



RUHR-UNIVERSITÄT BOCHUM

# NEURAL PROCESS MODELS OF LANGUAGE GROUNDING

Daniel Sabinasz – Dynamic Friday Tutorials – February 3rd, 2023

# MOTIVATION

- Towards understanding the biological neural processes that give rise to the language competence
- Build neural dynamic process model of important aspects of that competence

# THEORETICAL STARTING POINT

- The language competence is “grounded” in perceptual-motor processes
  - Makes use of these processes
  - Evolved “on top of” these processes
- Review: Barsalou (1999, 2008)

# RESEARCH PROGRAM

- Build models of how the language competence may emerge from the neural principles postulated in DFT
  - DFT primer: <https://www.youtube.com/watch?v=jFtt5KPg0lc>
- ... possibly using and extending the same neural architectures as more primitive sensory-motor processes

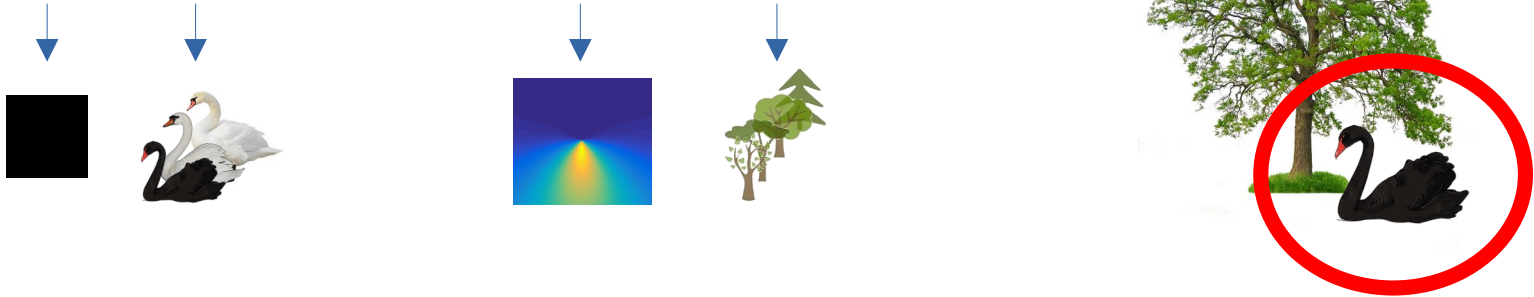
# PERCEPTUAL GROUNDING

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the black swan that sits below a tree



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- Primary motivation: Understanding the biological neural basis of human cognition
- But: Artificial systems that understand language need grounding (Lake & Murphy, 2021)
  - Insights may be gained to build better artificial systems that understand language by associating words with their perceptual meanings

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  - There is a wide range of grammatical constructions that can be combined in a wide number of ways
- Need to approach this in small steps

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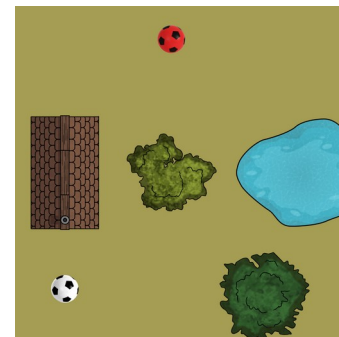
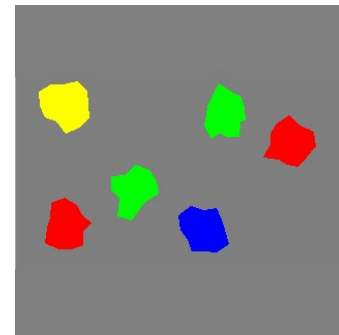
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- Such language is about things in the environment that are immediately perceivable
- Arguably the oldest form of communication

# OUTLOOK: FROM VISUO-SPATIAL CONCEPTS TO ABSTRACT CONCEPTS

- Many of our abstract concepts are metaphorically related to more basic concepts (Lakoff and Johnson, 1980; Hofstadter and Sander, 2013)
- These basic concepts often have a perceptual or spatial nature
  - e.g. up for happy, down for sad
- This arguably reflects an evolutionary history of abstract language evolving on top of visuo-spatial language
- → Towards general models of language grounding from models of visuo-spatial language grounding

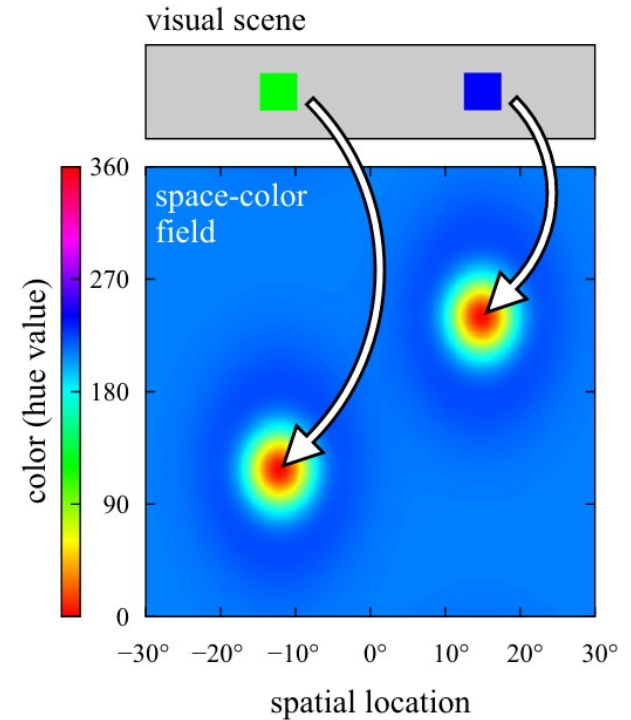
# PLAN

- February 3<sup>rd</sup>: Simple visuo-spatial language grounding
  - e.g., “the red to the right of the green”
  
- March 3<sup>rd</sup>: Compositional visuo-spatial language grounding
  - e.g., “the red ball that moves towards the big tree, which is to the left of the lake and to the right of the house”



# PRELIMINARIES

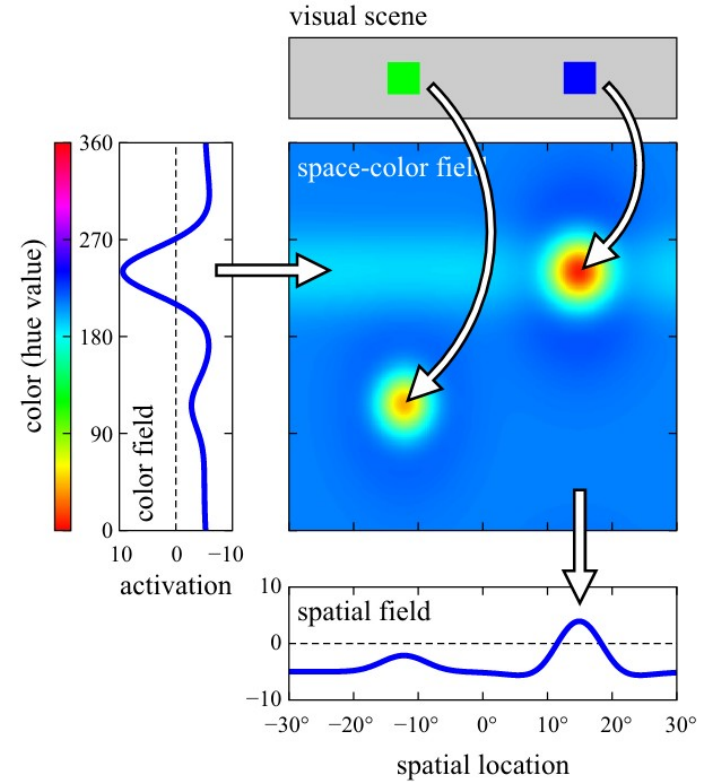
- Higher-dimensional fields enable binding dimensions



(Schneegans et al., 2016a)

