

# Neural Dynamics For Embodied Cognition

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# Survey

## ■ Session 1: Foundations

- Neural dynamics/neural fields [Daniel Sabinasz]

- Introduction to Cedar/Instabilities in DFT [Raul Grieben]

## ■ Session 2: Dimensions/Binding [Raul Grieben]

- Cedar architecture: visual search

# Survey

- Session 3: Grounded Cognition [Daniel Sabinasz]

- Cedar architecture: relational grounding

- Session 4: Sequence generation

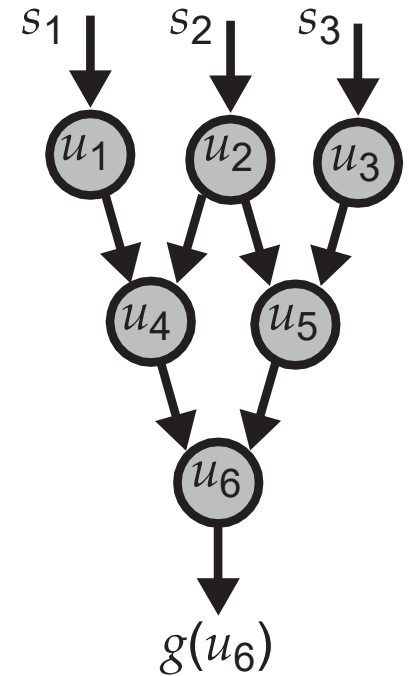
- Sequence generation/Embedding DFT [Raul Grieben]

- Cedar architecture sequence generation [Daniel Sabinasz]

- Neural fields: dimensions
- Binding
- Visual search

# Neural networks

- forward connectivity determines “what a neuron stands for” = **space code** (or labelled line code)
- while the activation level may “stand for” intensities = **rate code**
- generic neural networks combine both codes



intensity

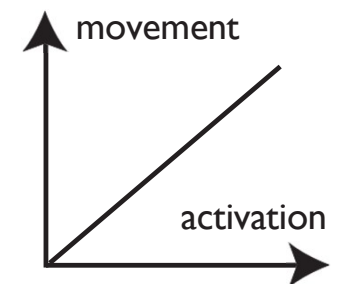
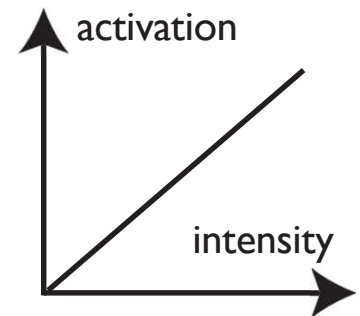


activation

activation

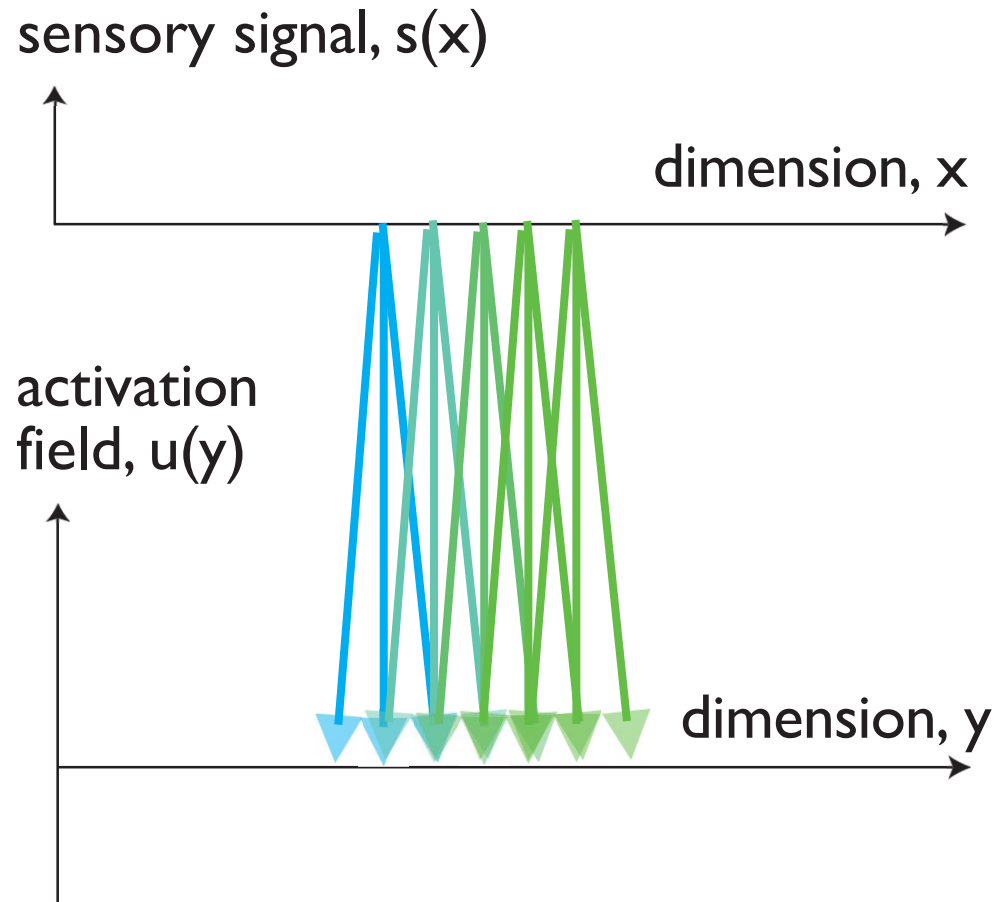


movement



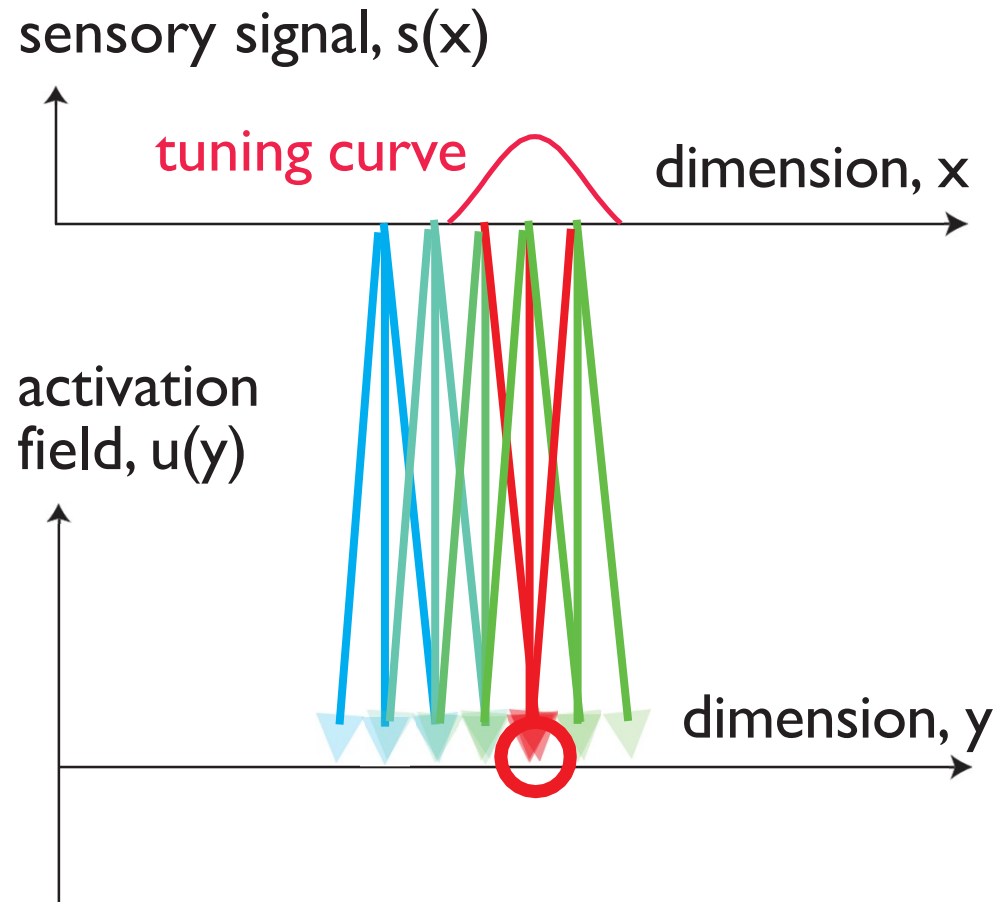
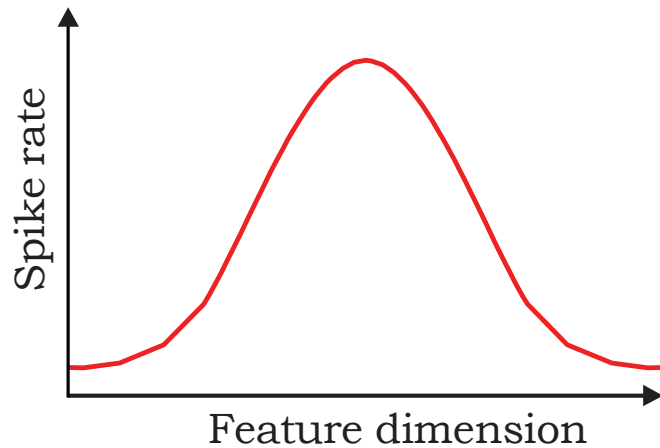
# Neural fields

- forward connectivity from the sensory surface extracts perceptual feature dimensions



