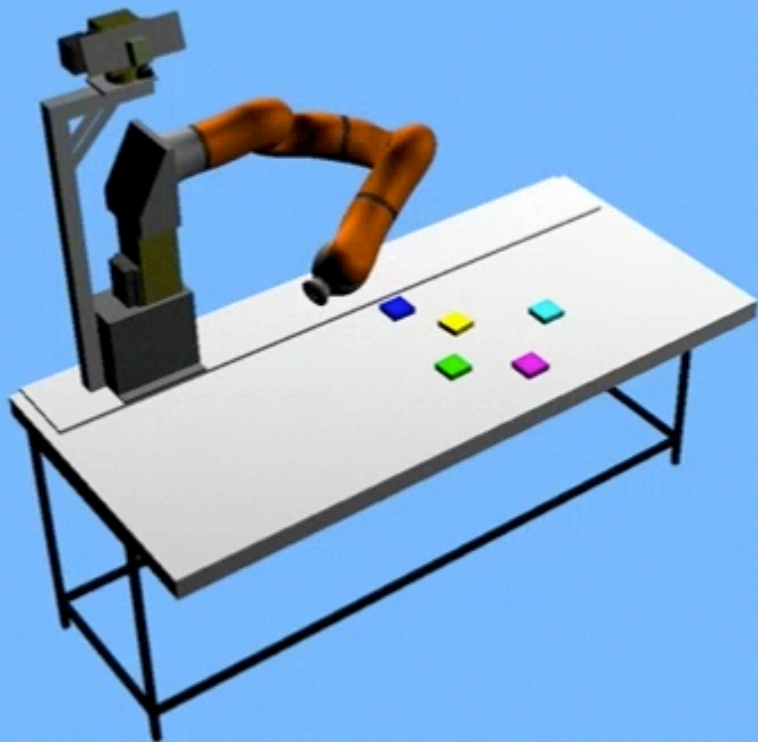
- essentially chaining with flexible contents
- good for fast learning of sequences...
  - e.g. imitation
  - a Hippocampus function?
- but: must have potential synaptic links to many representations...
- => such ordinal systems must exist for sub-representations... embodiment effects...

- Sequence generation: problem and example
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# Serial order demonstrated/enacted