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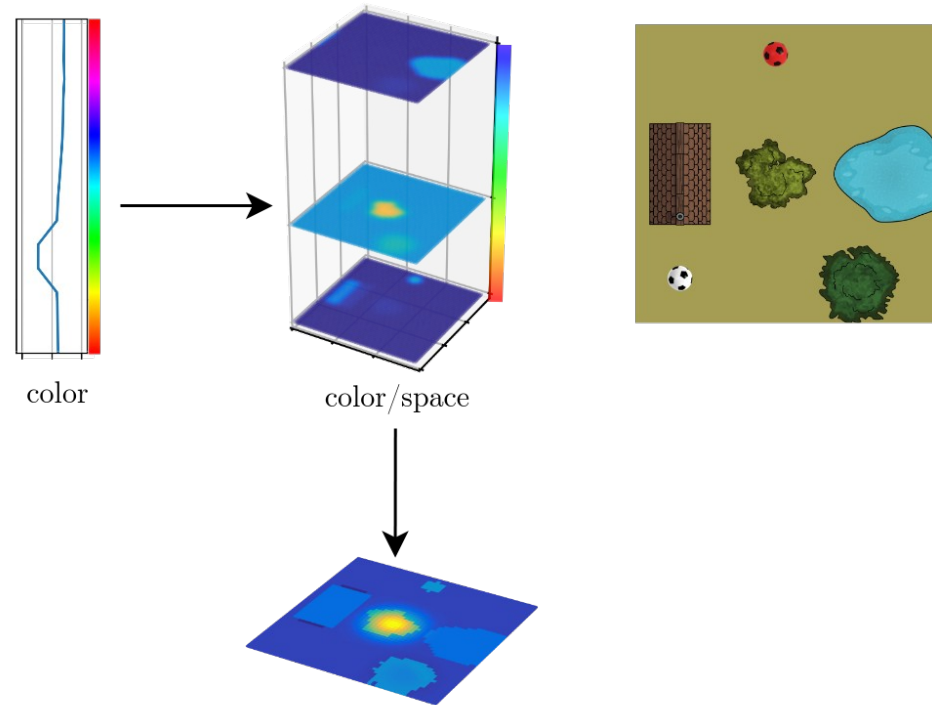
- Ridge input along one dimension extracts bound information



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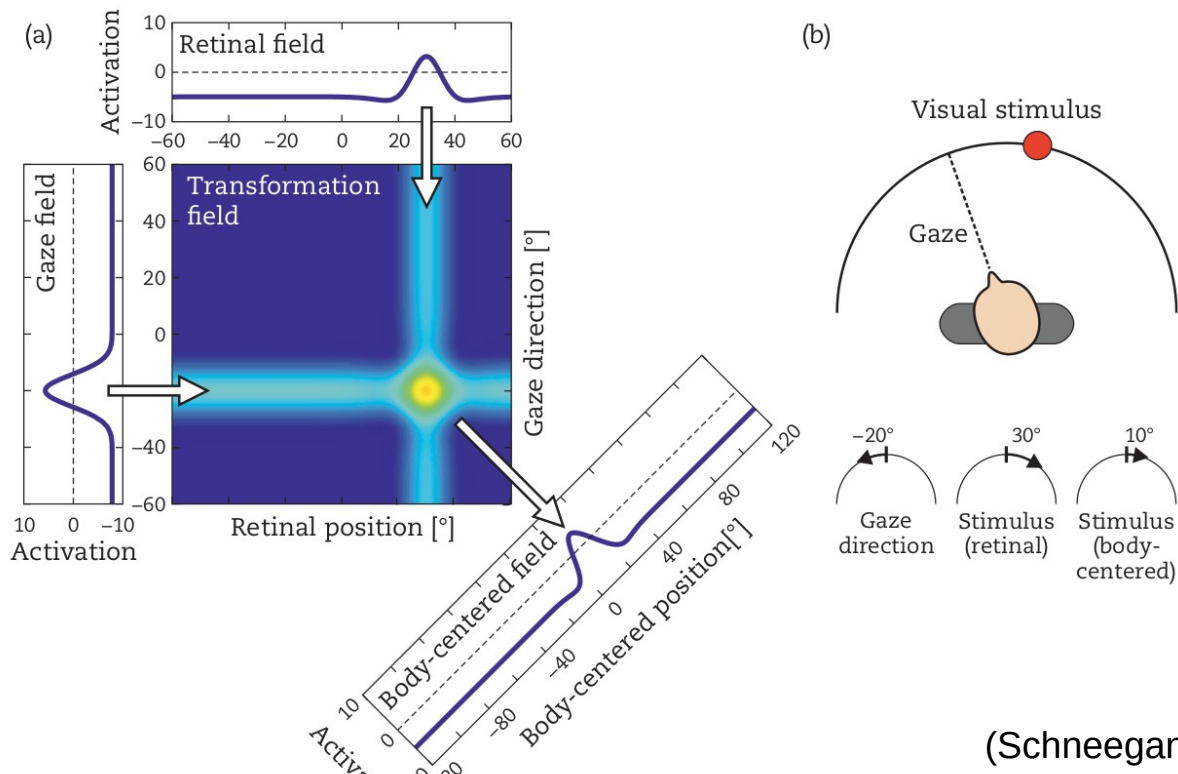
# PRELIMINARIES

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# PRELIMINARIES

- Transformation fields enable transforming spatial locations into a different coordinate system



(Schneegans et al., 2016b)



# PRELIMINARIES

- Evidence for neurons in the parietal cortex that have the response properties of transformation fields (Andersen and Mountcastle 1983; Andersen et al. 1985)
- Further evidence for the model (Schneegans & Schönner, 2012)

# Lipinski et al., 2012

- Cognitive architecture for grounding simple spatial language

# SPATIAL COMPARISON

- Compare two objects w.r.t. their spatial relation
- “Where is the green object relative to the red object?” → to the right



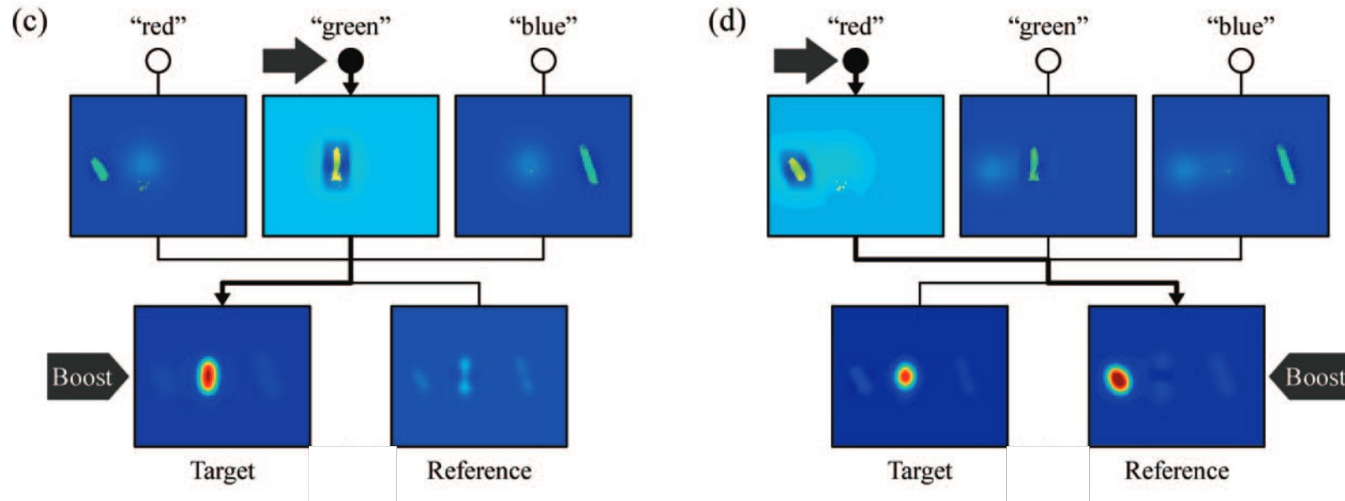
# SPATIAL COMPARISON: REQUIRED OPERATIONS

(Following a computational analysis by Logan & Sadler, 1996)

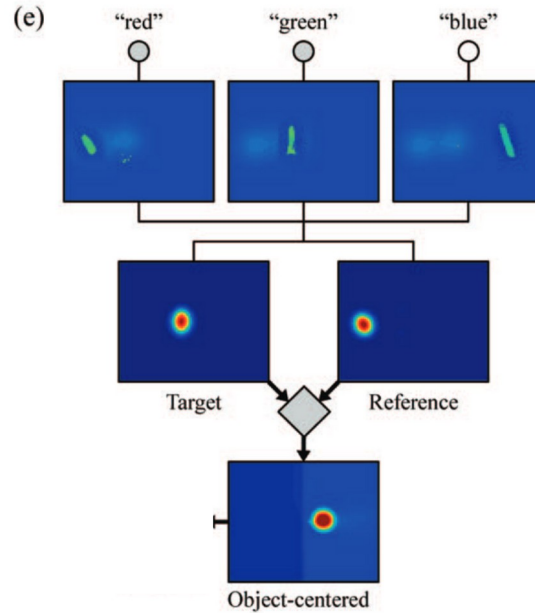
- Spatial indexing: bind objects in the perceptual input to target and reference roles
  - “Where is **the green object** relative to **the red object**?”  
target reference
- Alignment of reference frame with reference object (coordinate transformation)
- Compare that relative position to spatial templates that represent regions of acceptability