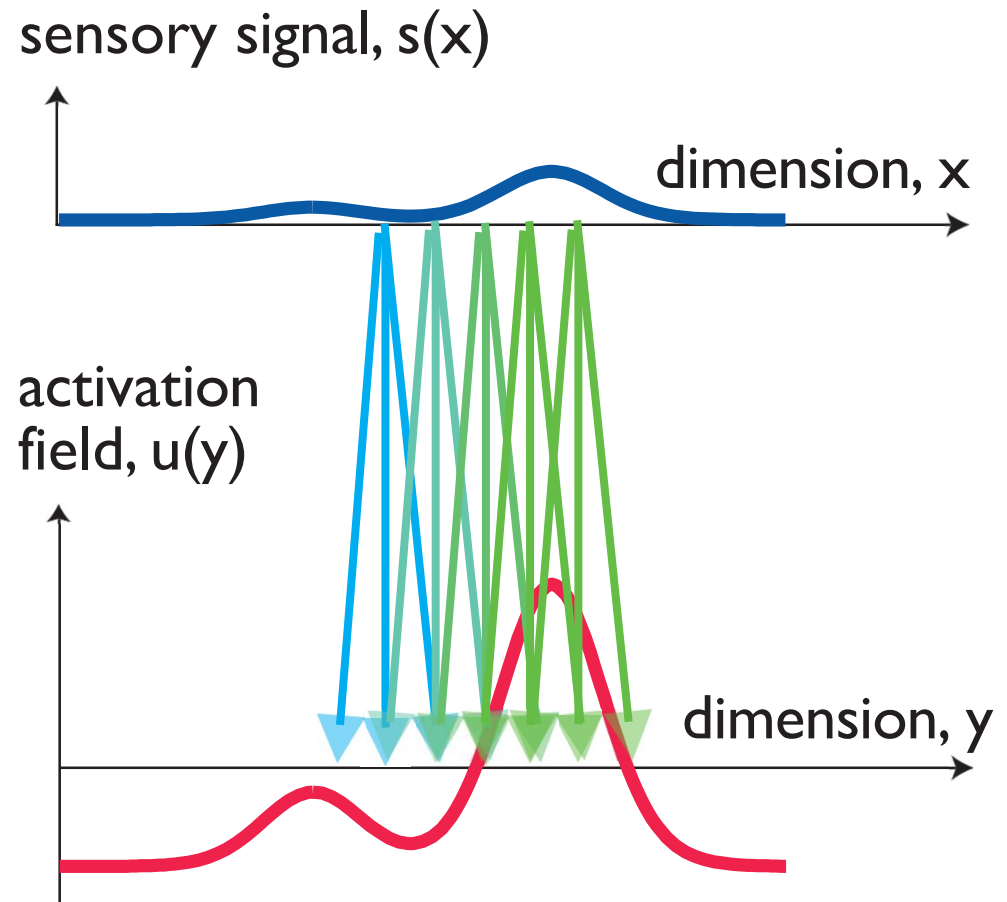
# Neural fields

■ as described by tuning curves or receptive fields



# Neural fields

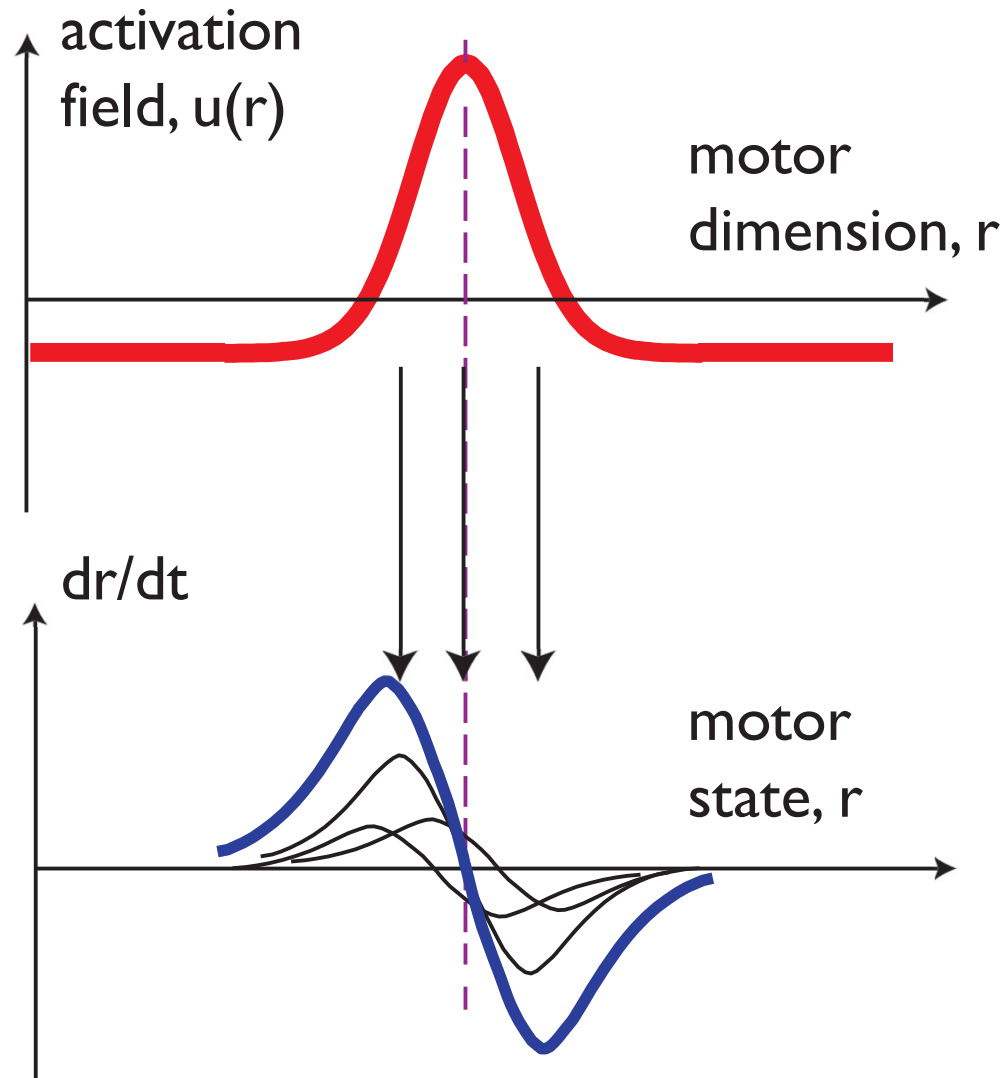
- => **neural map** from sensory surface to feature dimension
- neglect the sampling by individual neurons => **activation field**





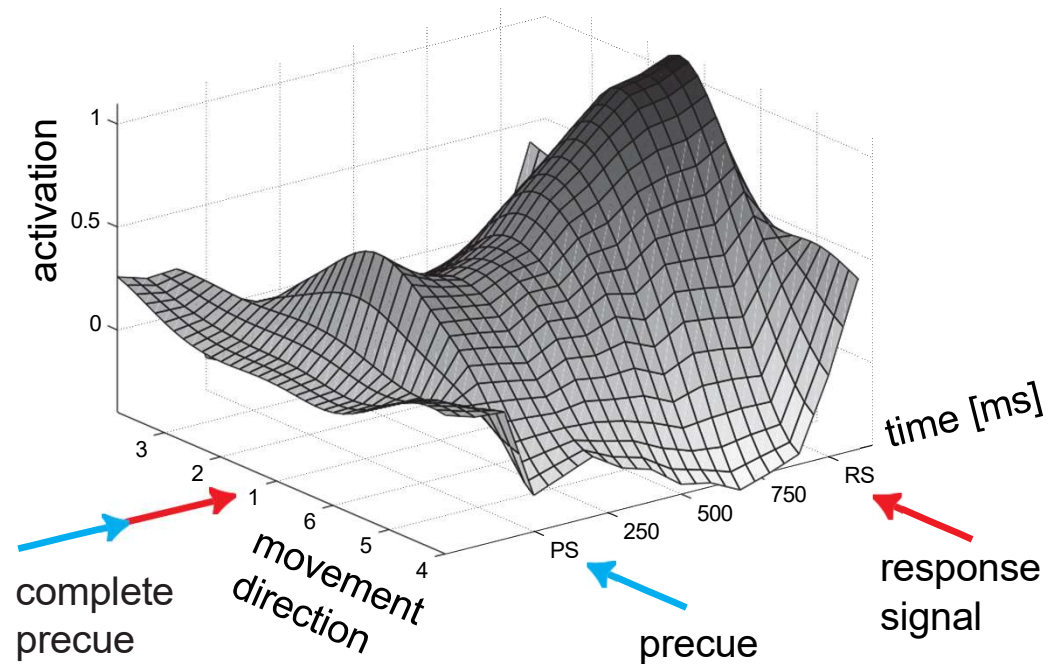
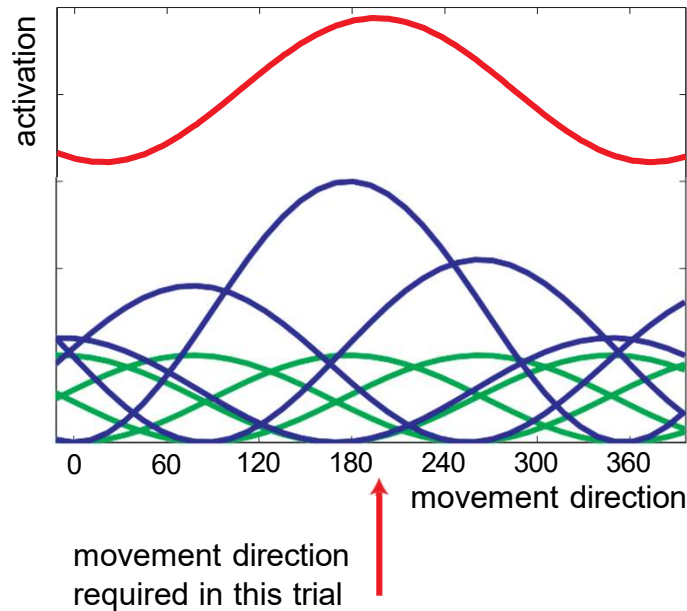
# Neural fields

- 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) $\Leftrightarrow$ neural field

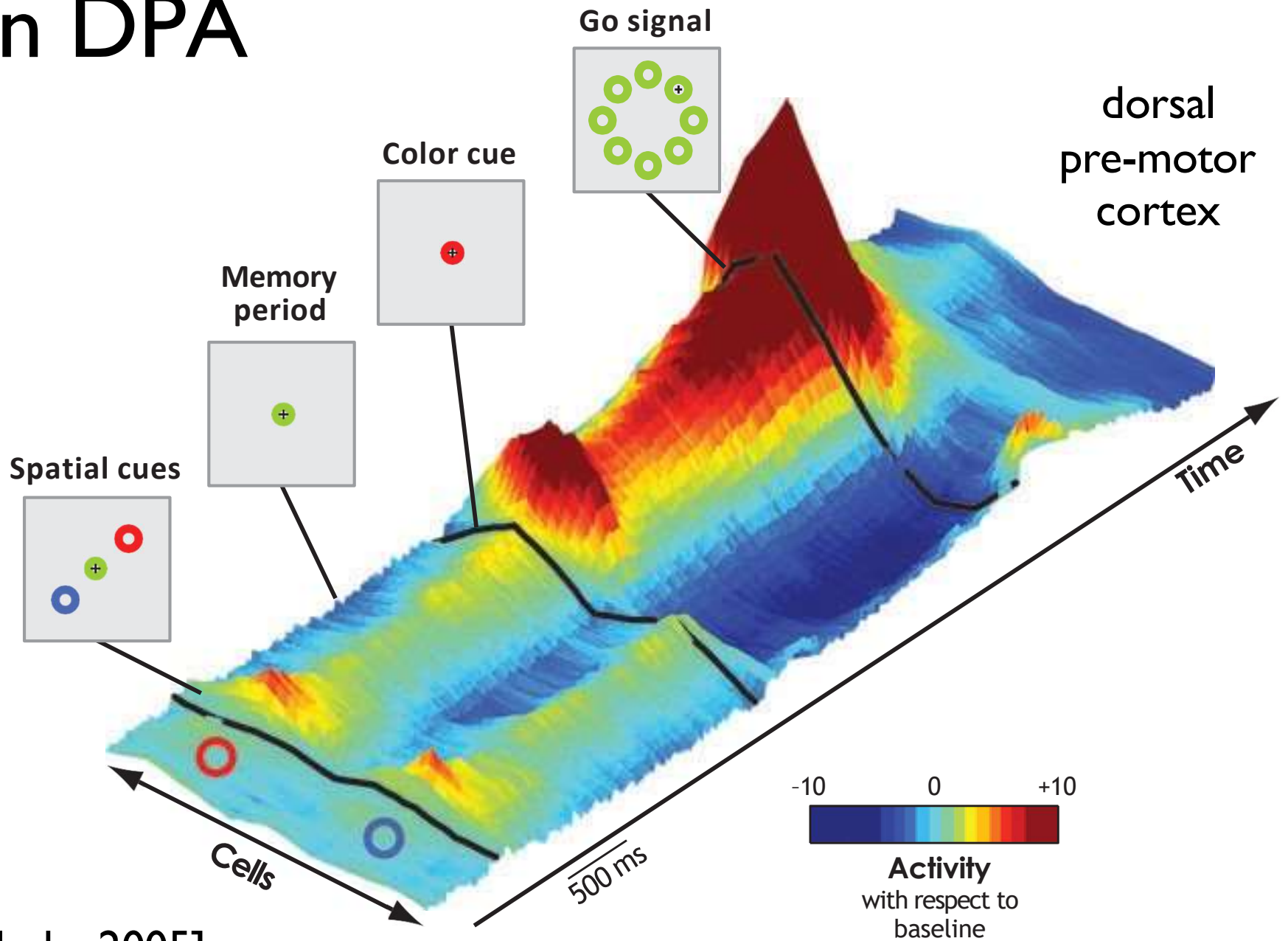
Distribution of population activation =  
 $\sum_{\text{neurons}} \text{tuning curve} * \text{current firing rate}$



note: neurons are not  
**localized** within DPA!

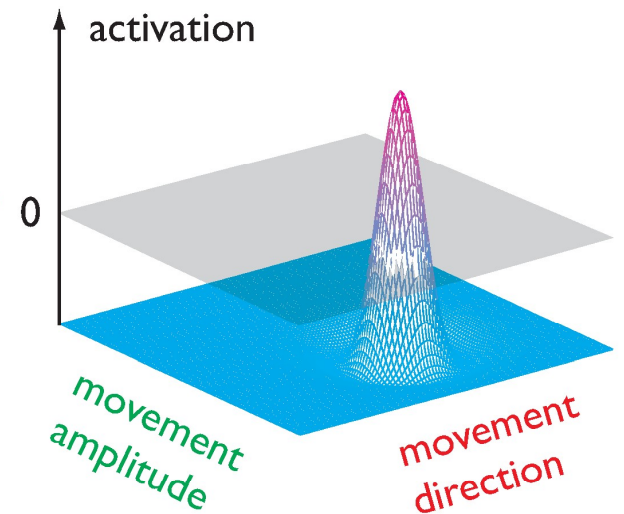
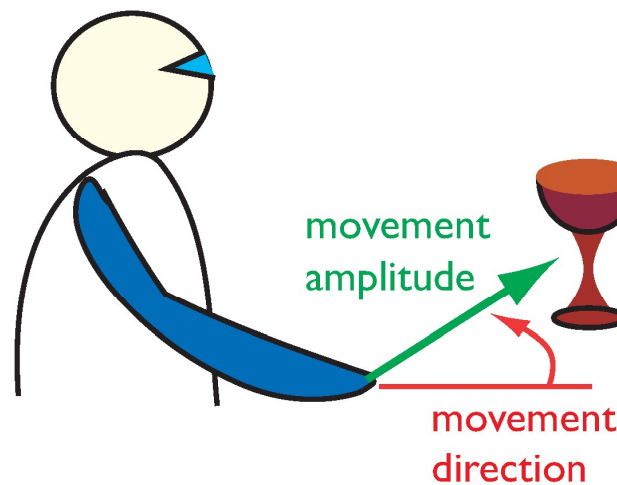
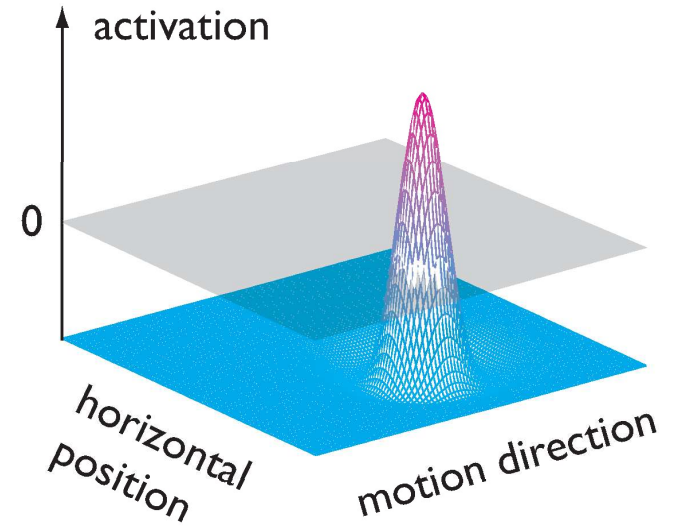
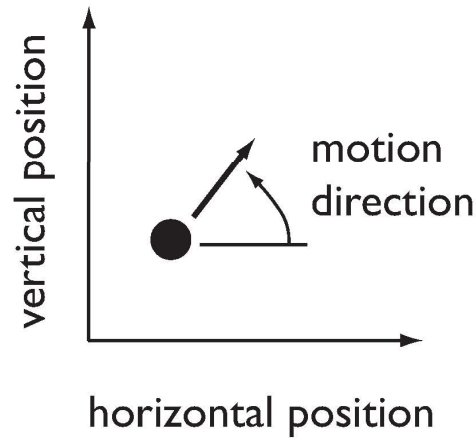
[Bastian, Riehle, Schöner, 2003]

