RUHR-UNIVERSITÄT BOCHUM

MODELS OF GROUNDED COGNITION

Daniel Sabinasz

MOTIVATION

AMODAL SYMBOL SYSTEMS

- Classical cognitive science: Higher cognitive competences (language, reasoning, planning, problem solving, ...) can best be explained as the algorithmic processing of abstract symbols (Fodor & Pylyshyn, 1988)
- Transduce subset of perceptual or motor states into nonperceptual/amodal representation language
- Higher cognitive functions modelled as algorithms operating on these amodal symbols

PROBLEMS

- No direct empirical evidence that amodal symbols exist
- Rather, higher cognitive tasks are **grounded in sensory-motor regions** of the brain
  - The same regions that involved in perception are also involved in conceptual reasoning (Pulvermüller, 2005)
- Inconsistencies with **neural principles of computation** (Richter et al., 2017)

GROUNDED COGNITION (Barsalou, 1999, 2008)

- Cognition is inherently perceptual
- No qualitative division between cognitive processes at sensory-motor level and higher cognitive processes
- Higher cognitive competences rely on perceptual/motor simulations

GROUNDED COGNITION

- Many of our abstract concepts are metaphorically related to more basic concepts (Lakoff and Johnson, 1980; Hofstadter and Sander, 2013)
  - e.g., up for happy, down for sad
- Conjecture: most or even all our concepts may be grounded in primitive perceptual/motor/spatial concepts

GROUNDED COGNITION

- Human reasoning relies on spatial layout models (Ragni & Knauff, 2013)

The Porsche is parked to the left of the Dodge

The Ferrari is parked to the right of the Dodge

Therefore, the Dodge is parked to the left of the Ferrari

Porsche Dodge Ferrari

Willy Brandt was more popular than Gerhard Schröder was

Gerhard Schröder was more popular than Angela Merkel is

Therefore, Willy Brandt was more popular than Angela Merkel is

Brandt Schröder Merkel

GROUNDED COGNITION

- Conjecture: models of perceptual and spatial cognition may be used to explain much (all?) of higher cognition

DFT MODELS OF GROUNDED COGNITION

SPATIAL LANGUAGE

- language involving terms that stand for spatial relational concepts
  - e.g., “the green object which is **to the left of** the red object”
  - “the green object which is **moving toward** the red object”
  - in front of, inside, bigger than, ...

SPATIAL COMPARISON

- Compare two objects w.r.t. their spatial relation
- "Where is the green object relative to the red object?" –> to the right

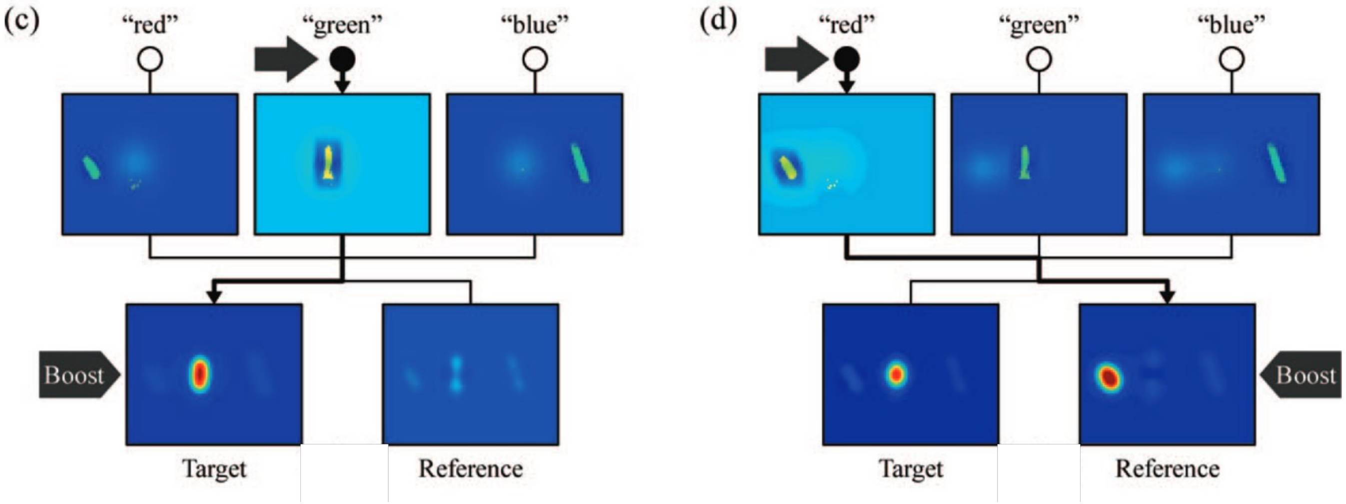
SPATIAL COMPARISON: REQUIRED OPERATIONS

- find objects in the perceptual input
  - “Where is **the green object** relative to **the red object**?”

    target reference
- perform coordinate transformation to get the position of the target object relative to the reference object
- compare that relative position to relational templates

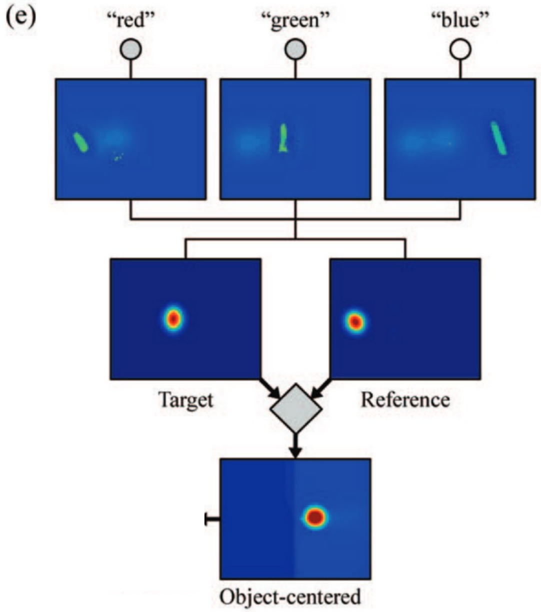
RUHR UNIVERSITÄT BOCHUM RUB

FINDING OBJECTS IN THE PERCEPTUAL INPUT



Lipinski et al. (2012)