# FINDING OBJECTS IN THE PERCEPTUAL INPUT



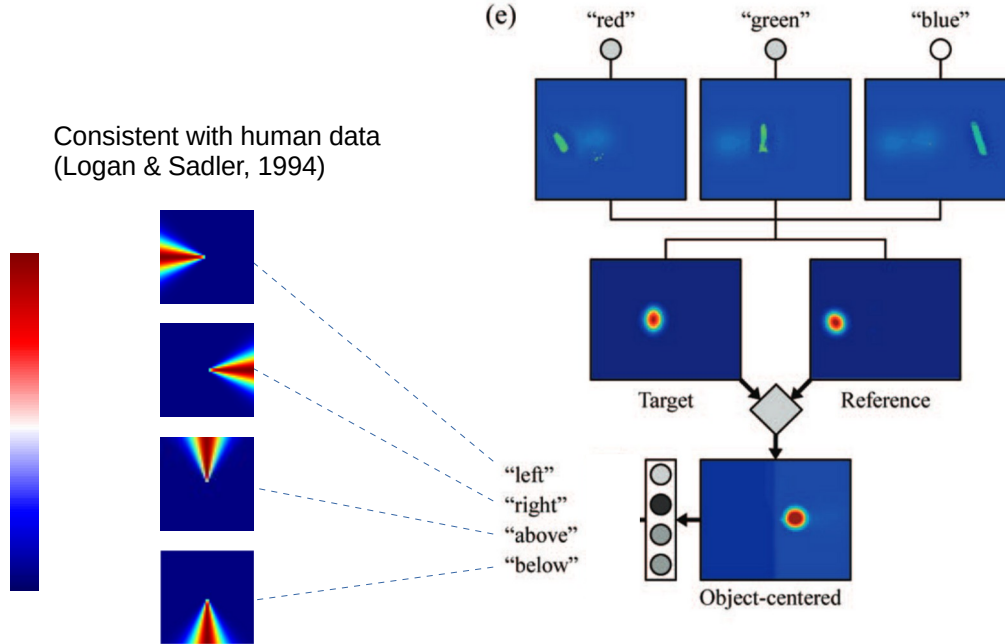
# COORDINATE TRANSFORMATION



# COMPARING TO A SPATIAL TEMPLATE



- “Where is the green object relative to the red object?”



# COMPARING TO A SPATIAL TEMPLATE

- Activation of the spatial relation nodes predict human acceptability ratings for spatial terms for a wide range of conditions



# TARGET IDENTIFICATION

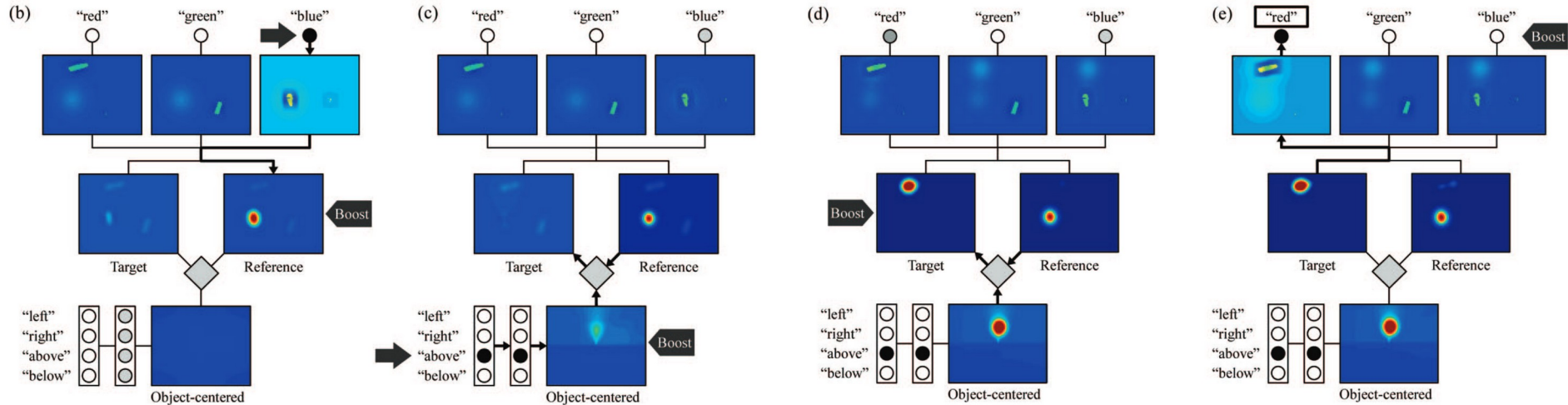
- Find an object which bears a given relation to a given reference object
- “Which object is above the blue object?”



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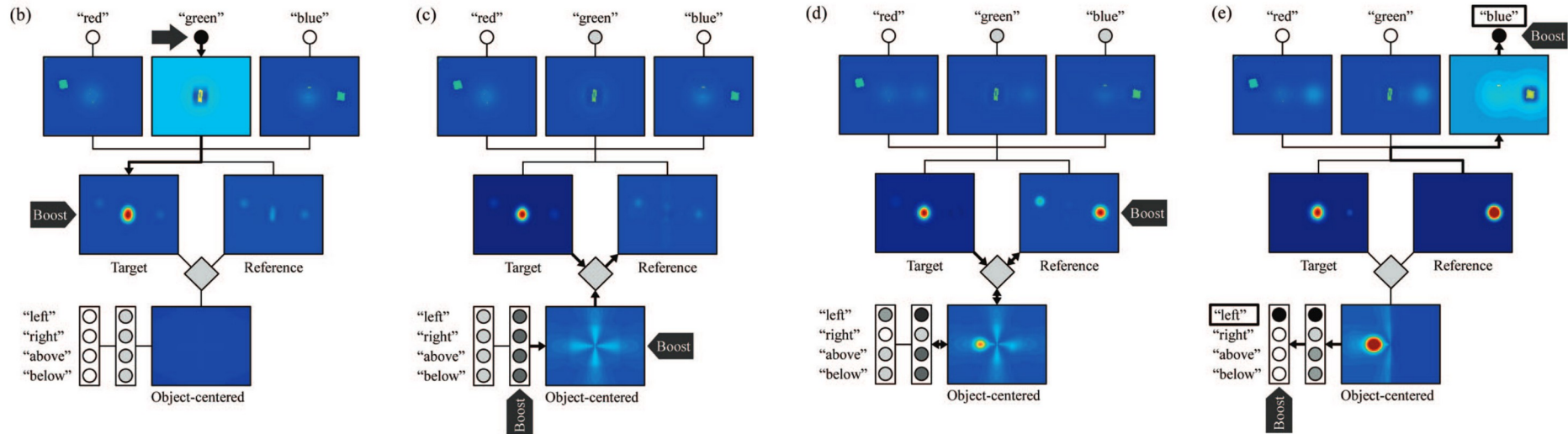
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# RELATION AND REFERENCE SELECTION



- “Where is the green object?”