# Decision making in DPA



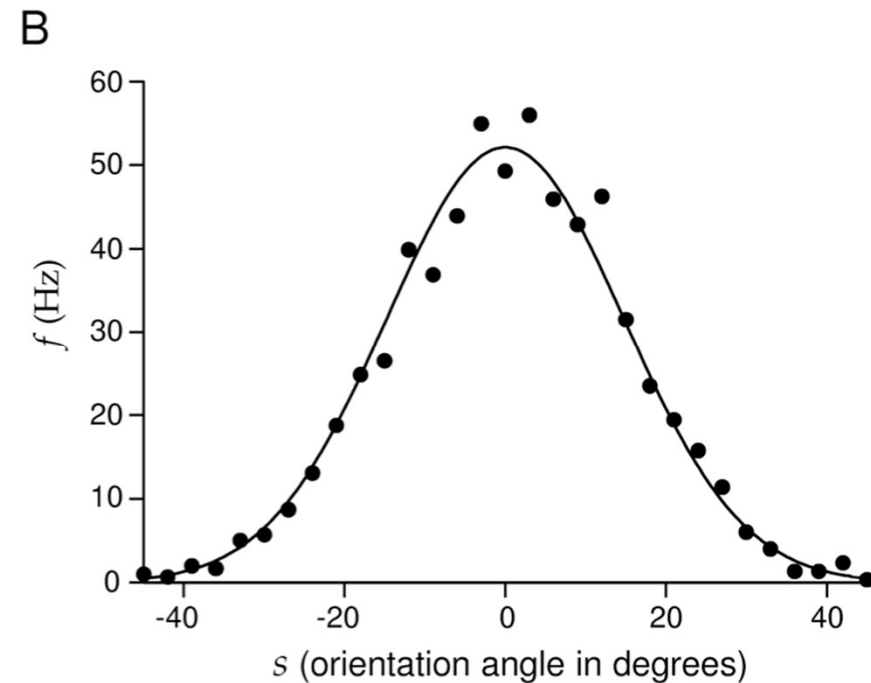
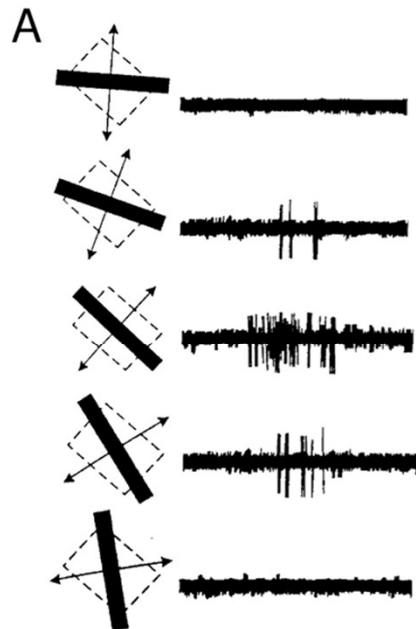
[Cisek, Kalaska 2005]

# Fields may jointly represent different dimensions: examples



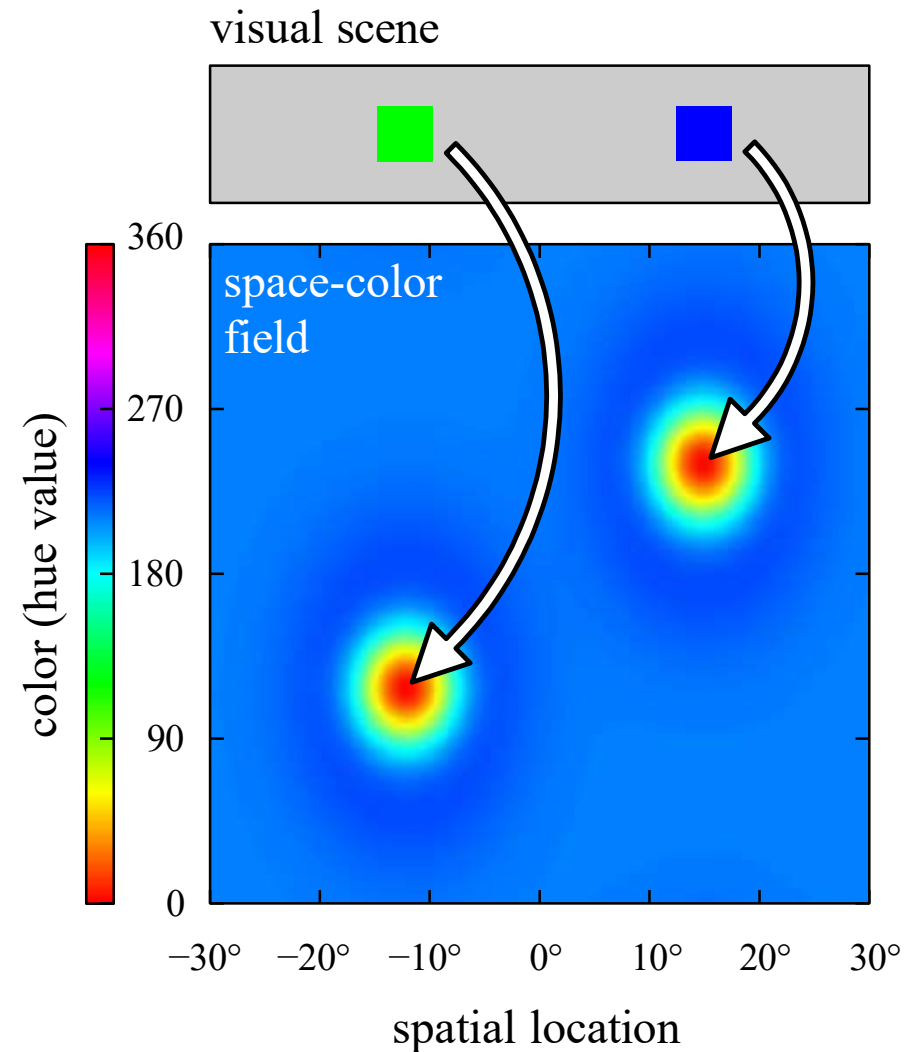
# Neurons may be tuned to multiple different feature dimensions

- example: receptive field + direction tuning
- => combines visual space and orientation
- => “anatomical” binding



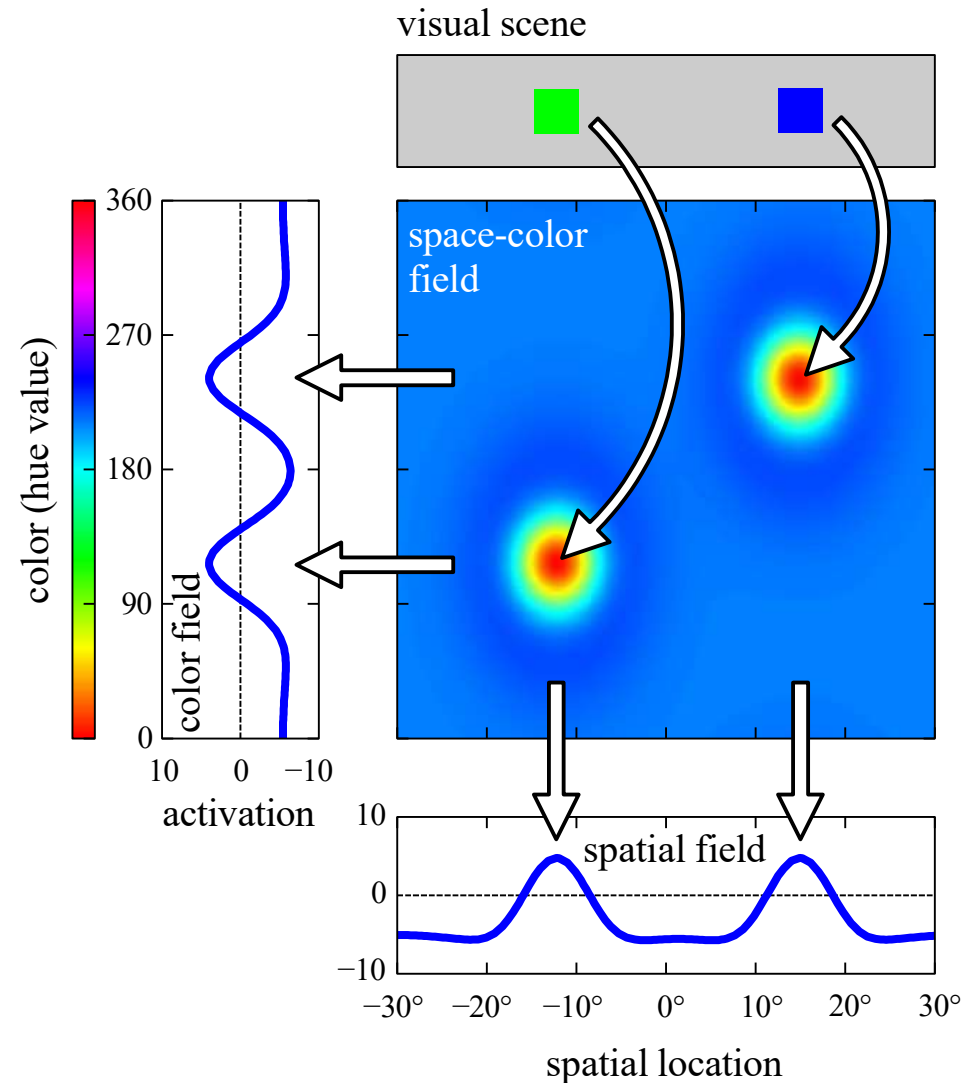
# Combining different feature dimensions

- example: a joint representation of color and visual space “binds” these two dimensions



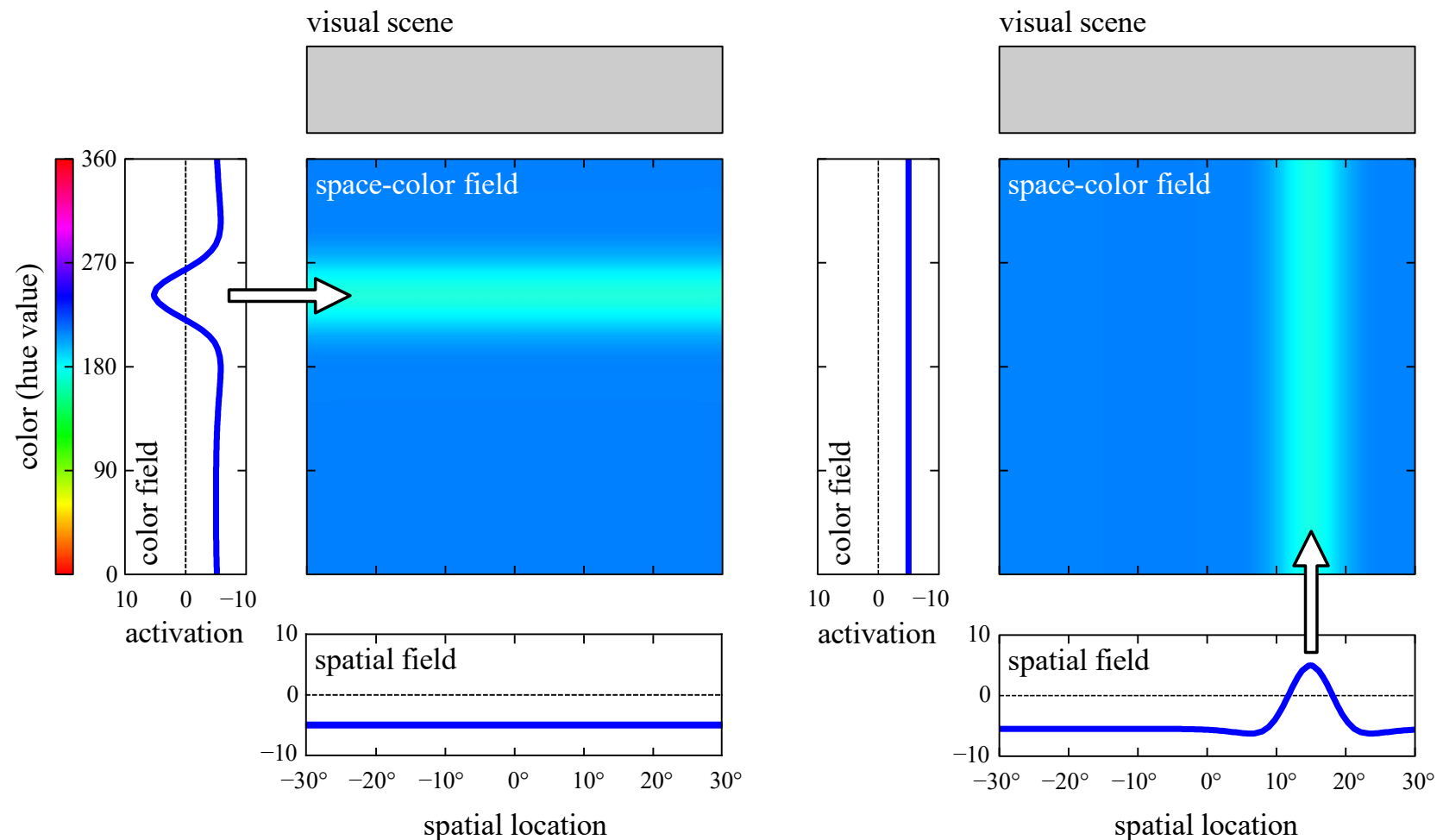
# Extract the bound features

- project to lower-dimensional fields
- by summing along the marginalized dimensions
- (or by taking the soft-max)