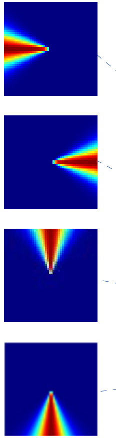
COORDINATE TRANSFORMATION

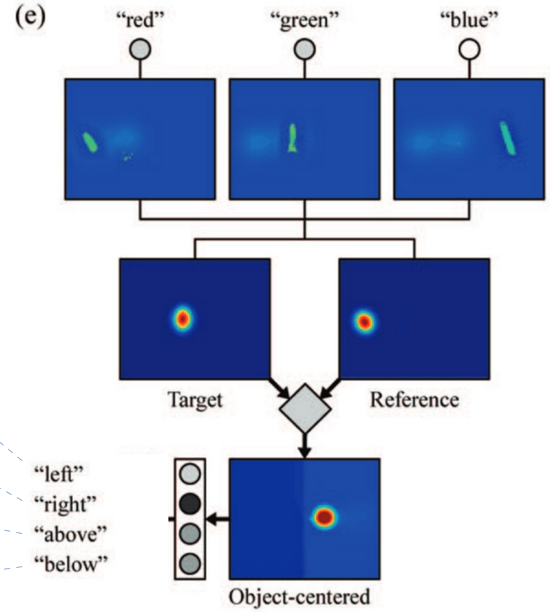


Lipinski et al. (2012)

COMPARING TO A SPATIAL TEMPLATE

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





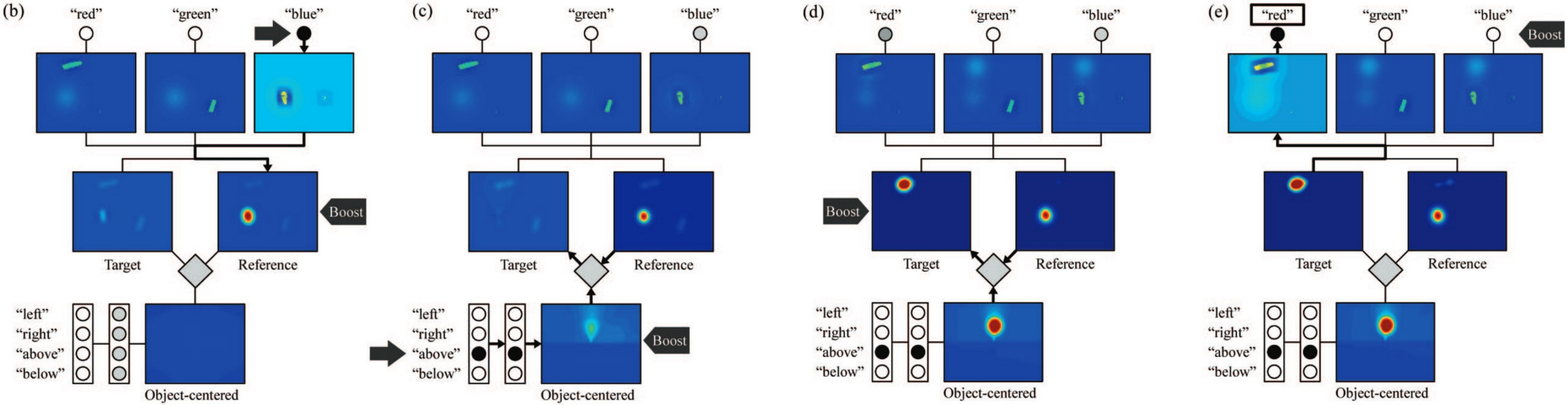
Lipinski et al. (2012)

TARGET IDENTIFICATION

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

TARGET IDENTIFICATION

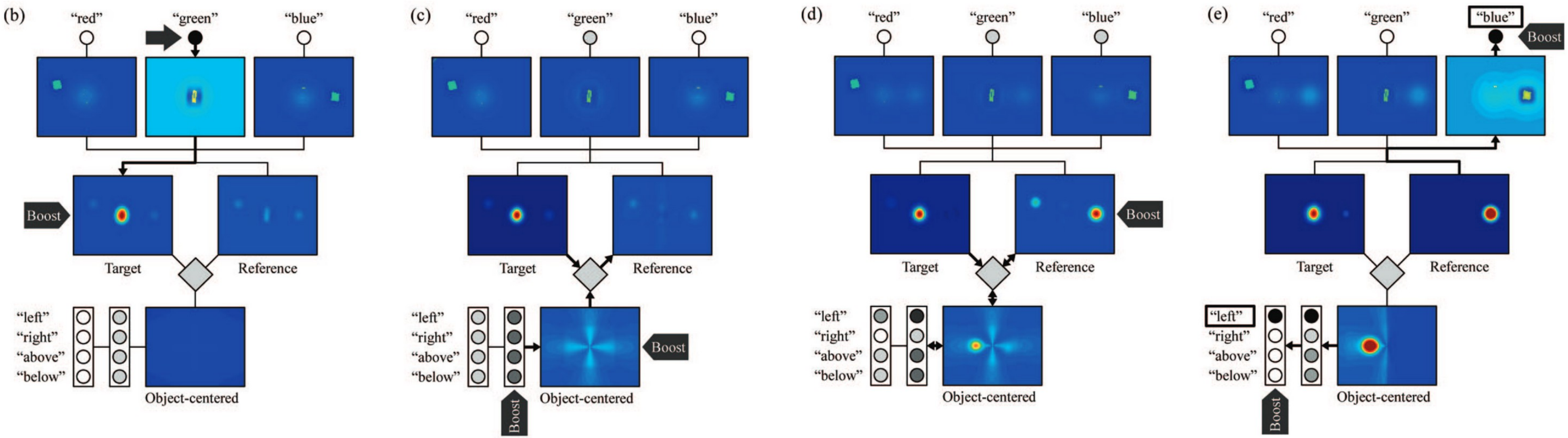
- "Which object is above the blue object?"