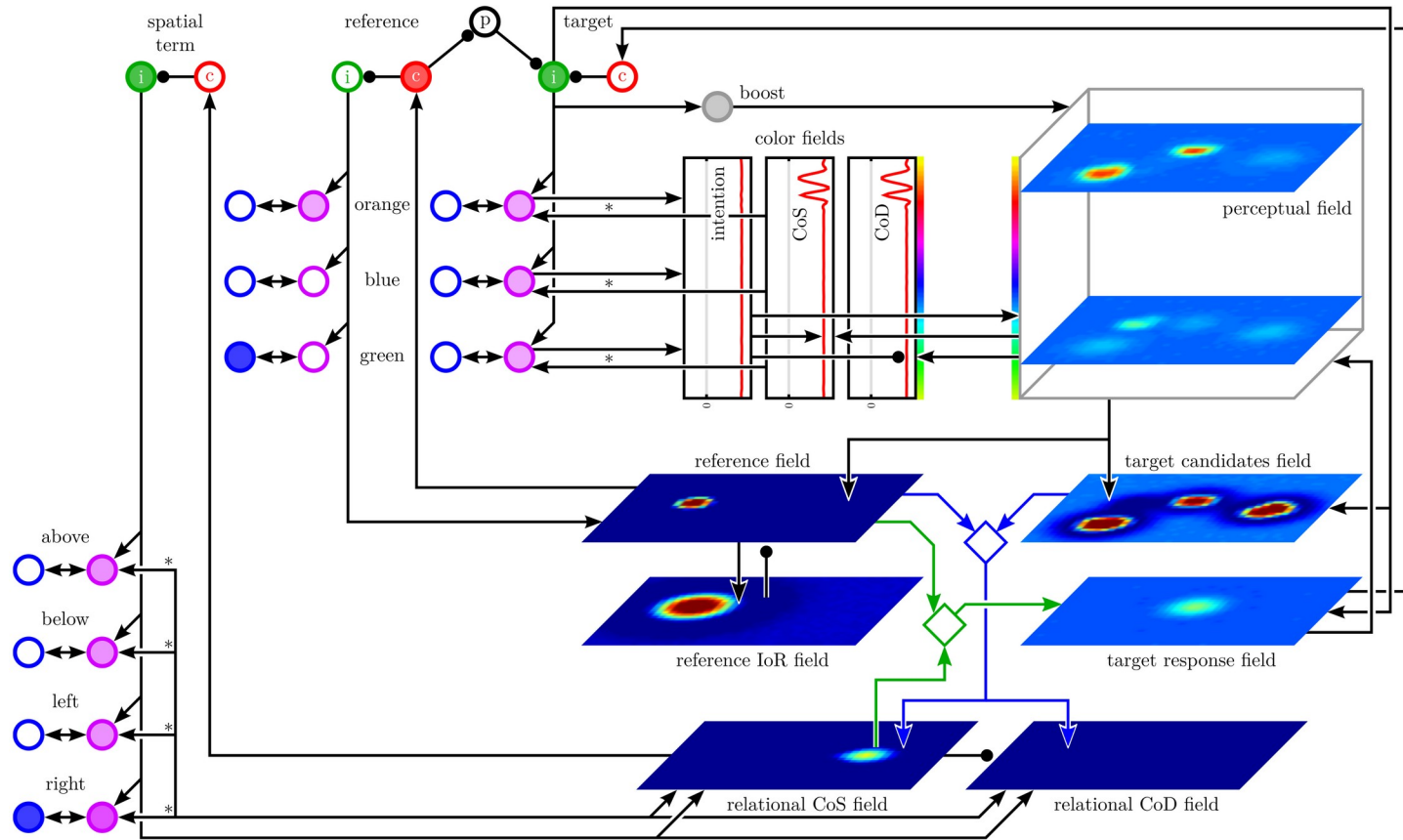


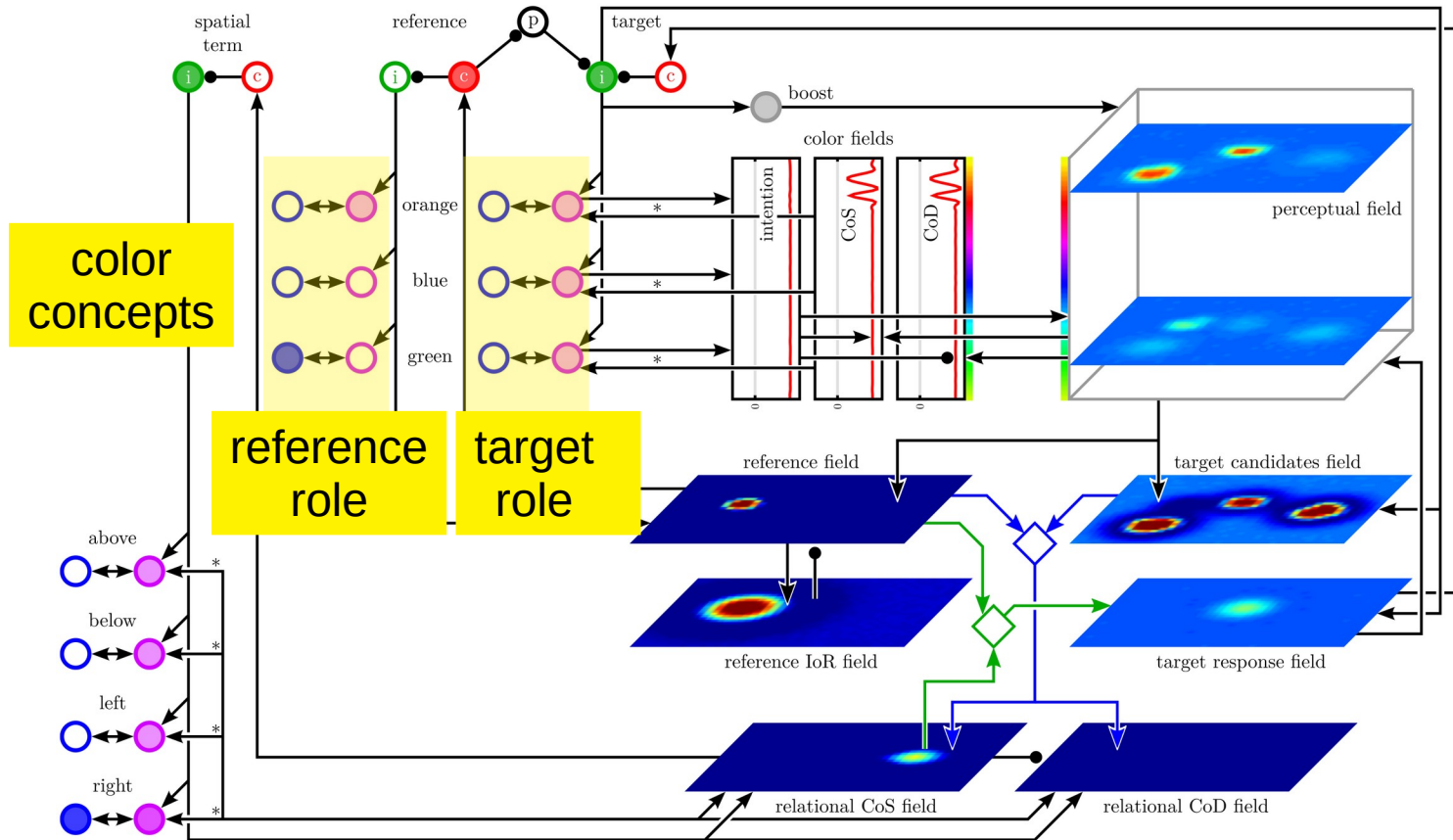
# GROUNDING

- Grounding a phrase which describes an object: finding the described object in the visual input
- e.g., “the red object to the left of the green object”
- Requires hypothesis testing