# Assemble bound representations

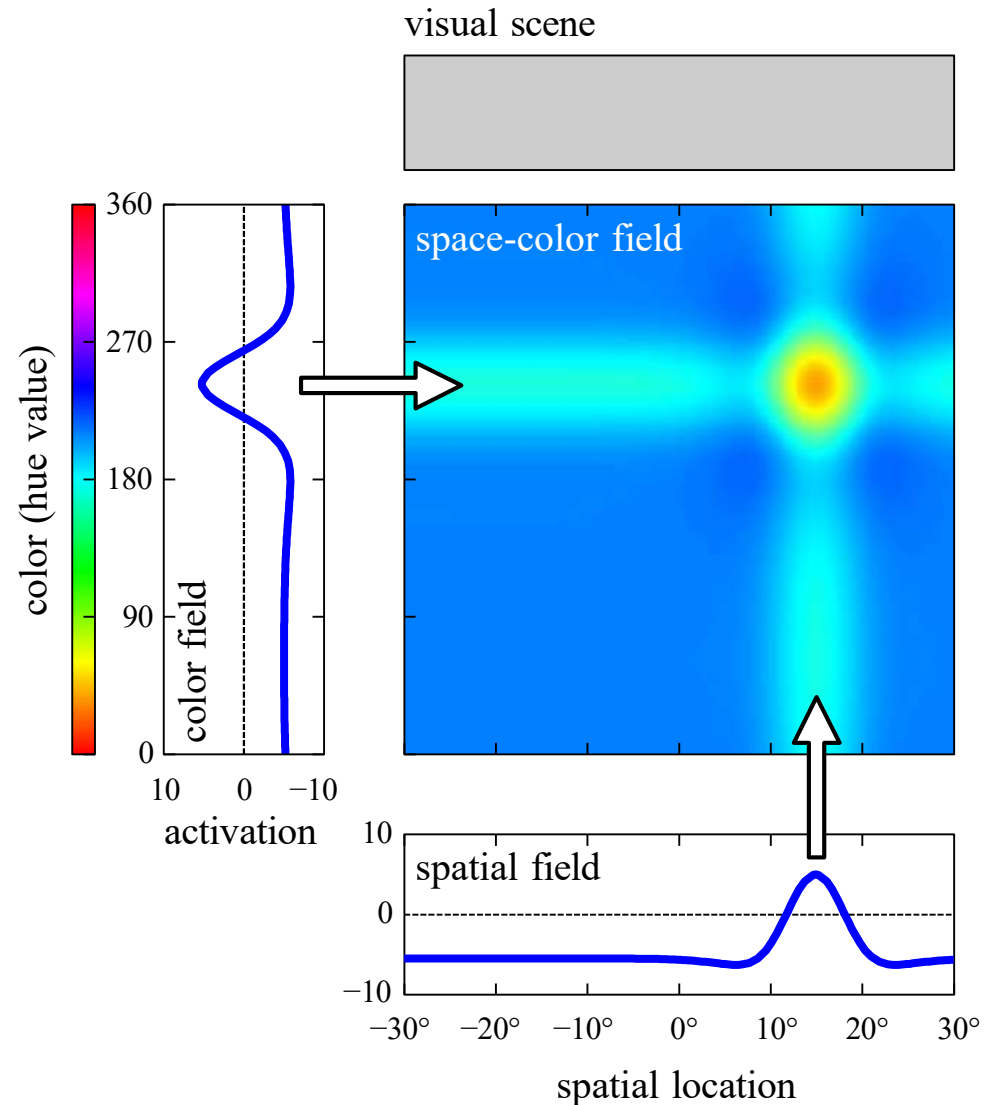
- project lower-dimension field onto higher-dimensional field as “ridge input”



[Schneegans et al., Ch 5 of *DFT Primer*, 2016]



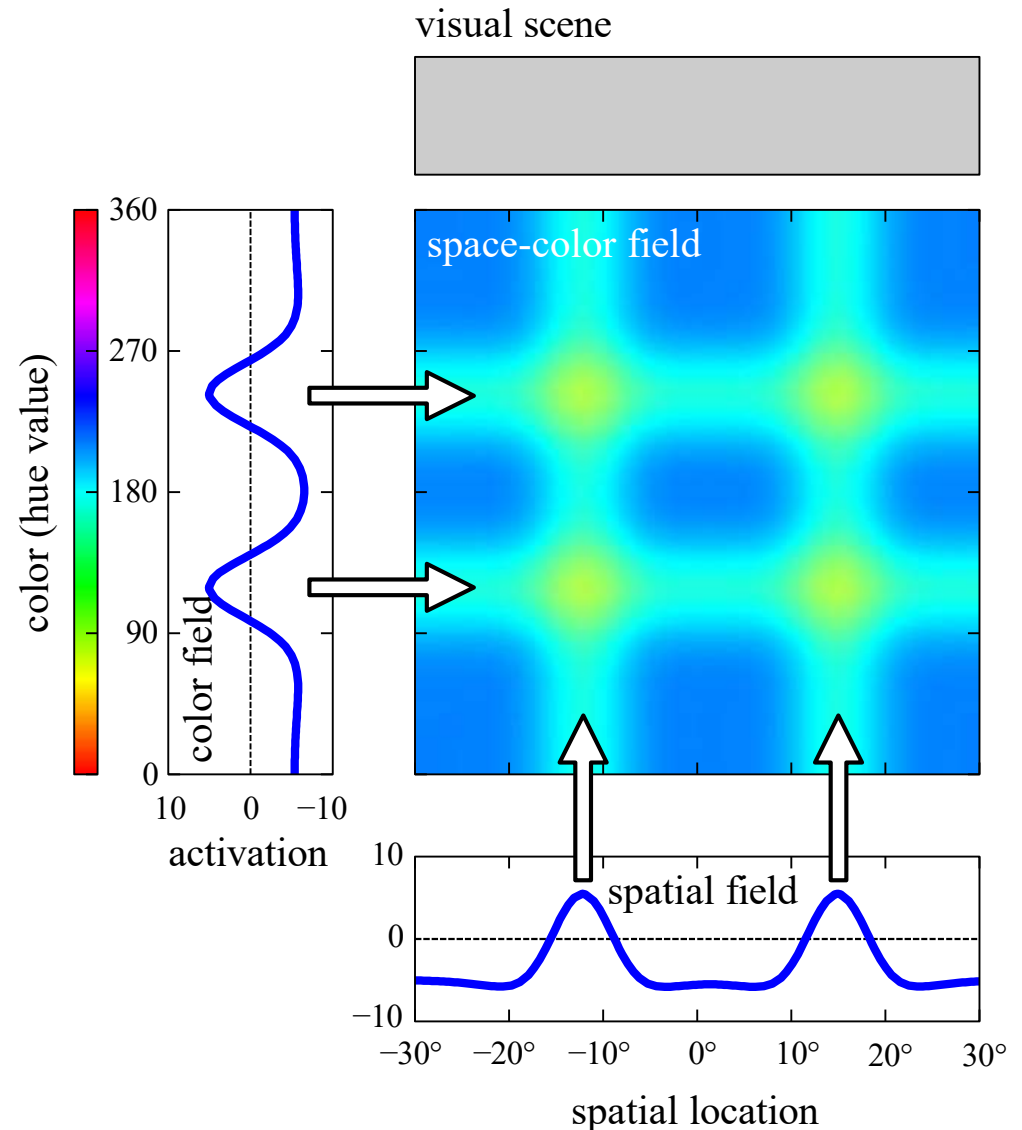
# Assemble bound representations



[Schneegans et al., Ch 5 of *DFT Primer*, 2016]

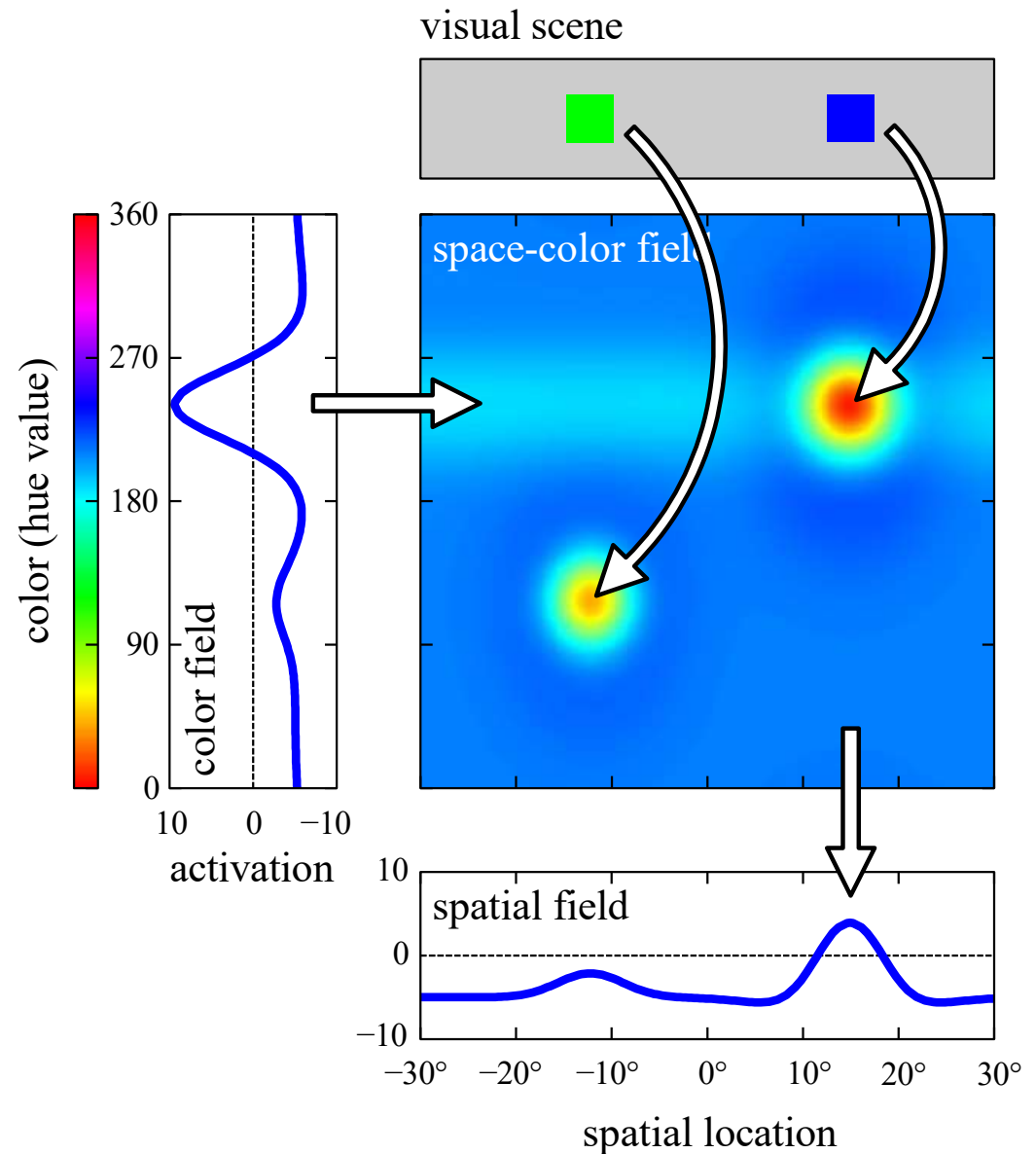
# Assemble bound representations

- **binding problem:**  
multiple ridges along lower-dimensional space lead to a correspondence problem
- => assemble one object at a time...
- => sequentiality bottleneck!



# Search

- ridge input along one dimension extracts from bound representation matching objects
- other dimensions of those objects can then be extracted
- e.g. visual search



# Scaling feature dimensions

- 2 spatial dimensions

- depth

- orientation

- color

- texture

- movement direction

- size

- etc...