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



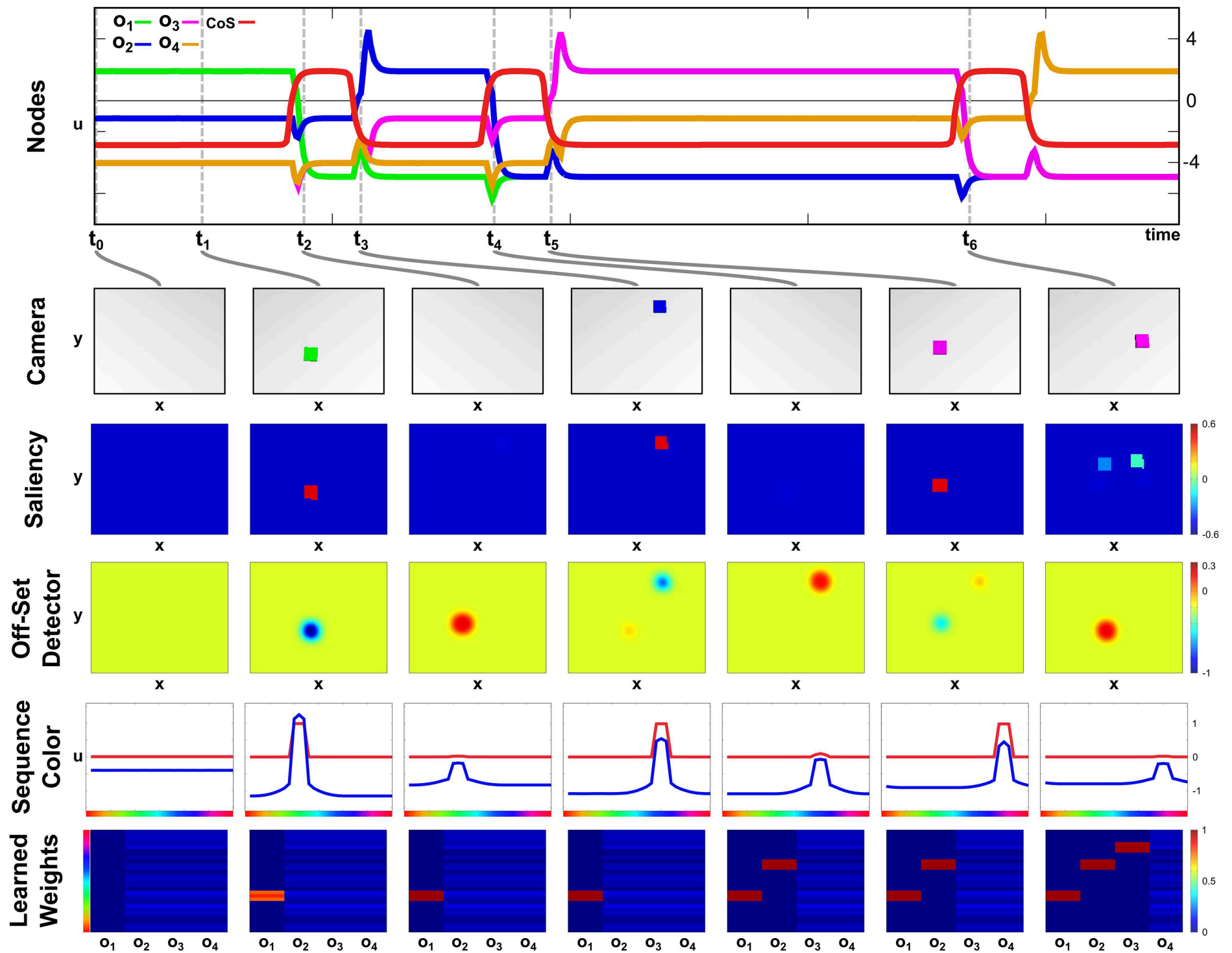


FIGURE 5 | Time course of learning a three element sequence with varying presentation time.