Lipinski et al. (2012)

RELATION AND REFERENCE SELECTION

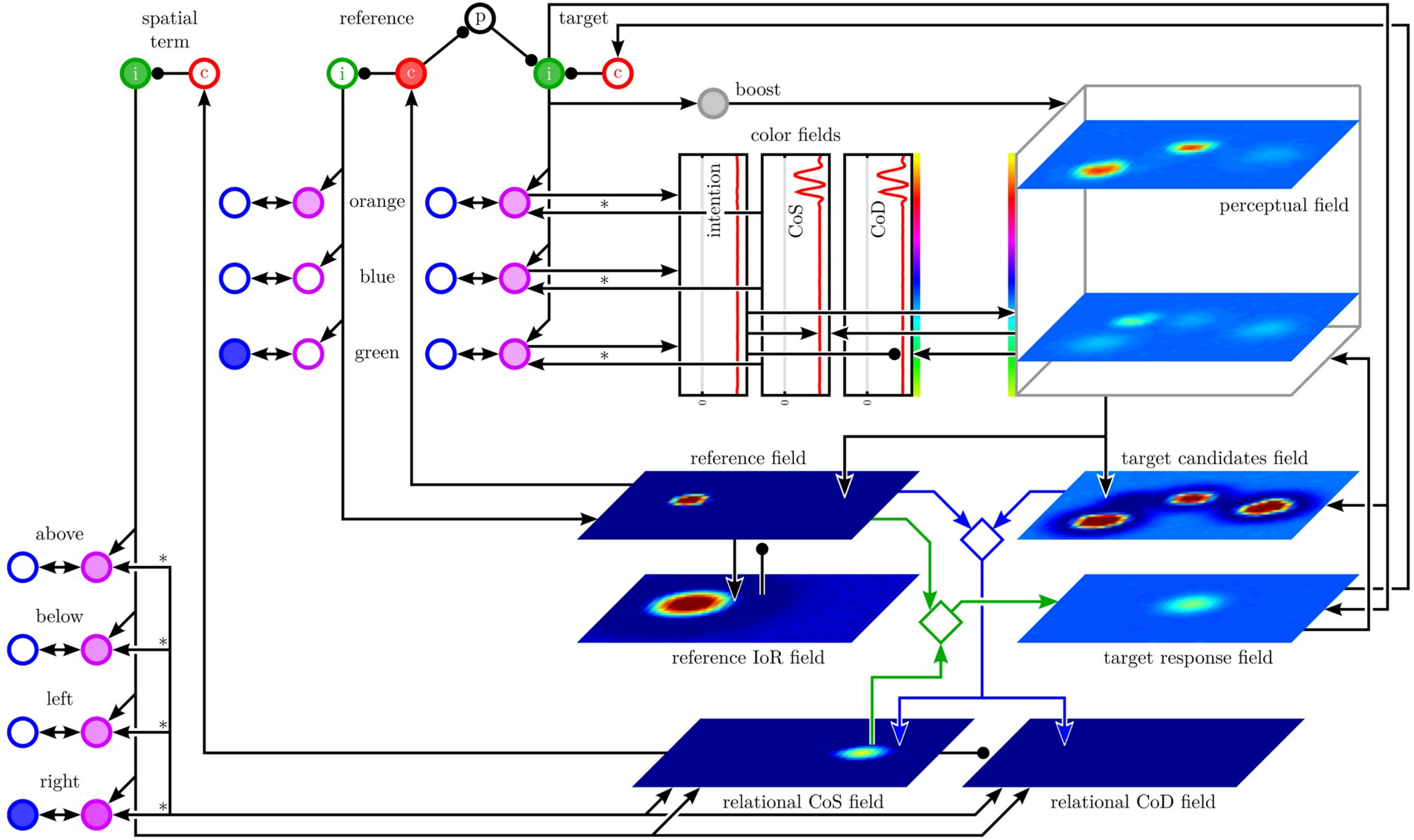
- "Where is the green object?"



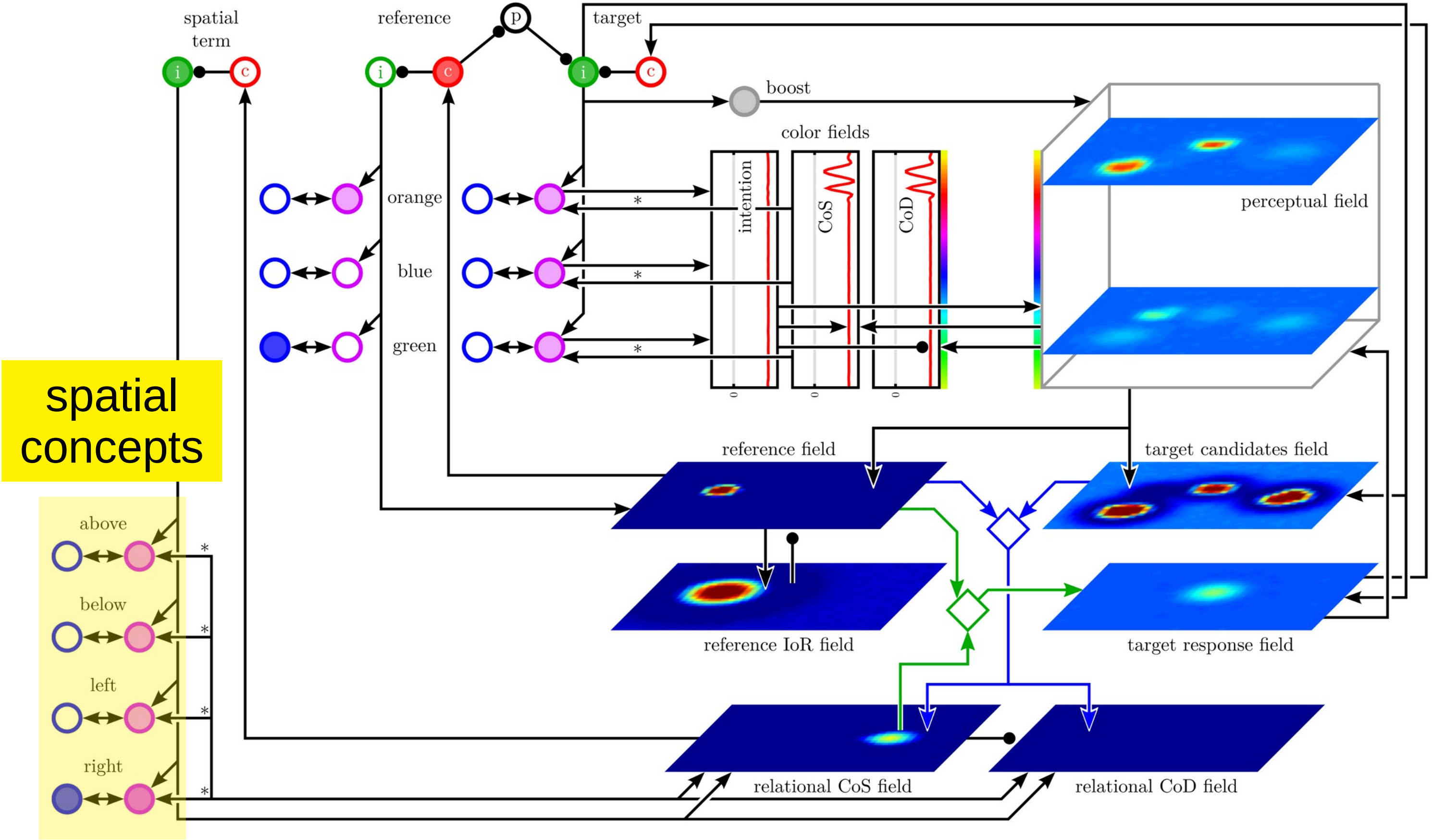
Lipinski et al. (2012)