=>

- e.g. 8 dimensions

- 100 neurons per dimension

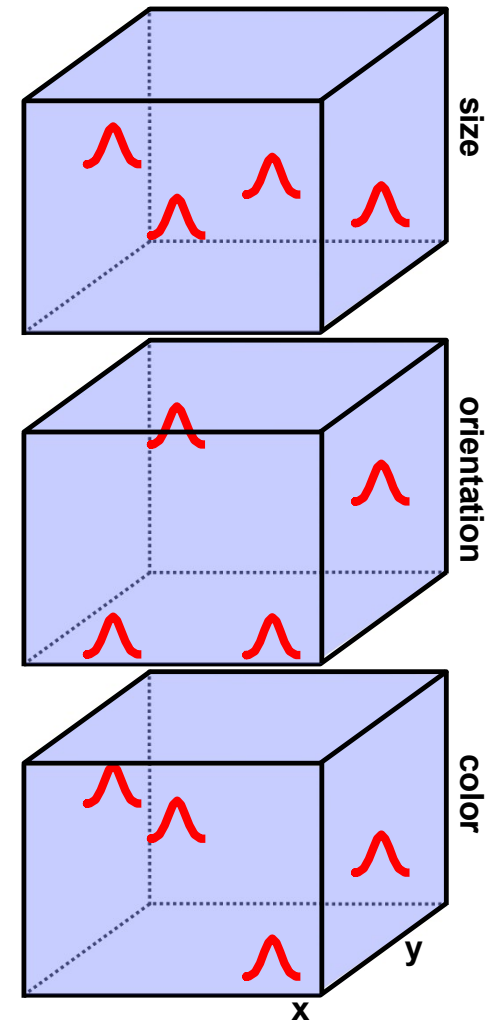
- $10^{2*8} = 10^{16}!$

- more than there are in the entire brain!

- => only small sets of feature dimensions can be bound “anatomically”

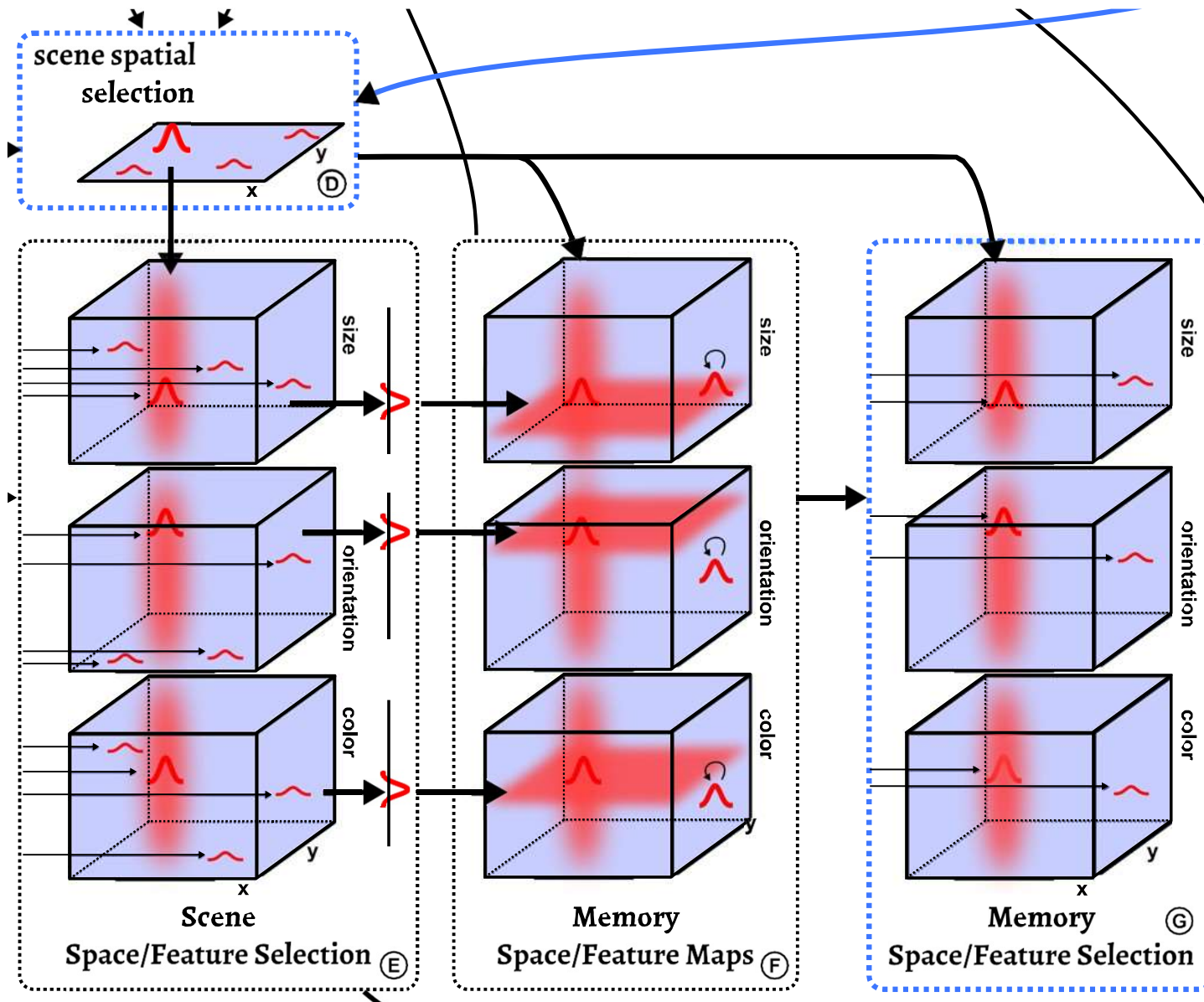
# Binding through space

- many 3 to 4 dimensional feature fields
- all of which share the one dimension: visual space (~all neurons have receptive fields)
- bind through space à la Feature Integration Theory (Treisman)

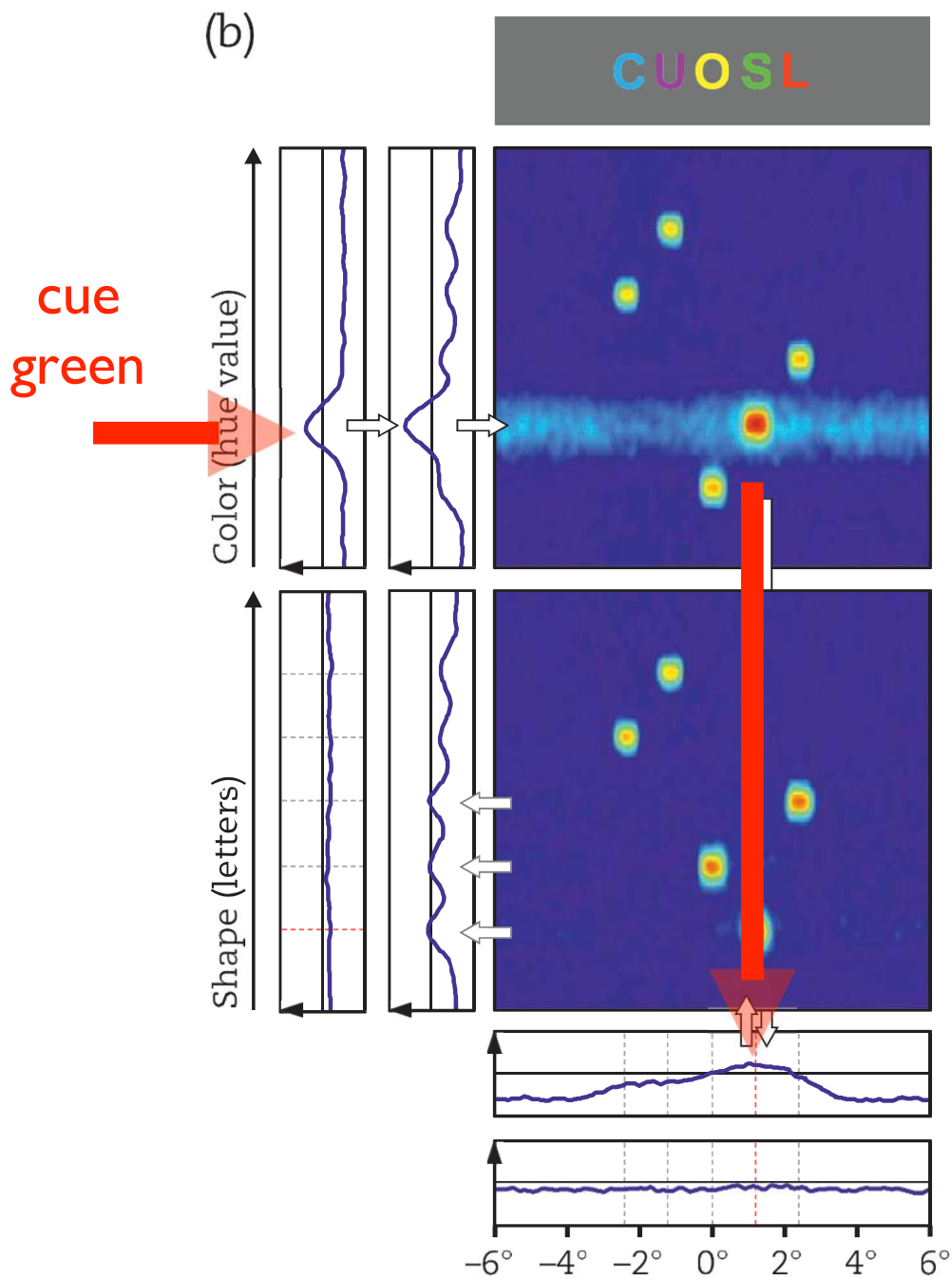


[Griegen et al. *Attention, Perception & Psychophysics* 2020]

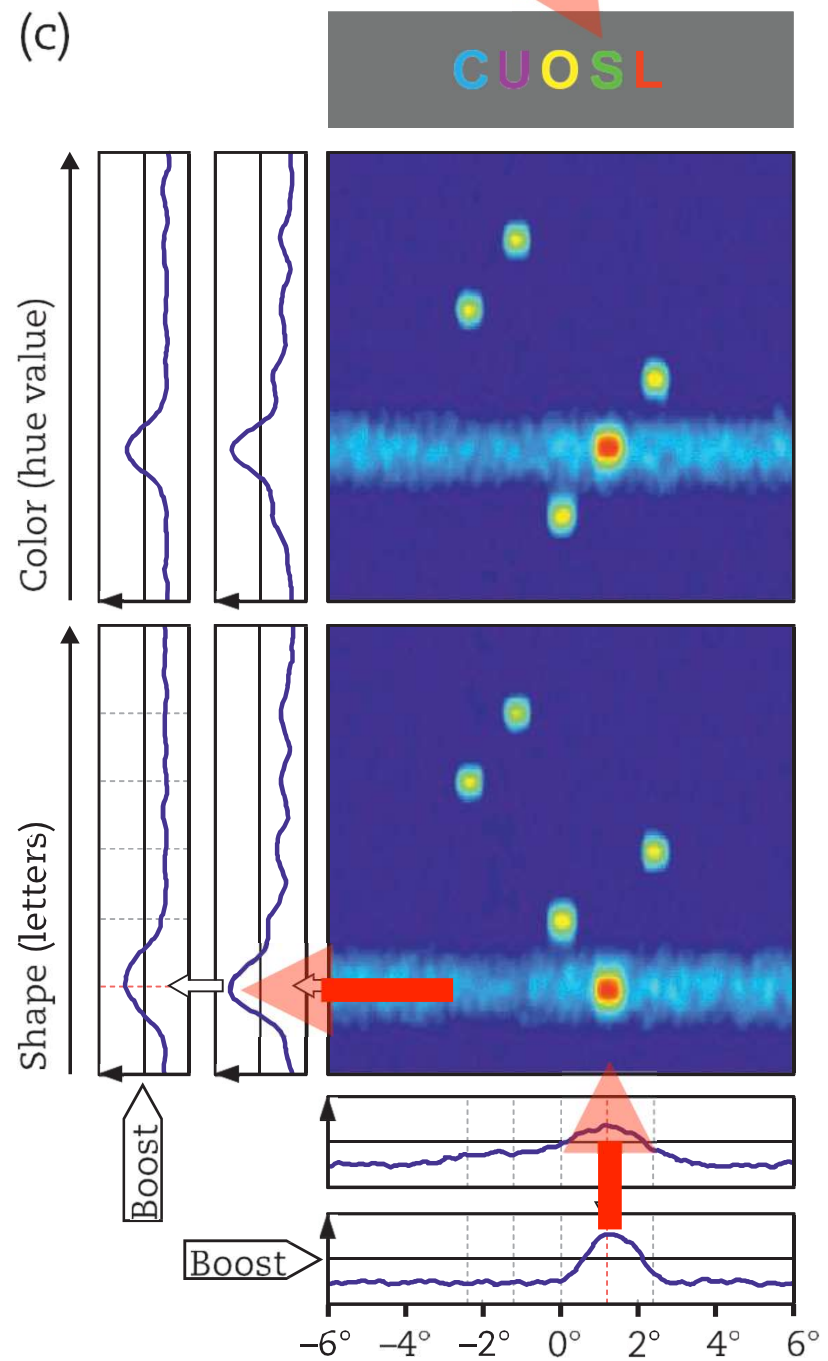
# Binding through space



[Griegen et al. *Attention, Perception & Psychophysics* 2020]