# Time course of attention selection and building of scene memory

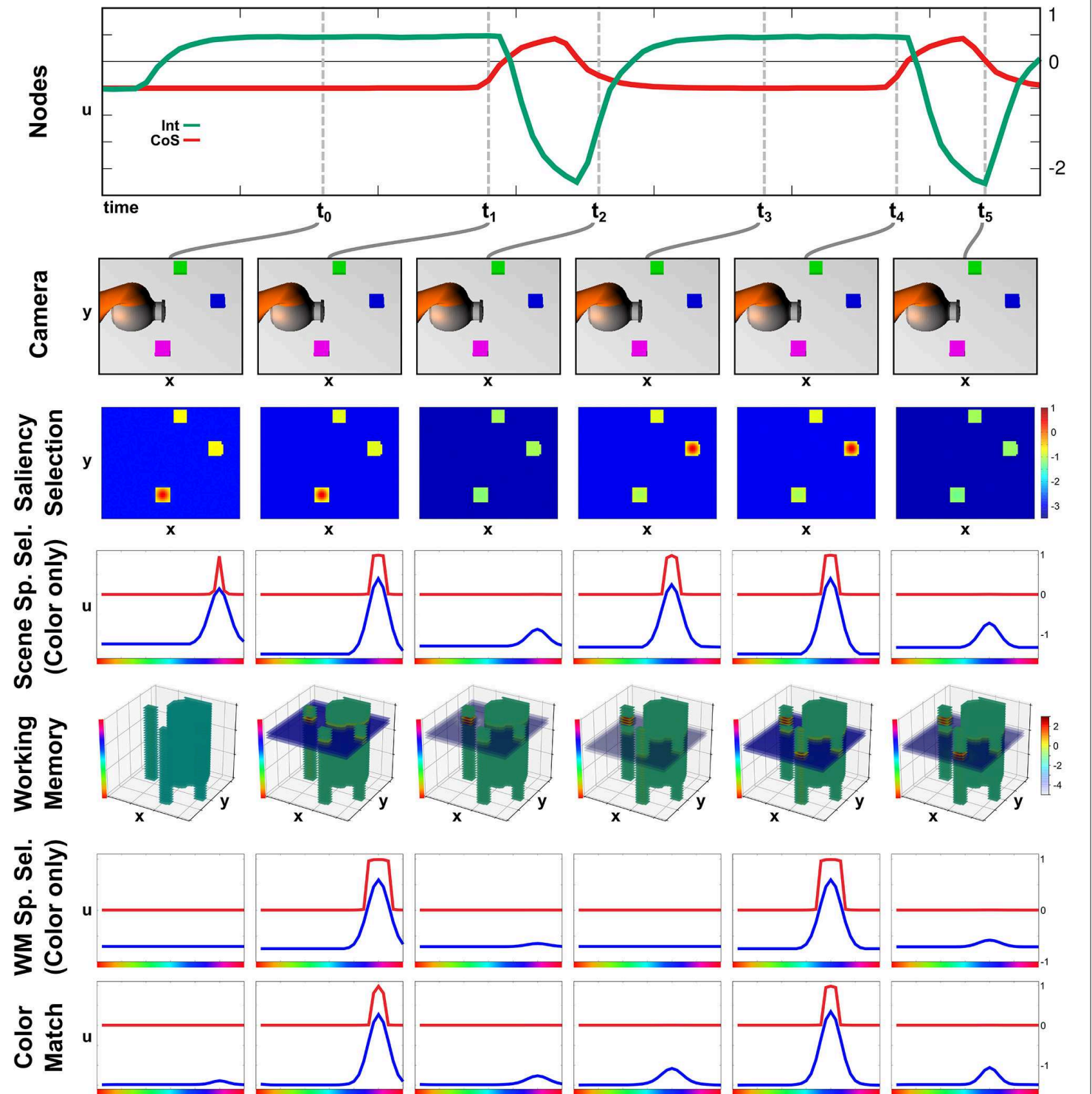
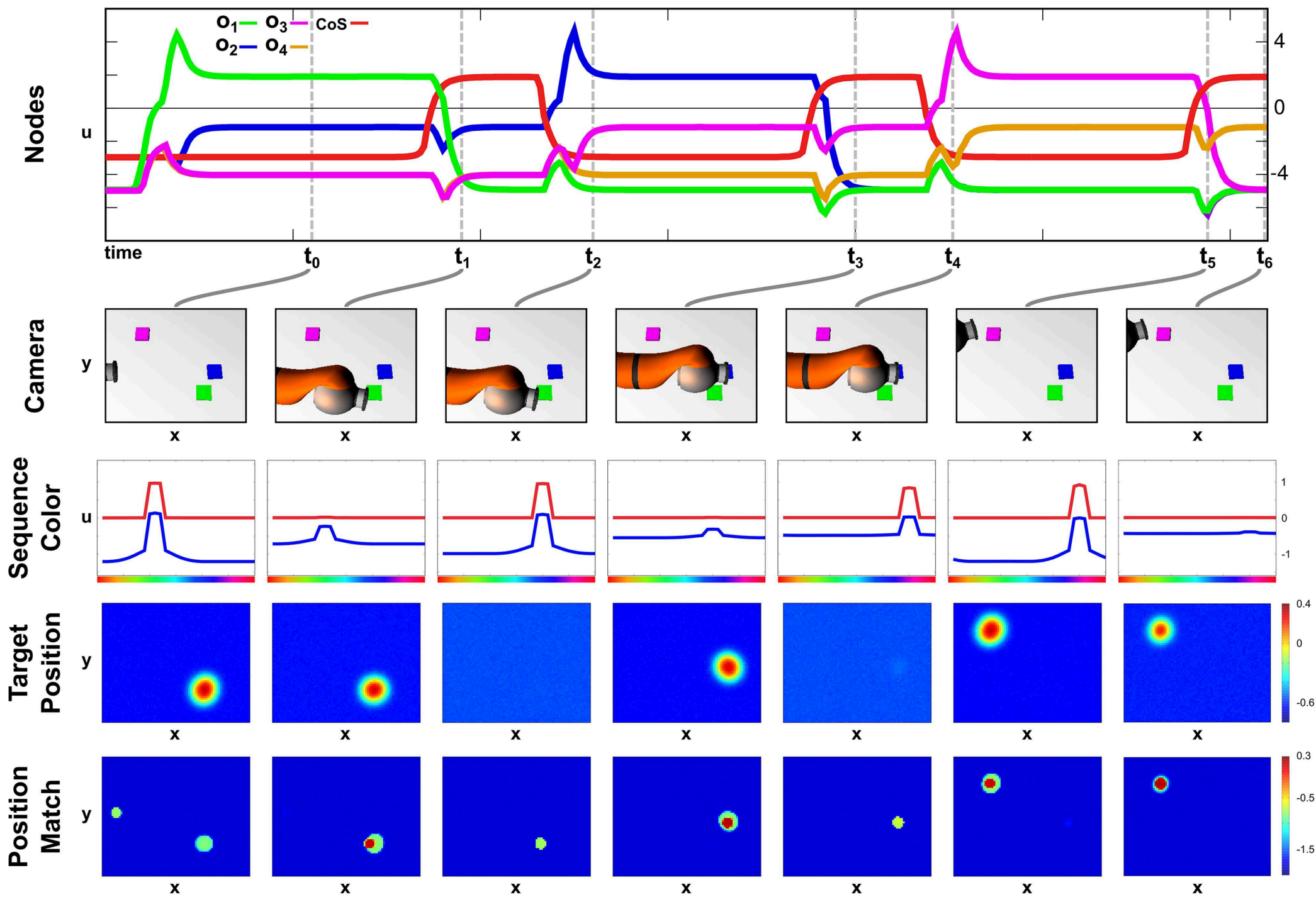