GROUNDING

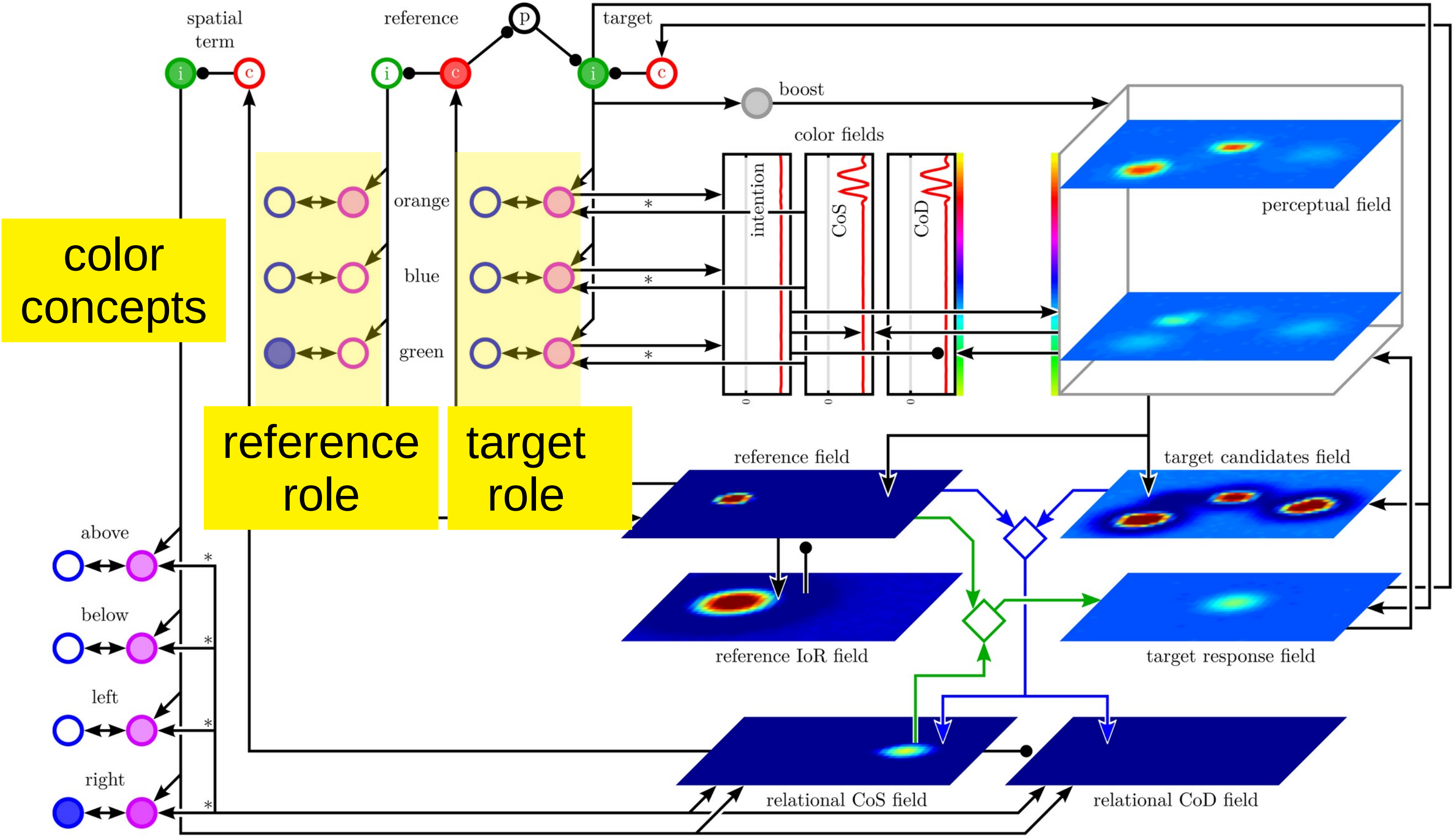
- Grounding a phrase: finding the denoted object in the visual input
- e.g., “the red object to the left of the green object”
- Requires autonomous hypothesis testing



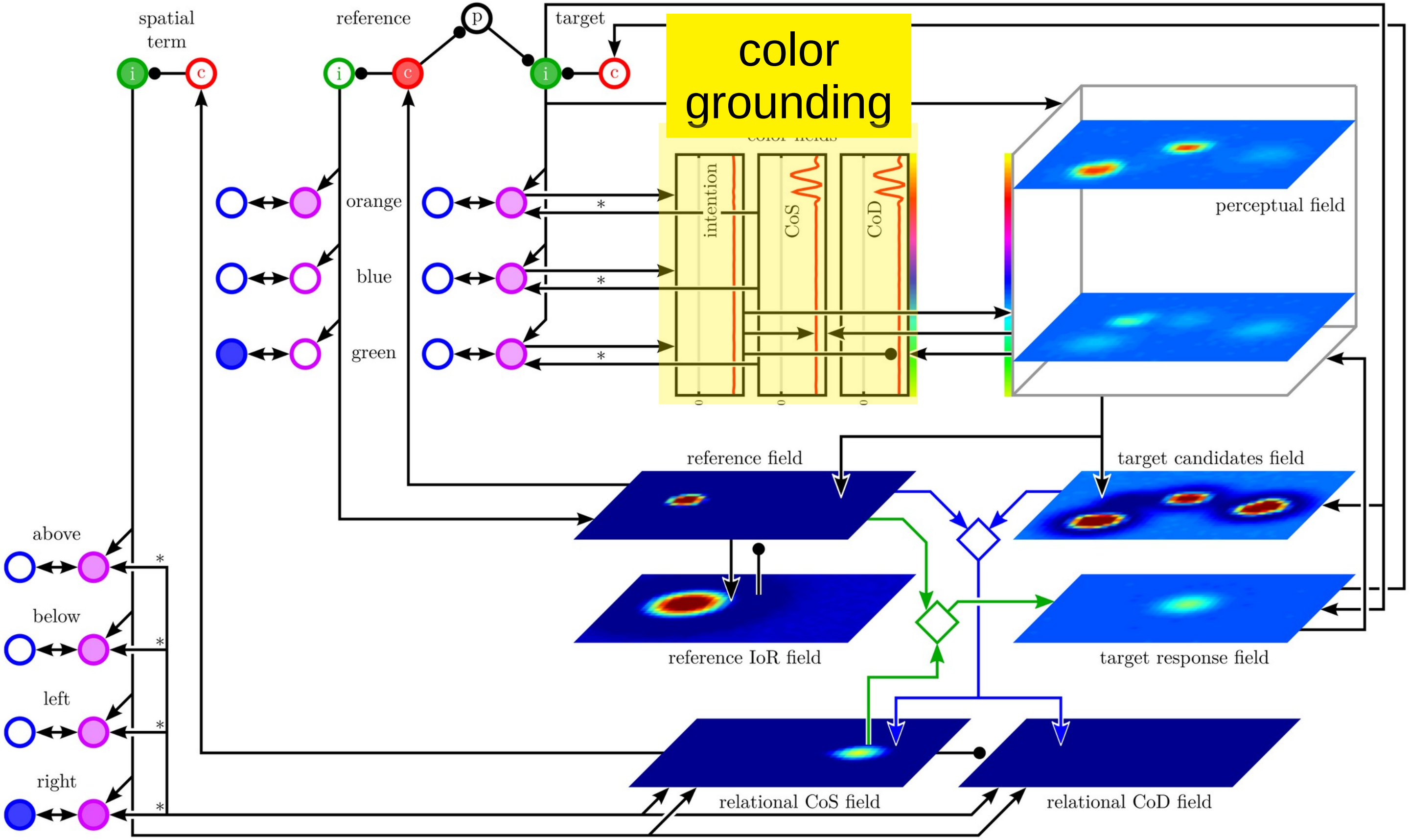
Richter et al. (2014)