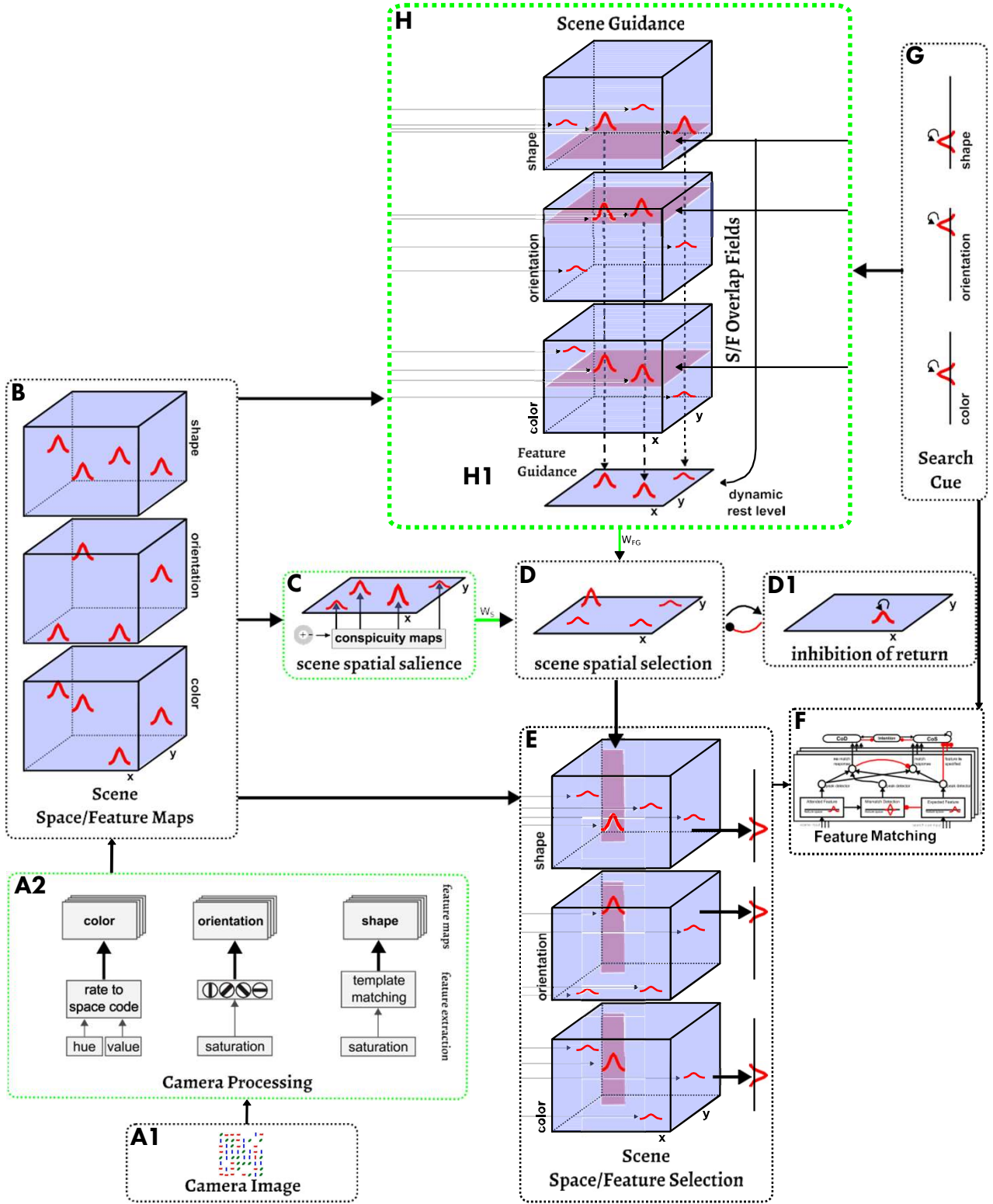
answer  
"s"



[Schneegans et al., Ch 5 of *DFT Primer*, 2016]

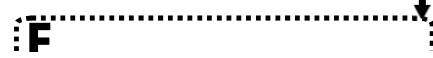
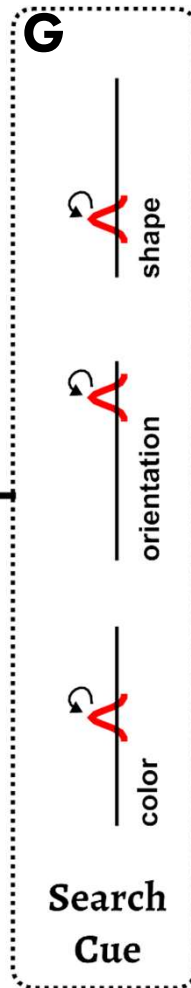
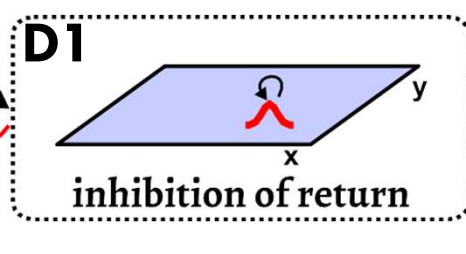
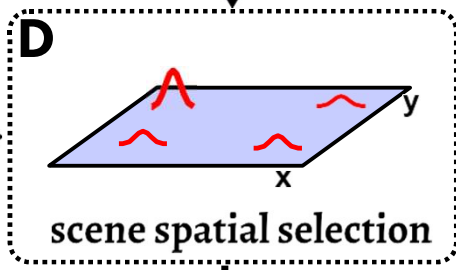
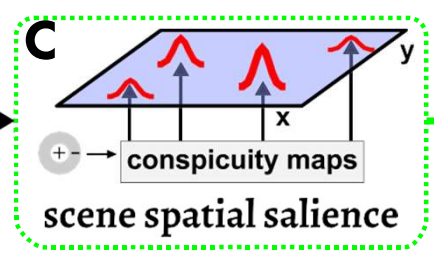
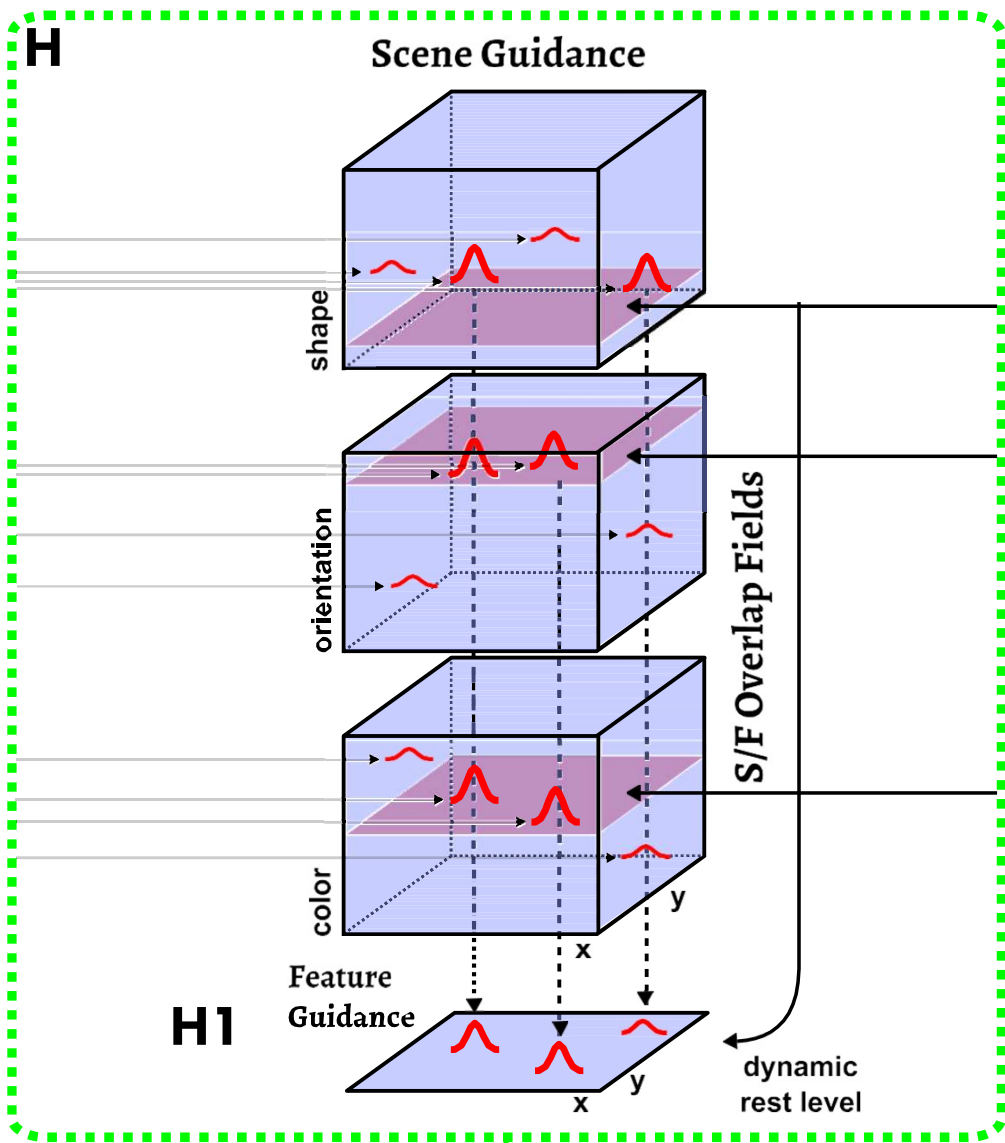
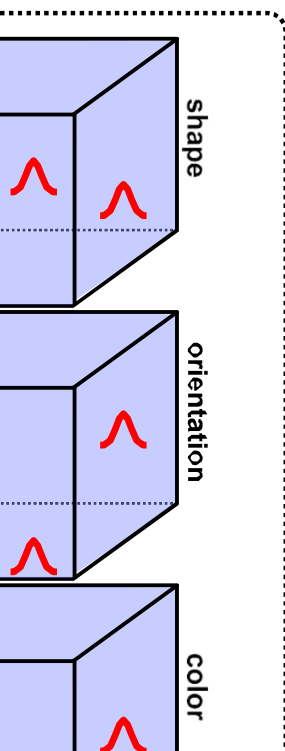
# Conjunctive visual search

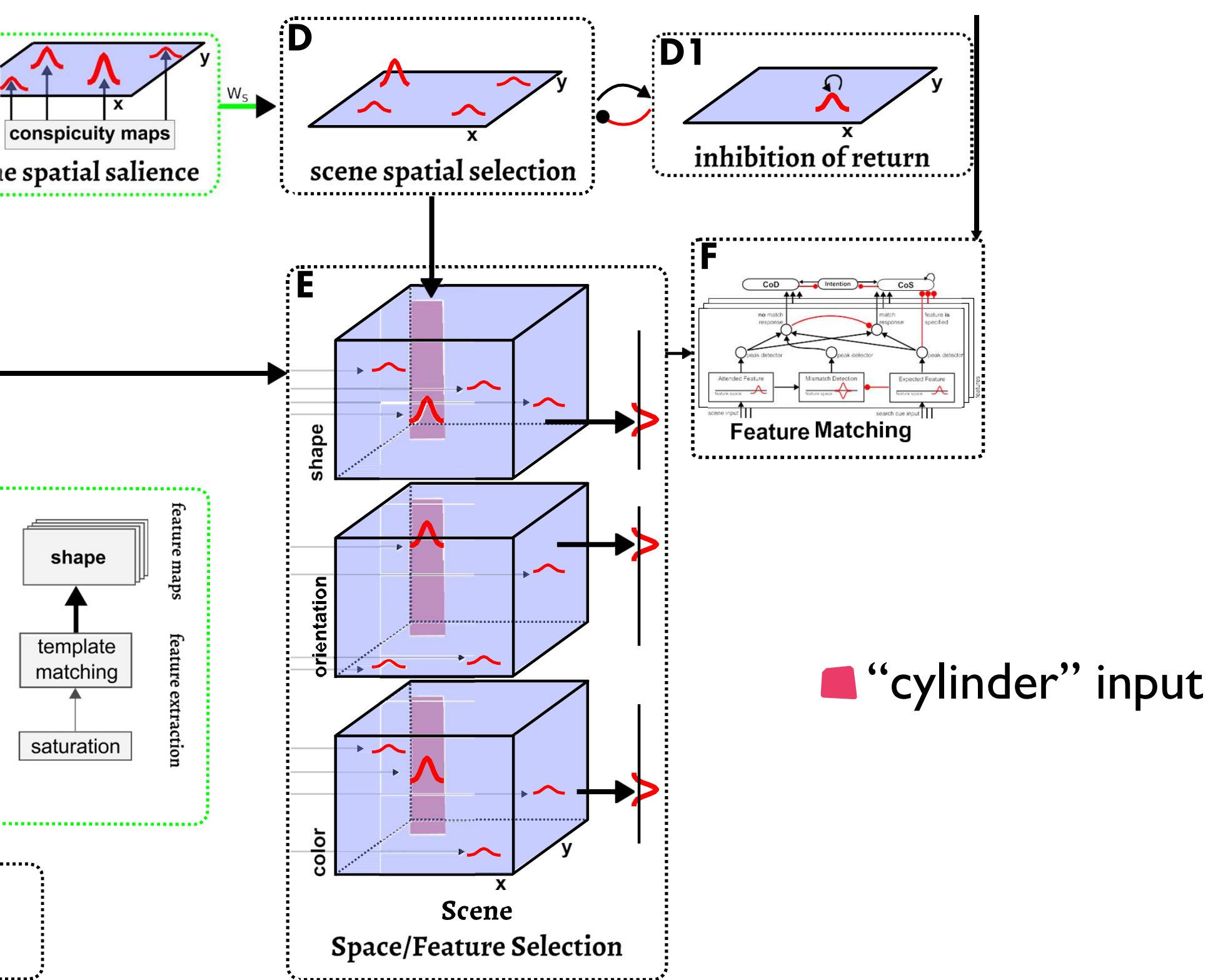
[Griegen et al. *Attention, Perception & Psychophysics* 2020; *CogSci* 2021]