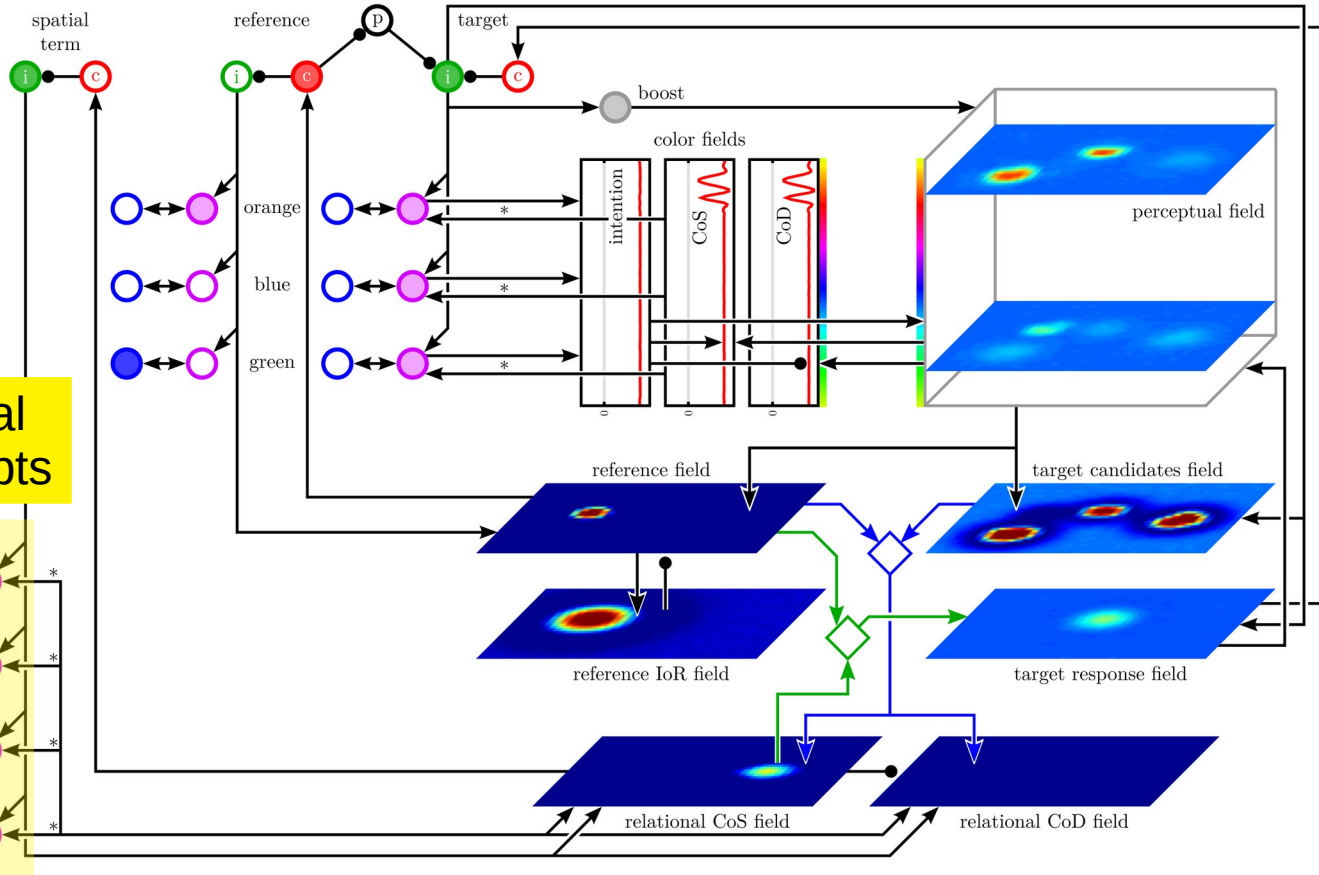
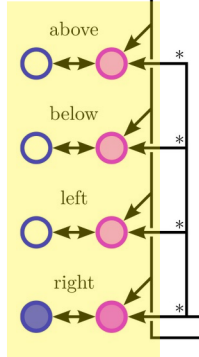