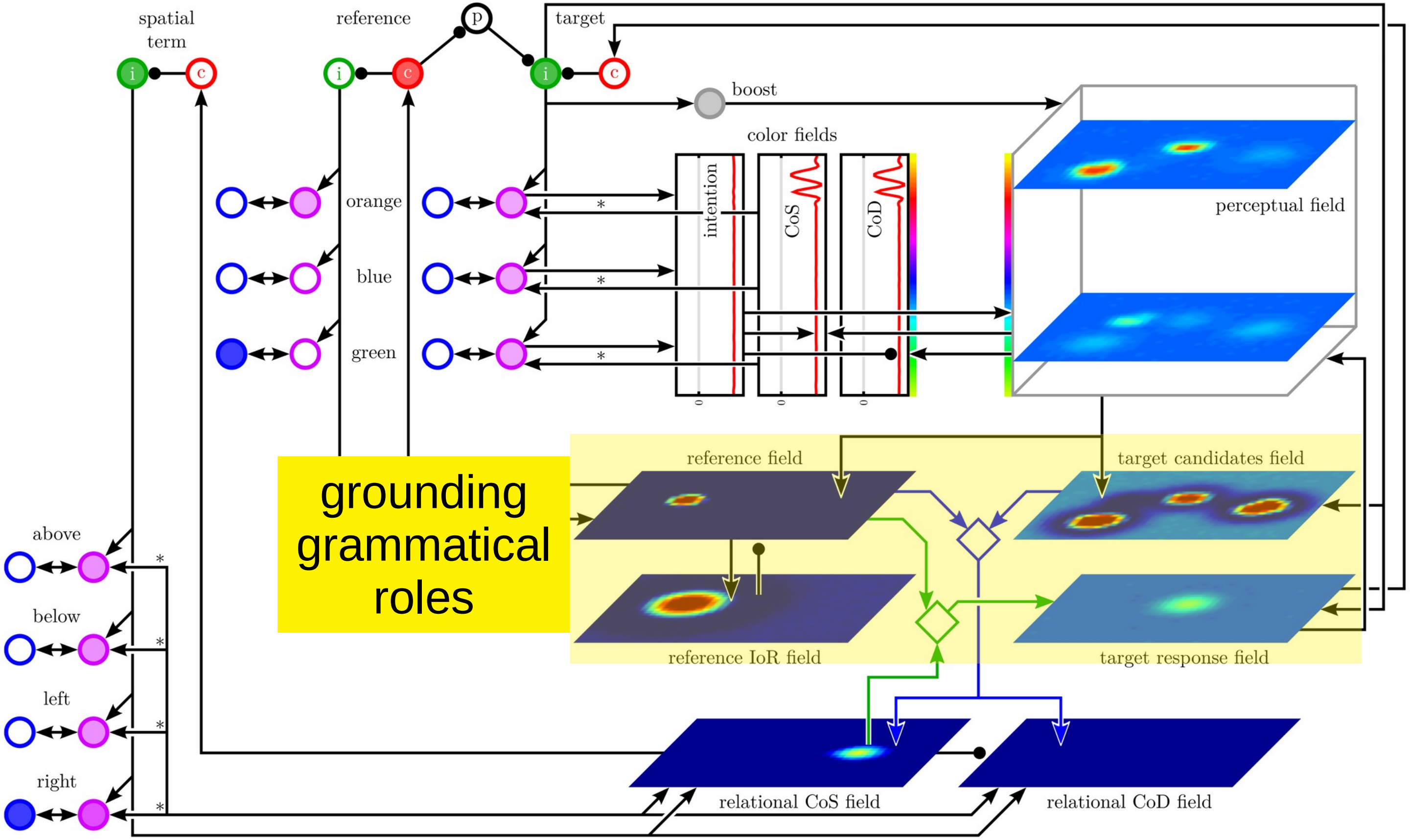
Richter et al. (2014)