■ “slice” input

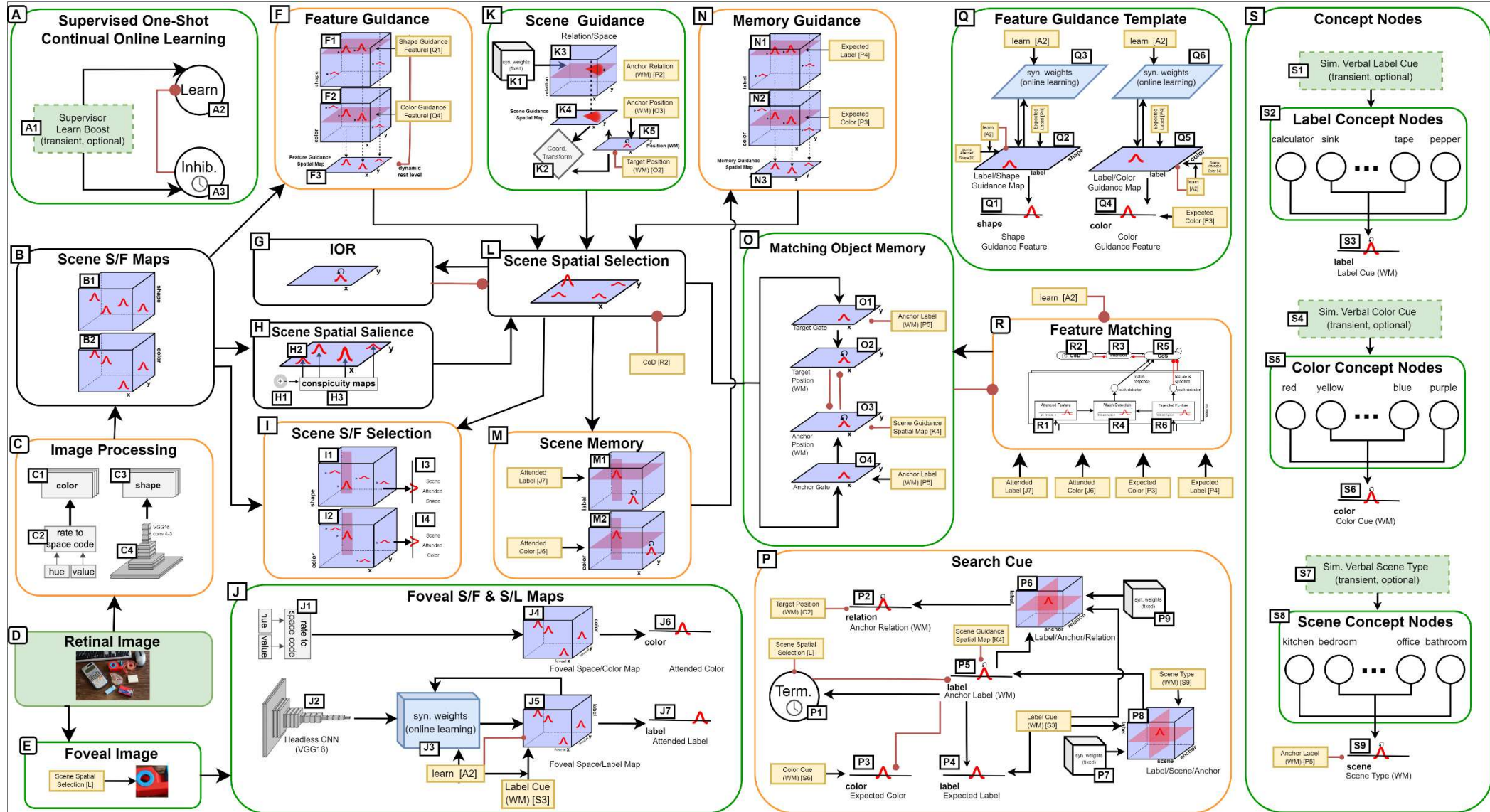




# Visual search









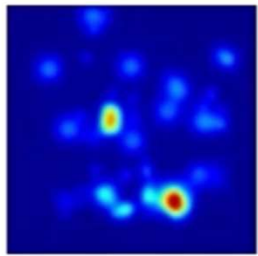
Camera Image



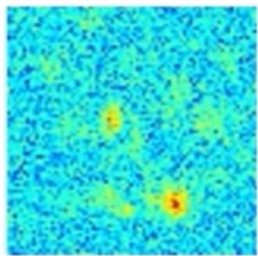
Foveal Image



Target Position (WM)



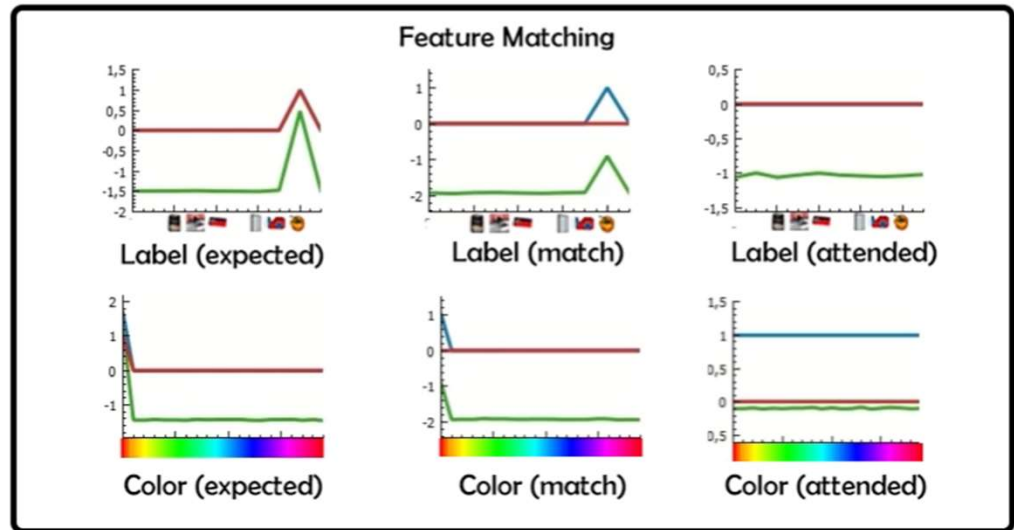
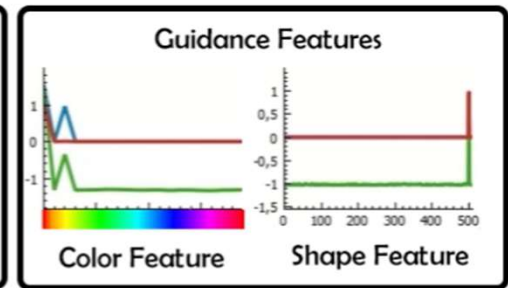
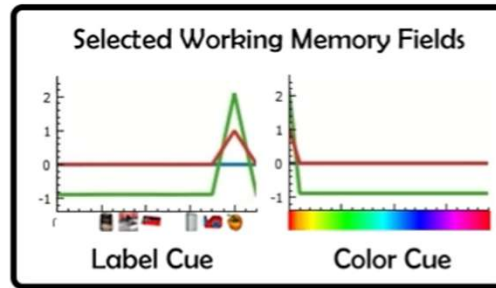
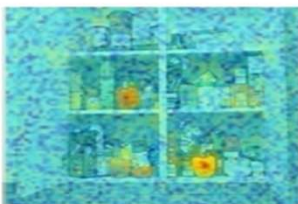
Attention (Input)



Attention (Activation)

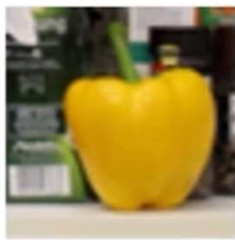


Attention (Sig. Activation)





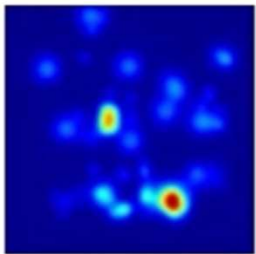
Camera Image



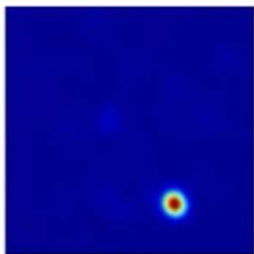
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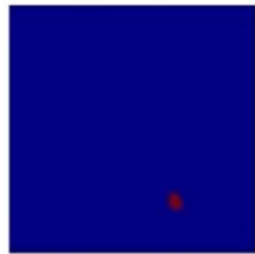
Target Position (WM)



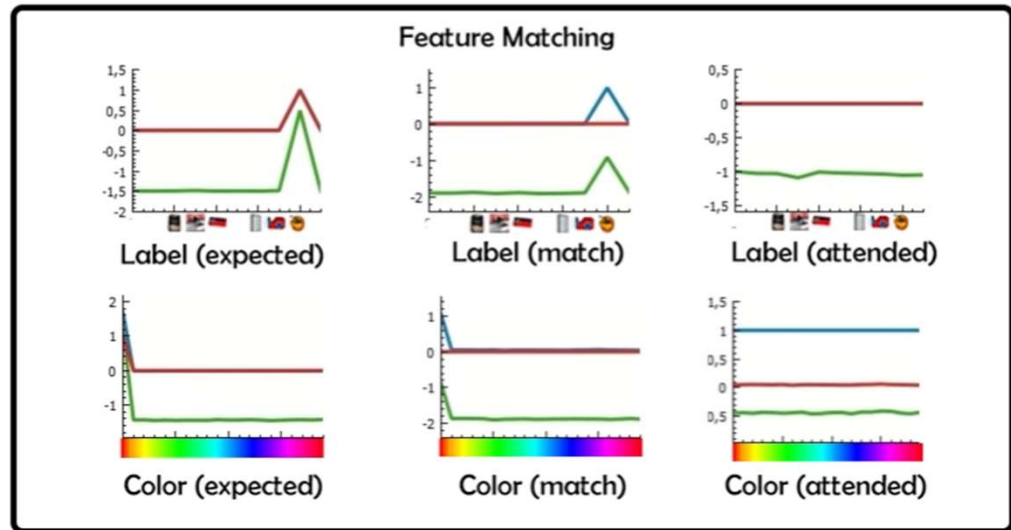
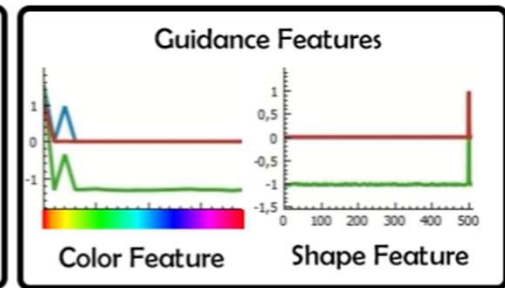
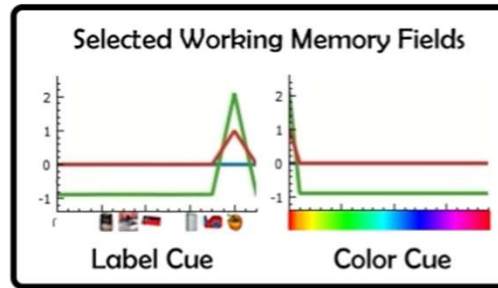
Attention (Input)



Attention (Activation)



Attention (Sig. Activation)







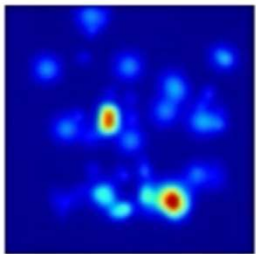
Camera Image



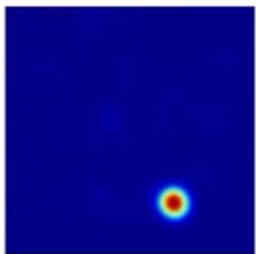
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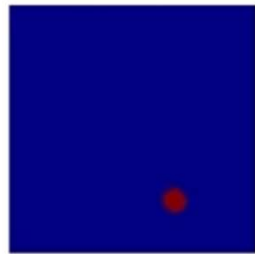
Target Position (WM)