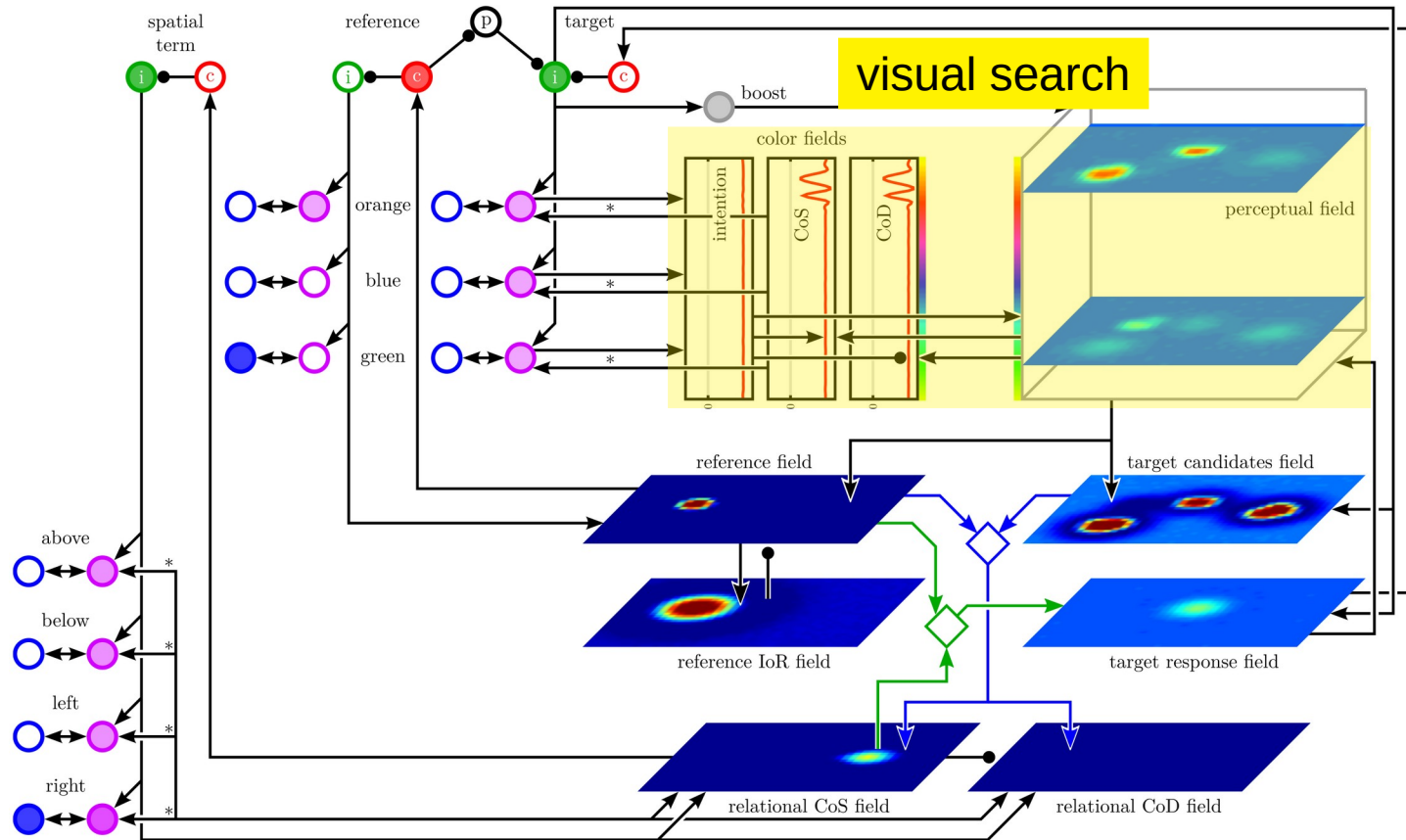
- Another desideratum: Autonomy





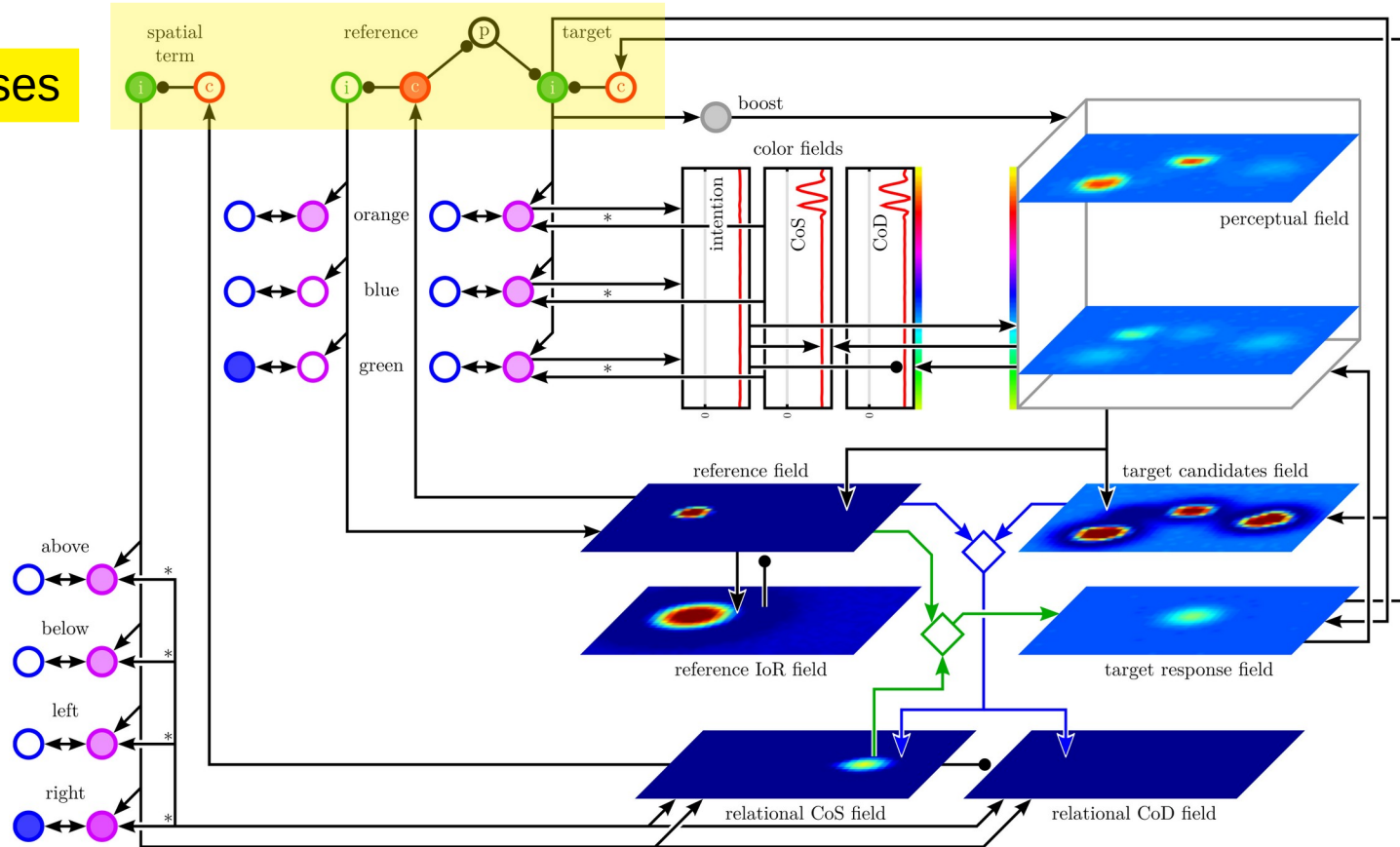
# spatial concepts

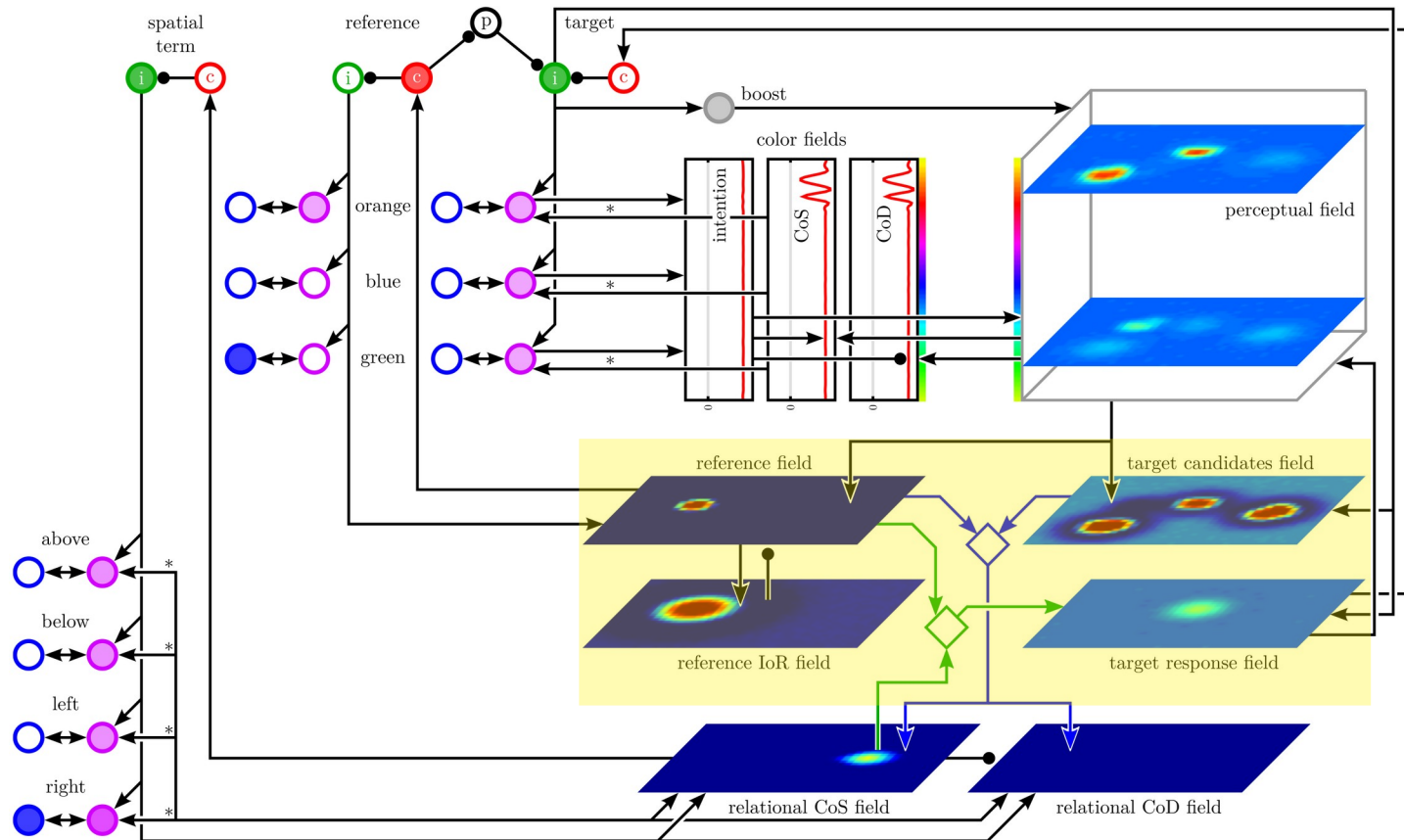


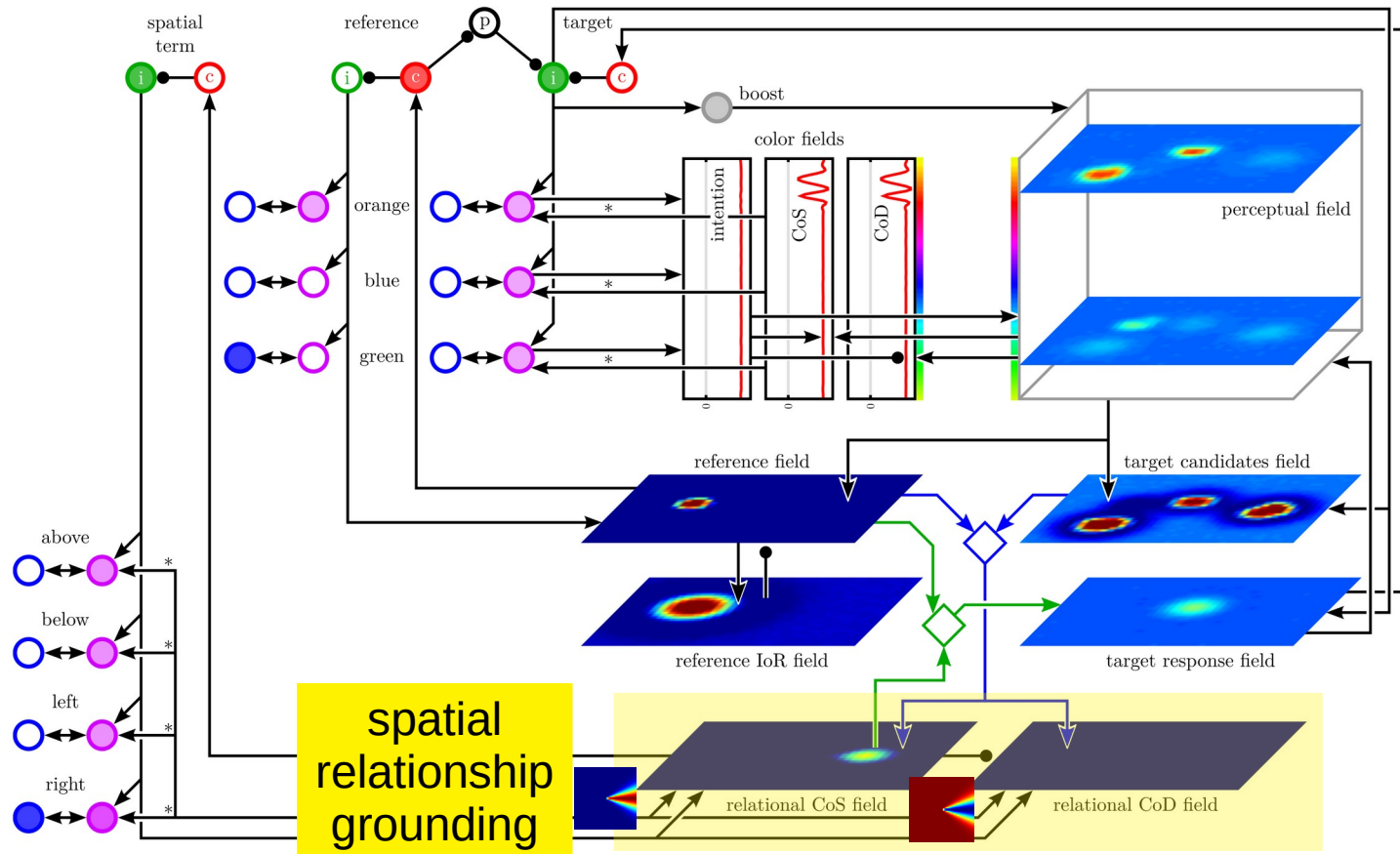




# processes



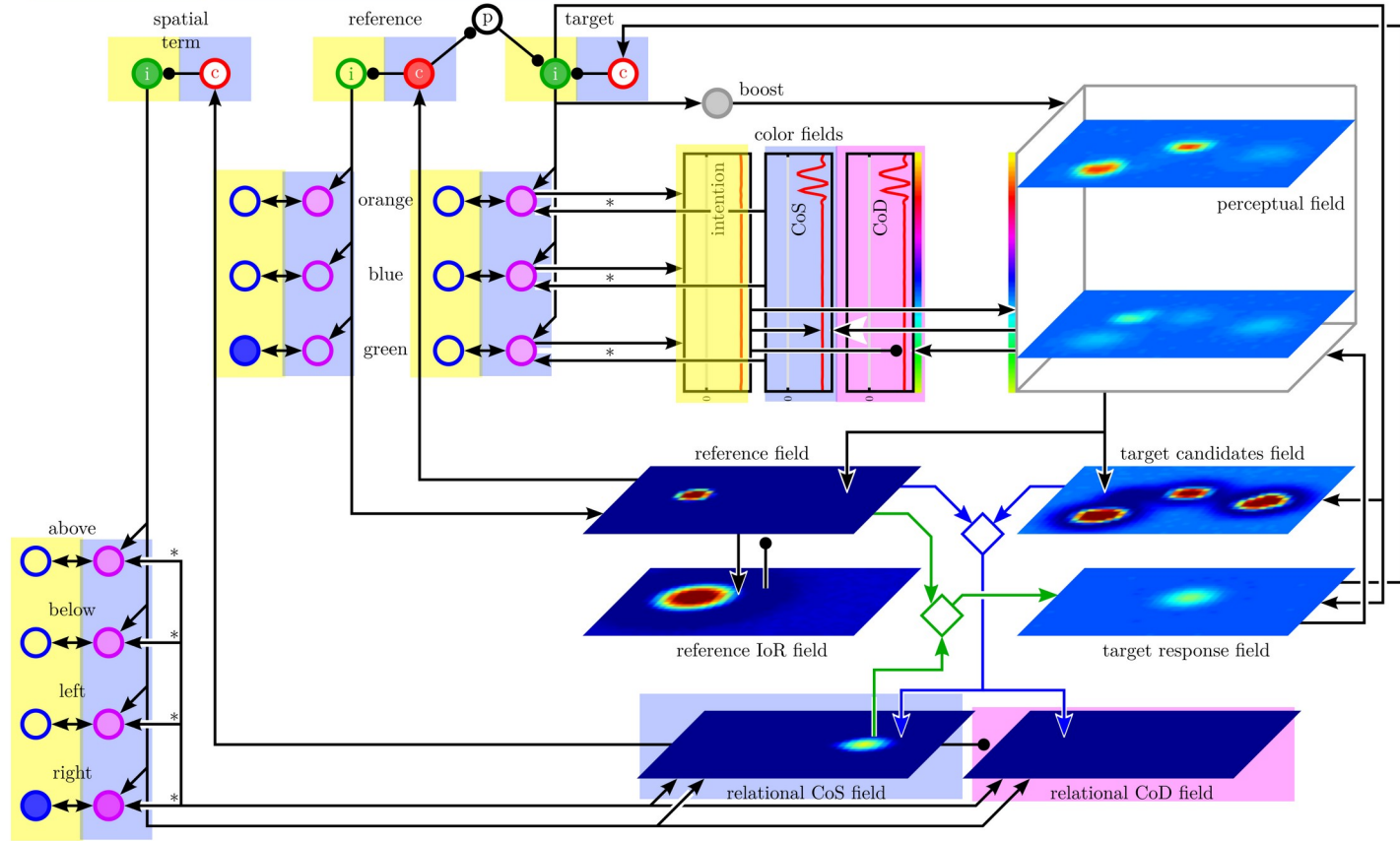




# Intention

# Condition of Satisfaction

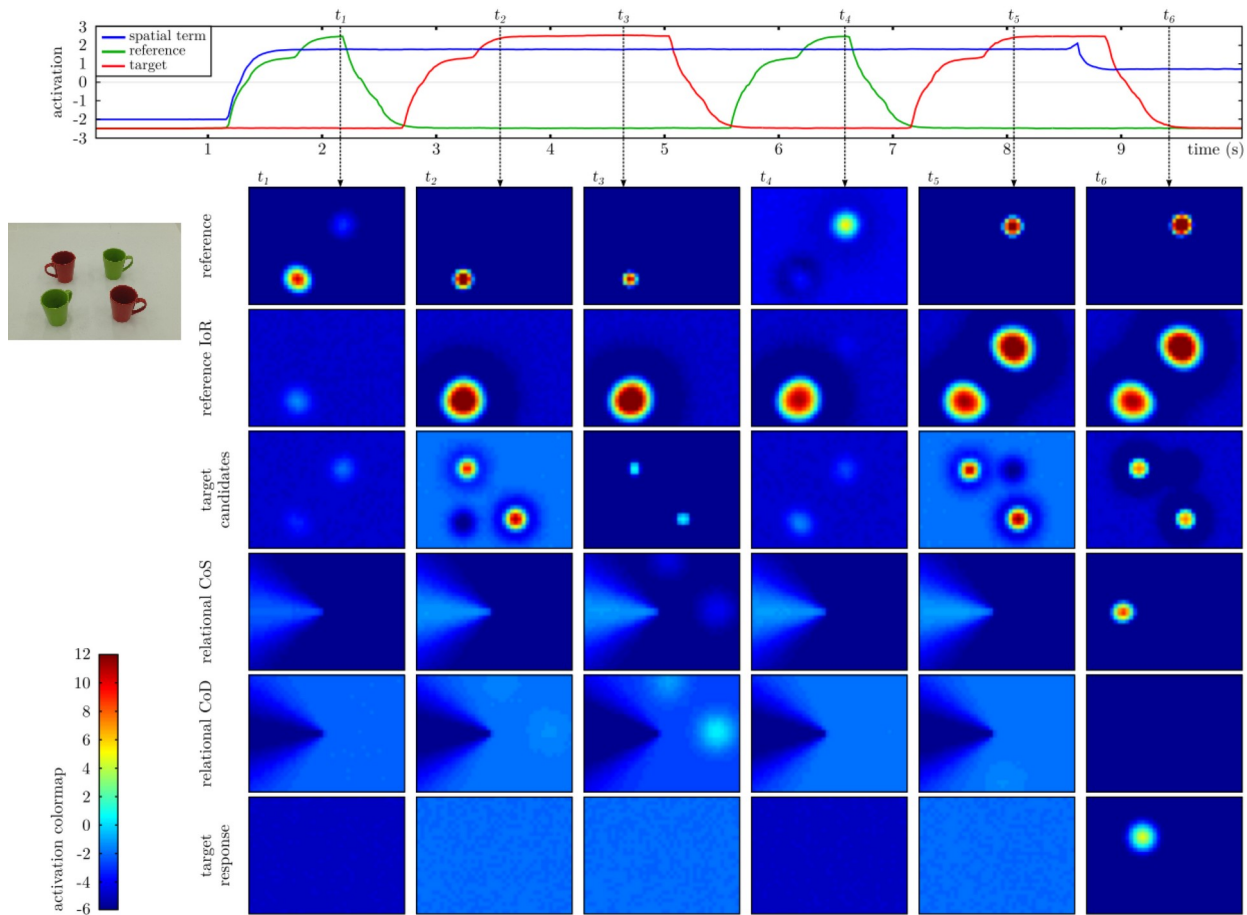
# Condition of Dissatisfaction



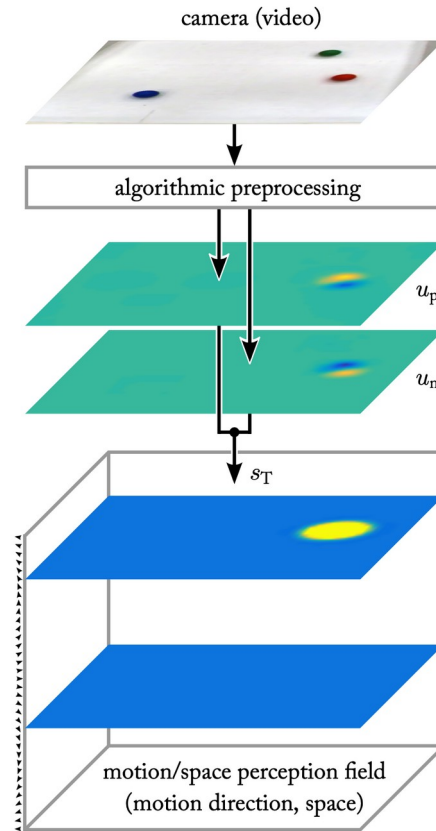