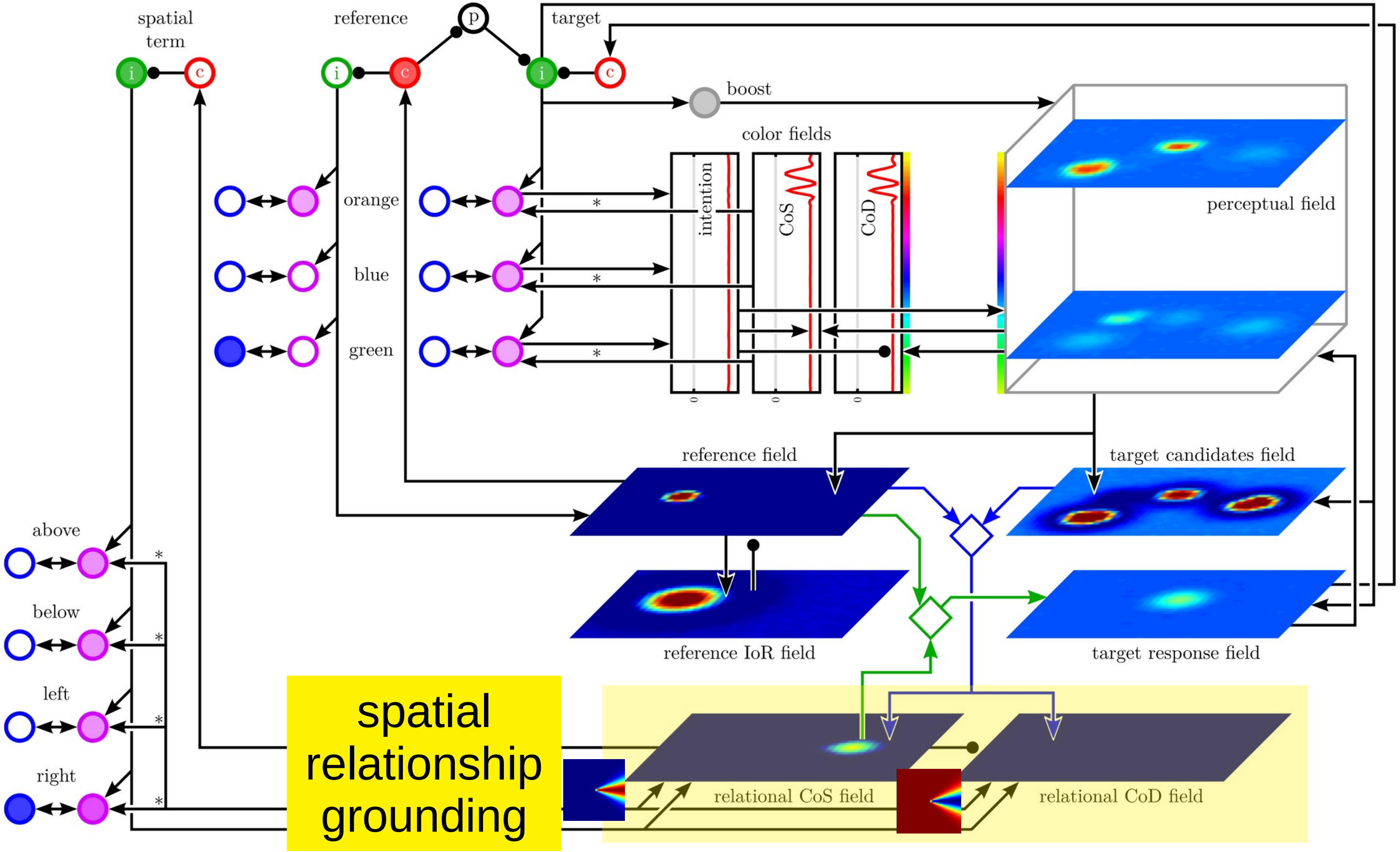
Richter et al. (2014)



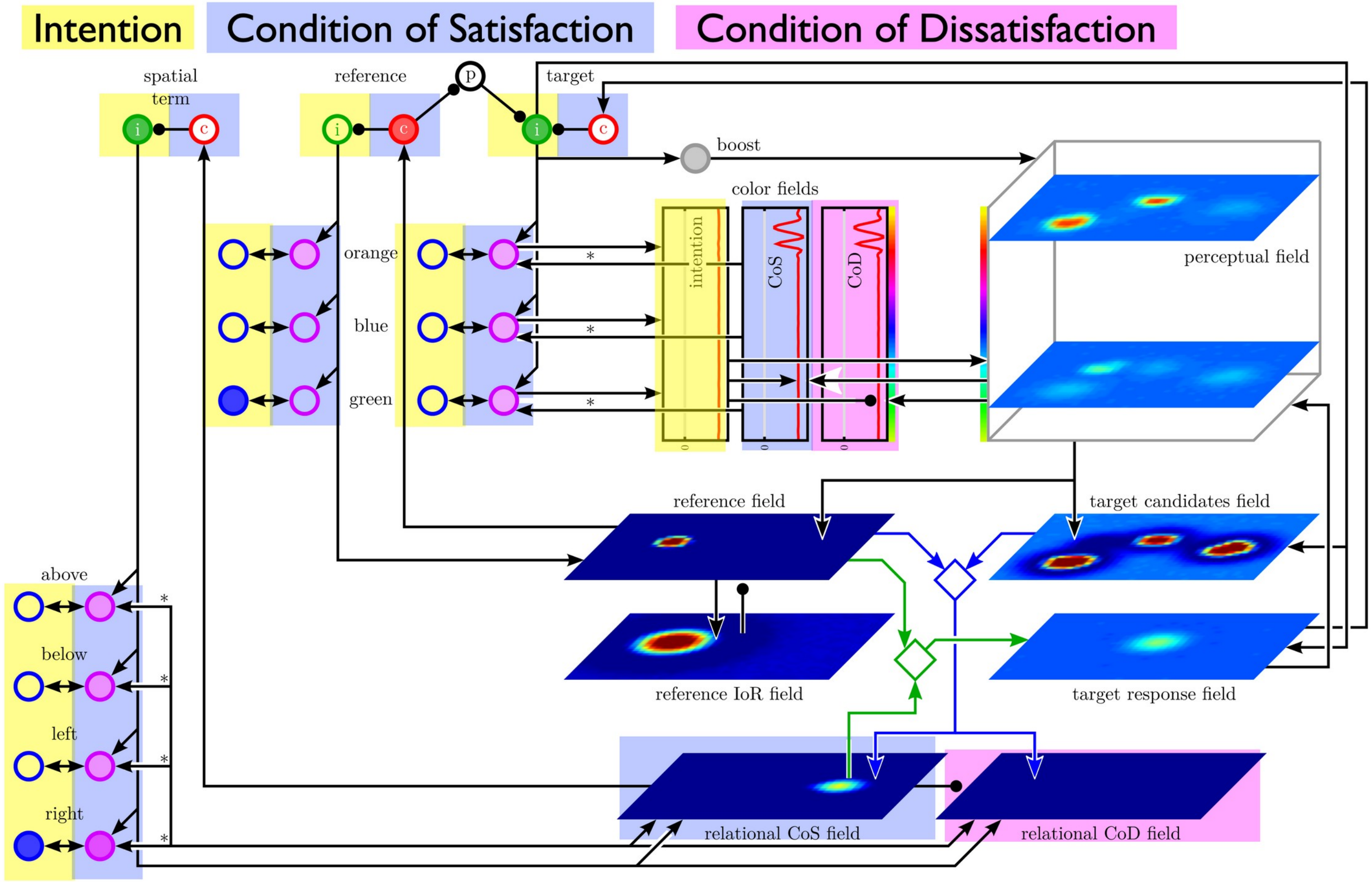
Richter et al. (2014)