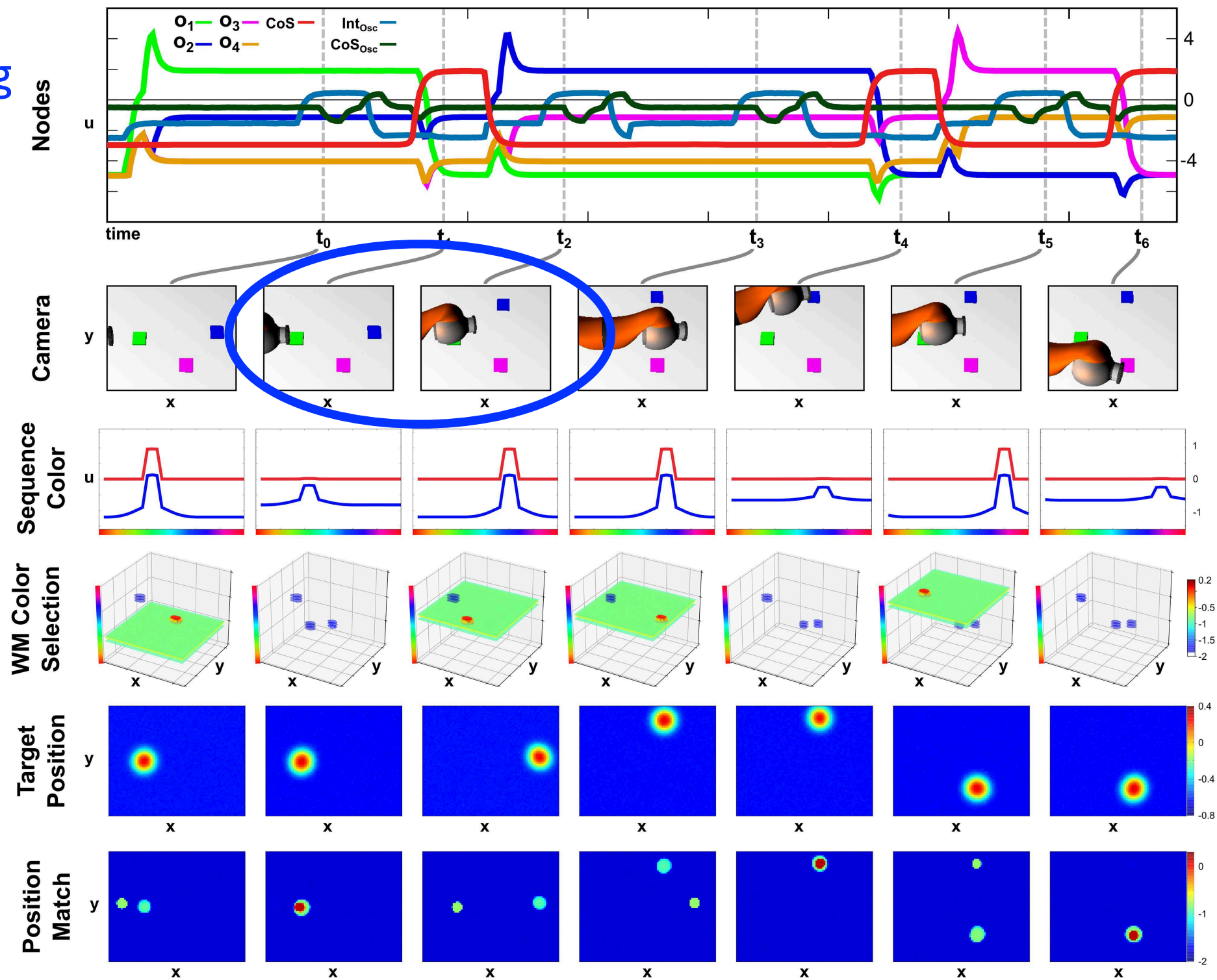
FIGURE 4 | Time course of building a scene memory.





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

online  
updating



- Sequence generation: problem and example
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# Conclusion

- we now have the minimal set of DFT concept in place to understand DFT architectures...