# EXAMPLE



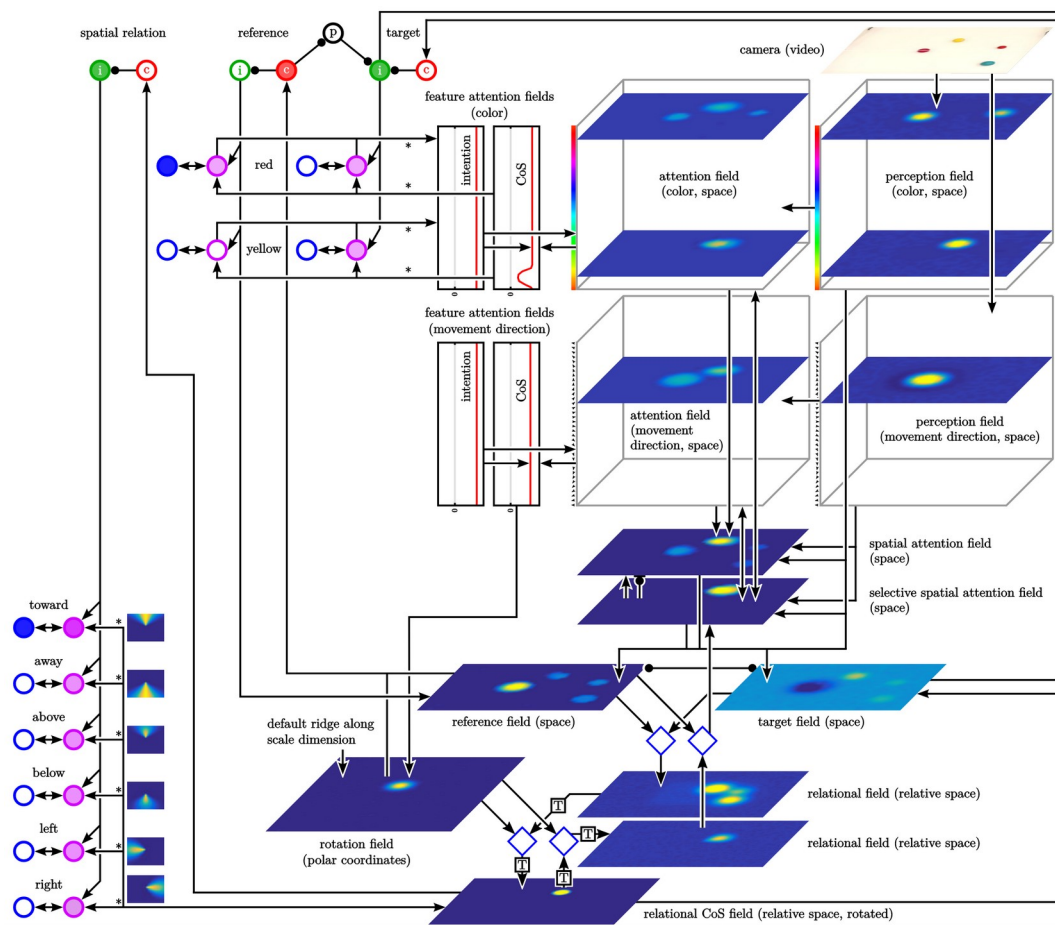
“The red object to the left of the green object”

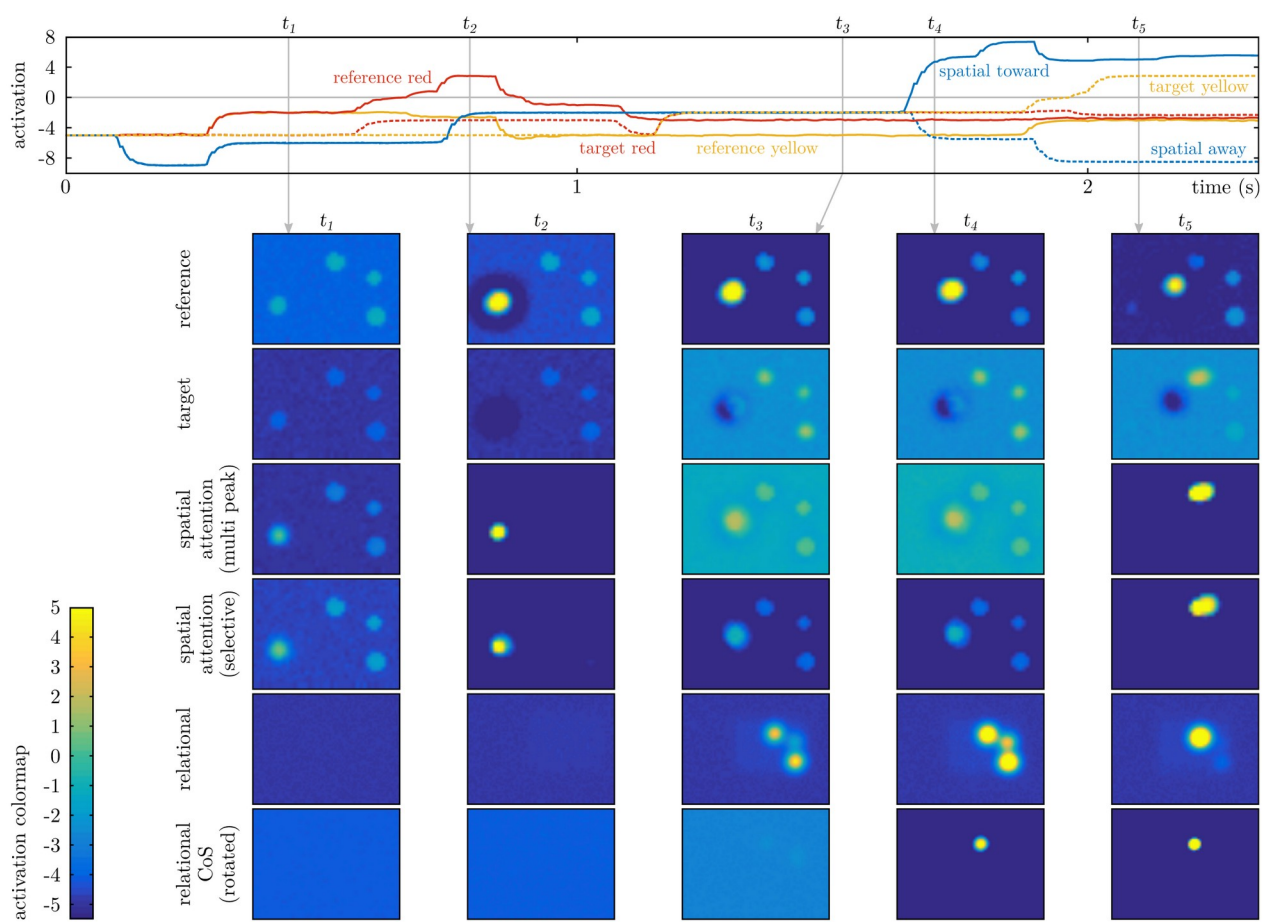


# MOVEMENT RELATIONS









# DRIVING HOME THE POINT

- Presented a neural dynamic architecture that can ground simple spatial language composed of two color terms and a spatial relation term
- ... using neural principles formalized in DFT
- ... and building on perceptual-motor representations and processes
  - Neural fields... with their instabilities
  - Coordinate transformations
  - Visual search
  - Perceptual Concepts
- These are necessary steps towards language grounding architectures more generally and, consequently, language understanding architectures

# NEXT SESSION (3<sup>rd</sup> March)

- Extensions to the architecture that can ground grammatically complex sentences
  - ... towards compositionality

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