Richter et al. (2014)



Richter et al. (2014)



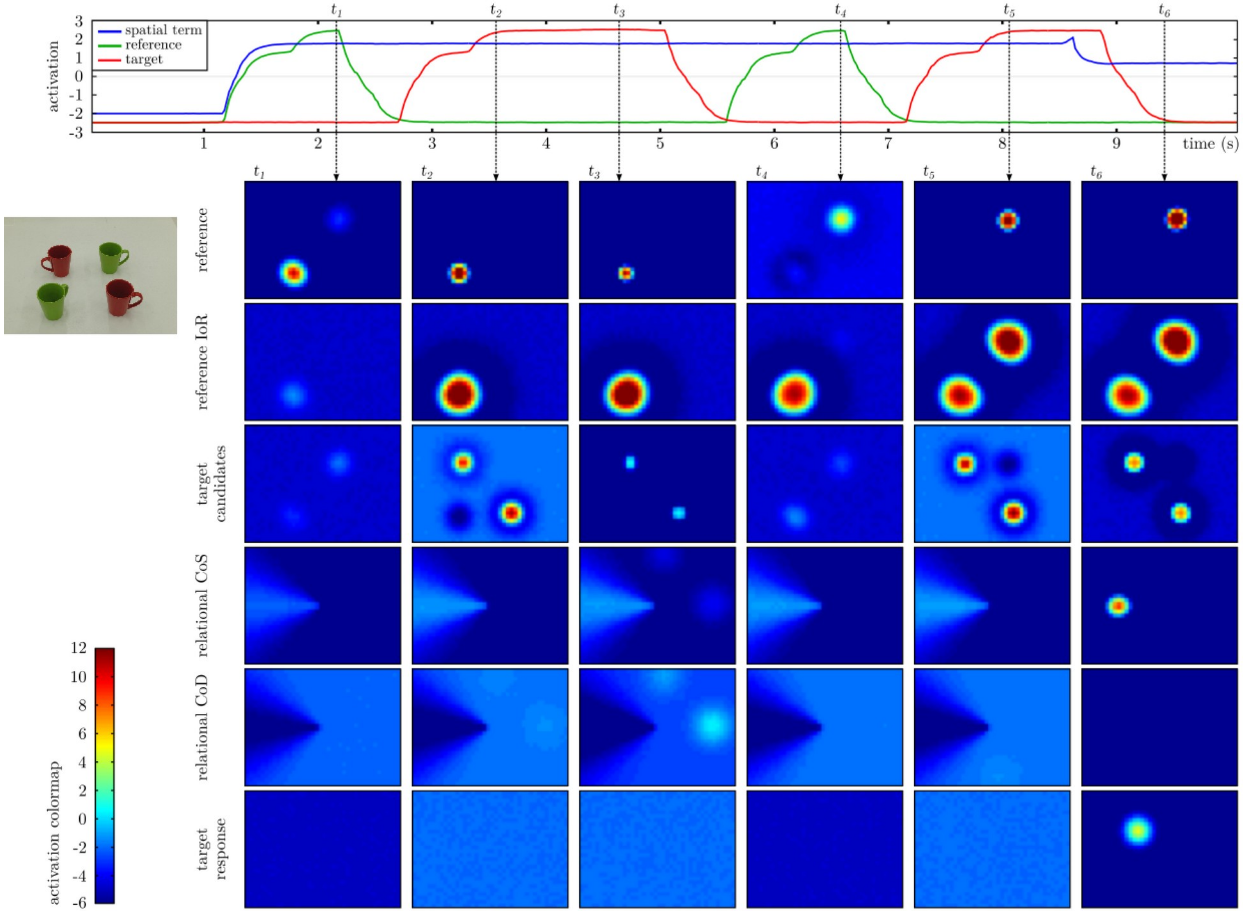
Richter et al. (2014)

RUHR UNIVERSITÄT BOCHUM RUB

EXAMPLE

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

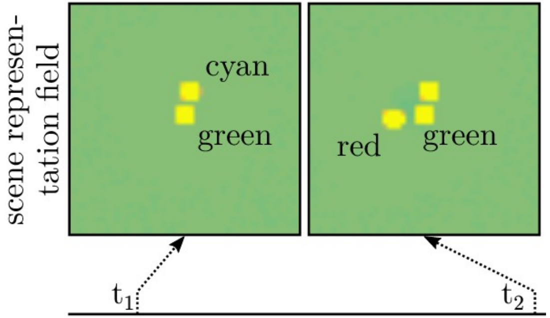
Richter et al. (2014)