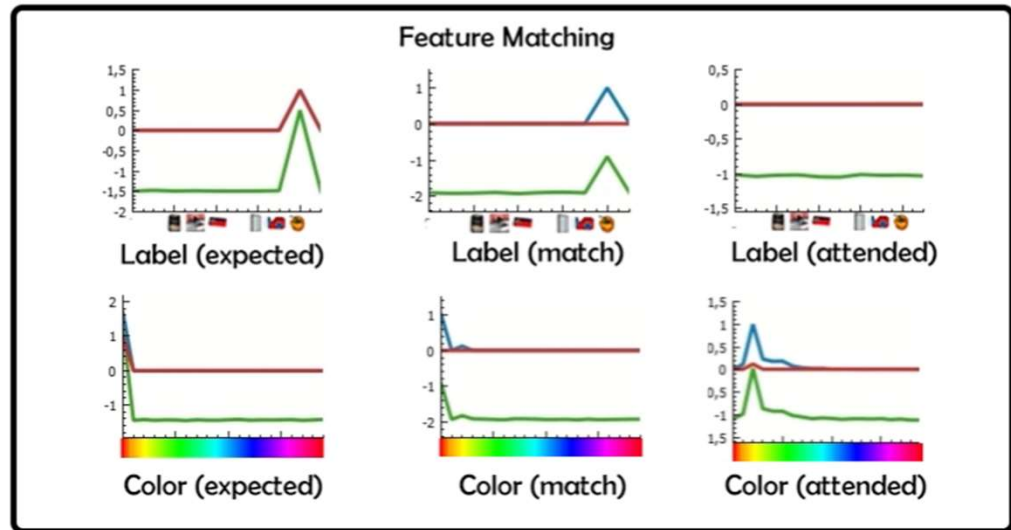
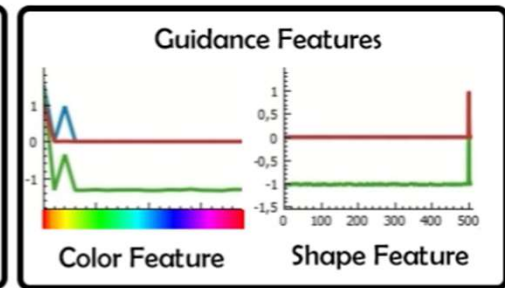
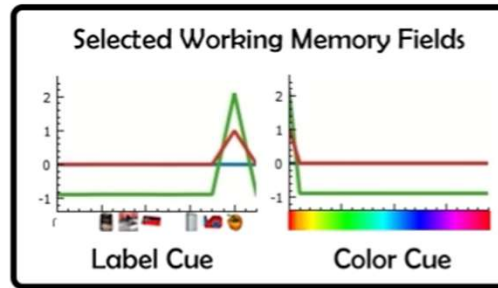
Attention (Input)



Attention (Activation)

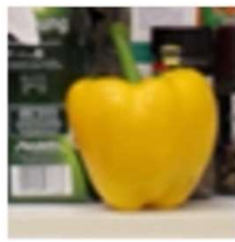


Attention (Sig. Activation)





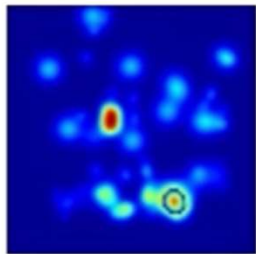
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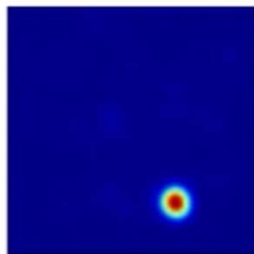
Foveal Image



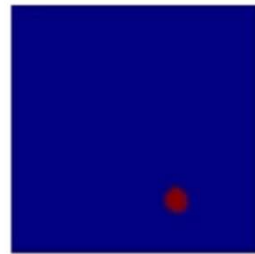
Target Position (WM)



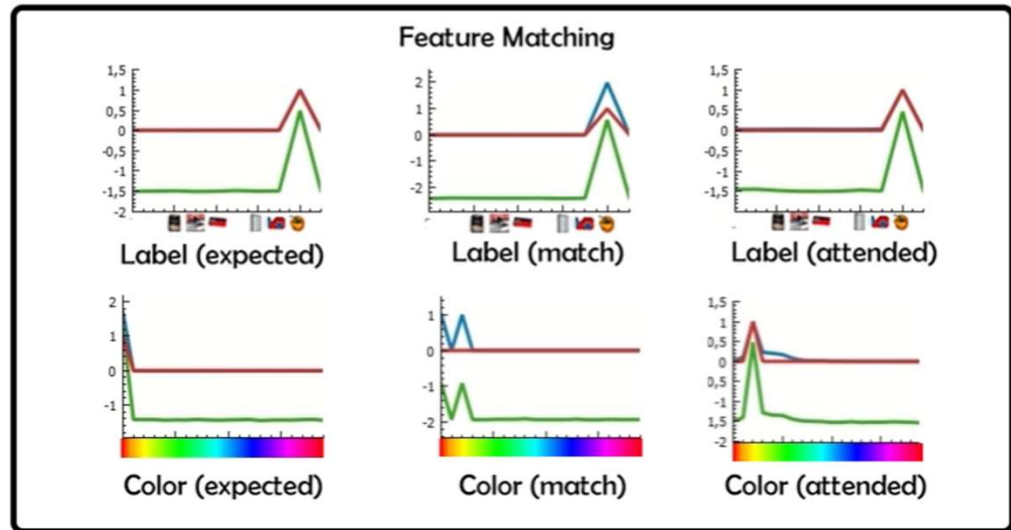
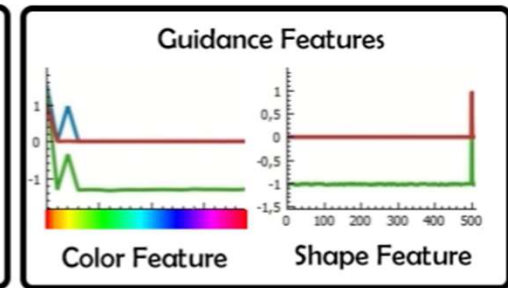
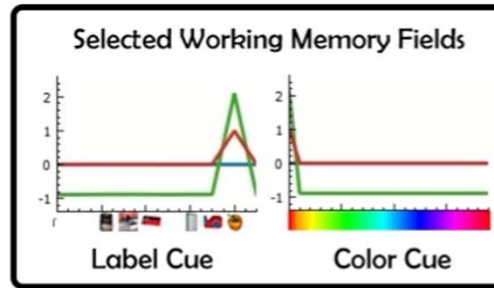
Attention (Input)



Attention (Activation)



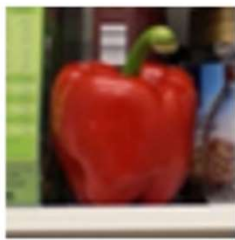
Attention (Sig. Activation)







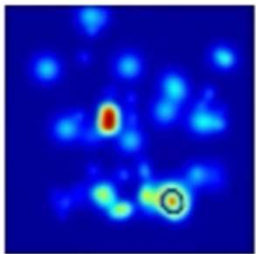
Camera Image



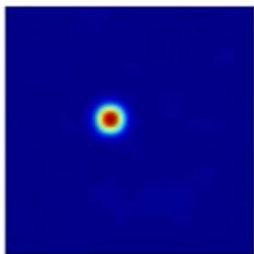
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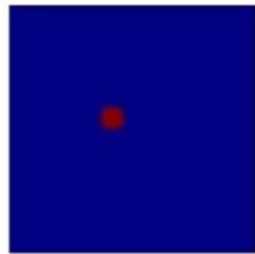
Target Position (WM)



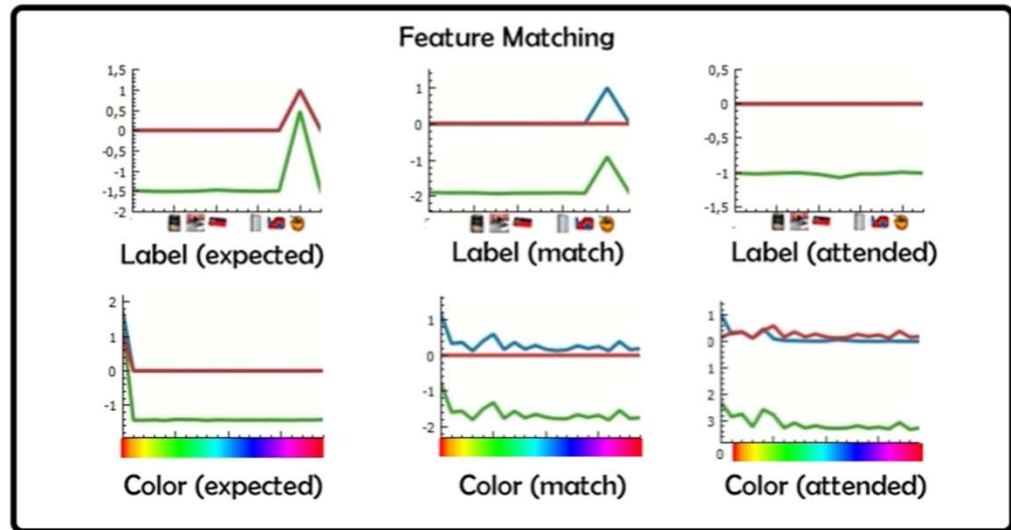
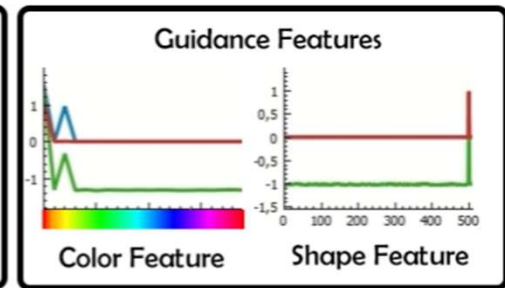
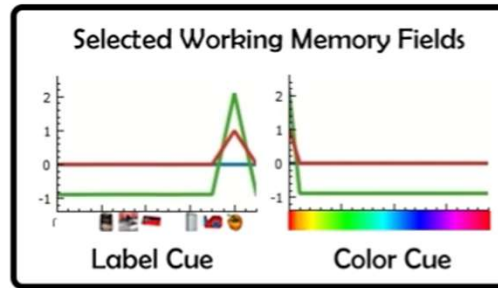
Attention (Input)



Attention (Activation)



Attention (Sig. Activation)





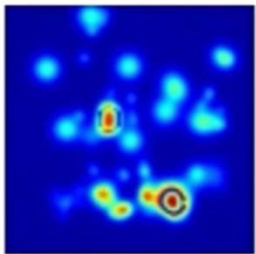
Camera Image



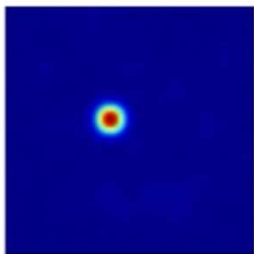
Foveal Image



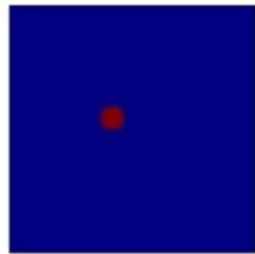
Target Position (WM)



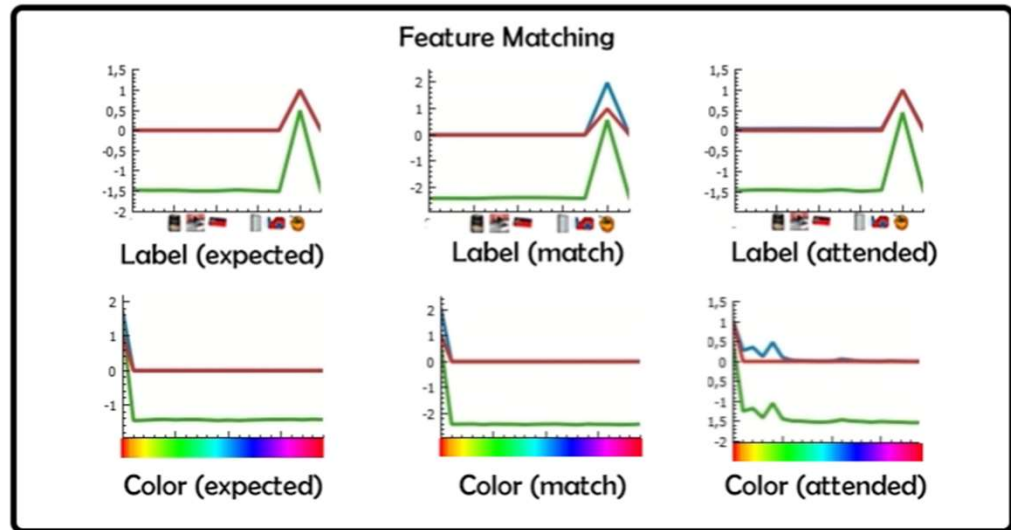
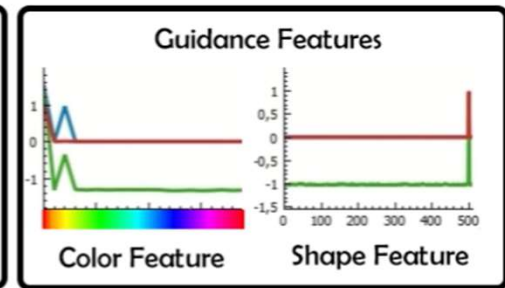
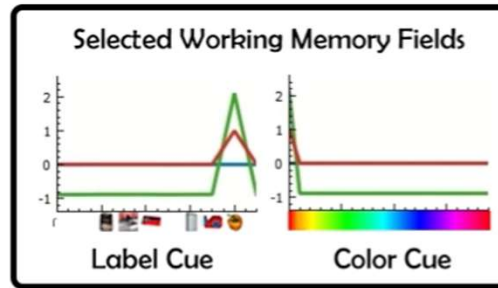
Attention (Input)



Attention (Activation)



Attention (Sig. Activation)



- Neural fields: dimensions
- Binding
- Visual search