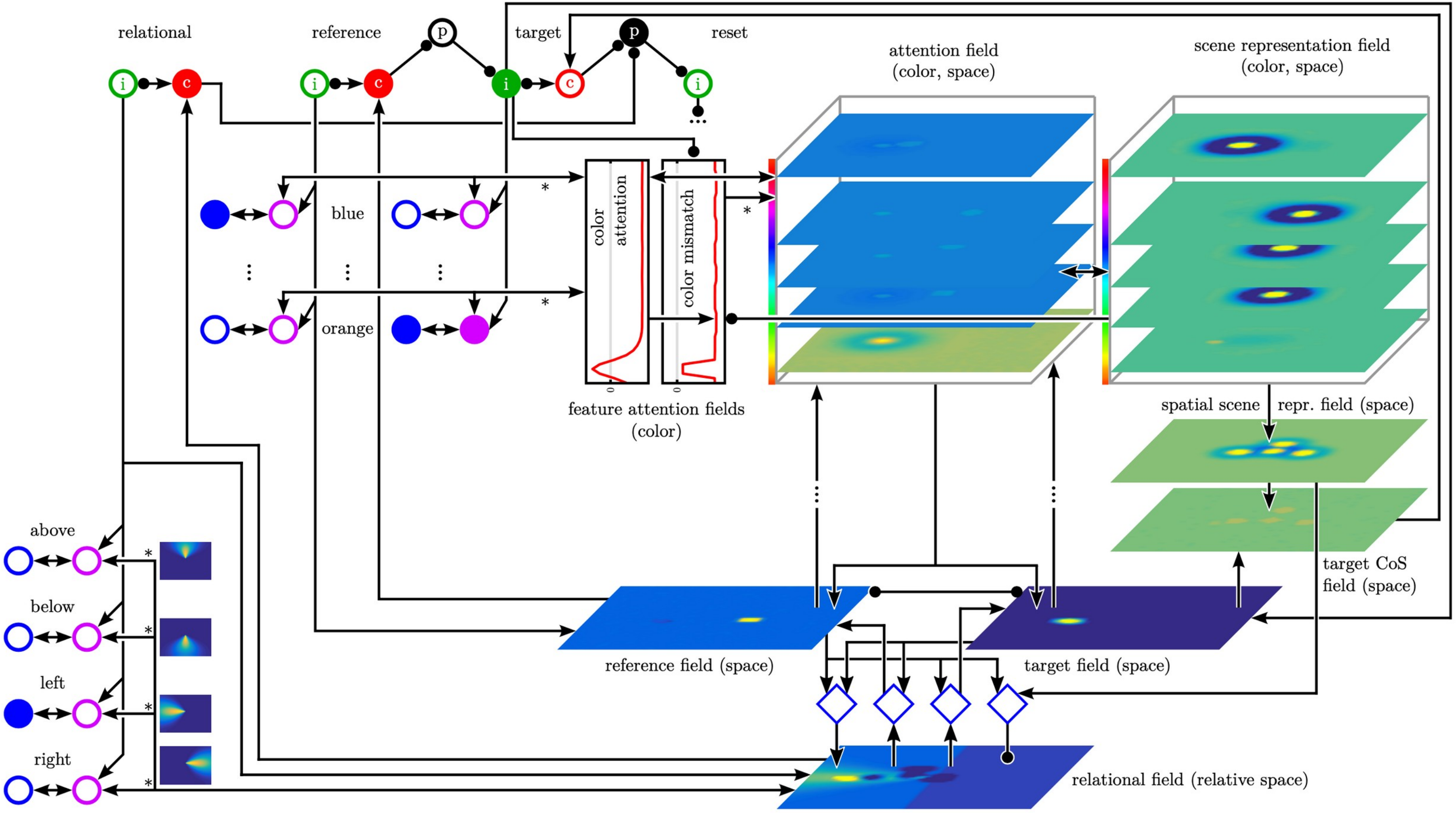


Richter et al. (2014)

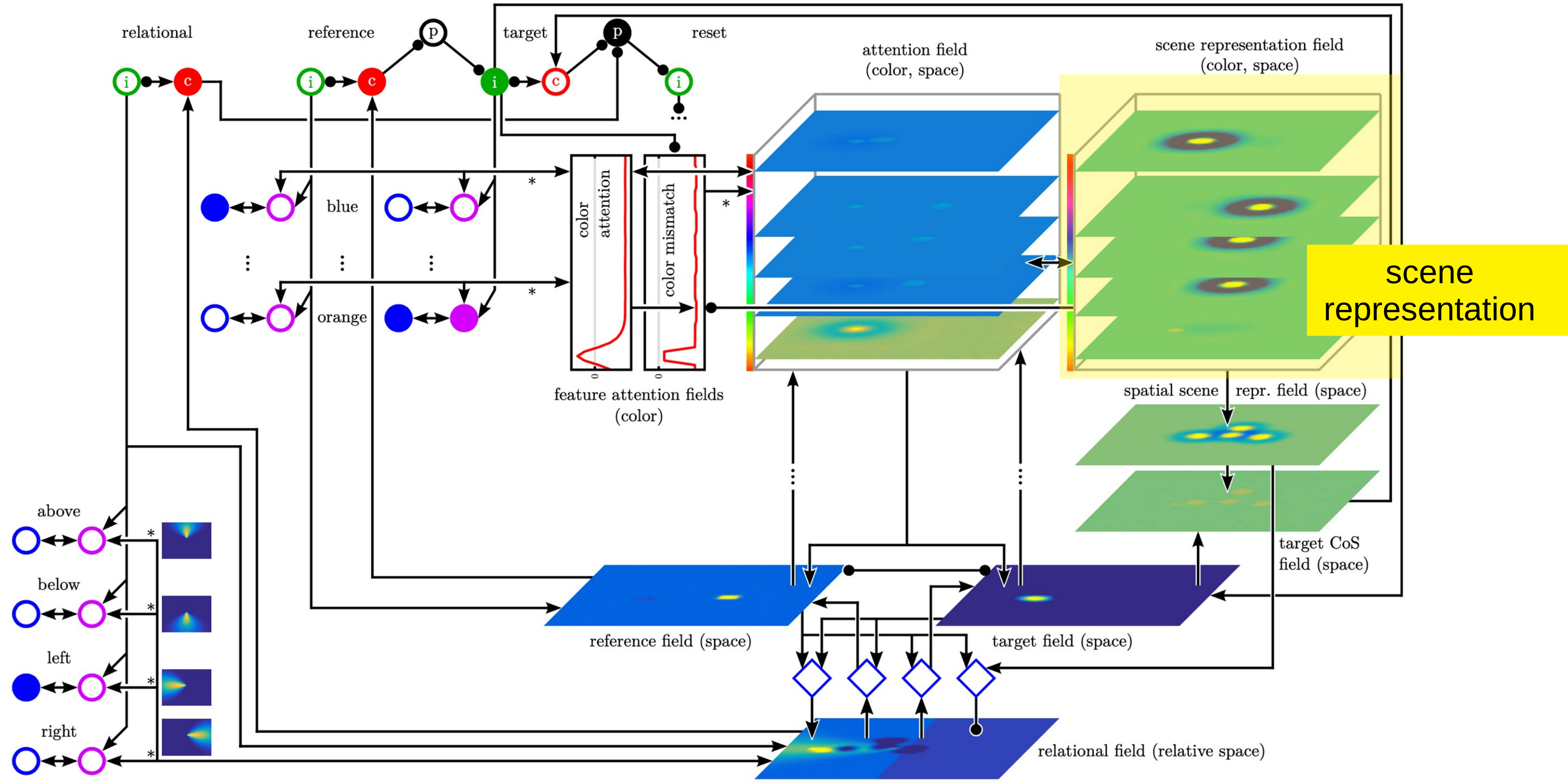
MENTAL IMAGERY

- Imagining a described arrangement of objects
- e.g.,
  1. There is a cyan object above a green object.
  2. There is a red object to the left of the green object.



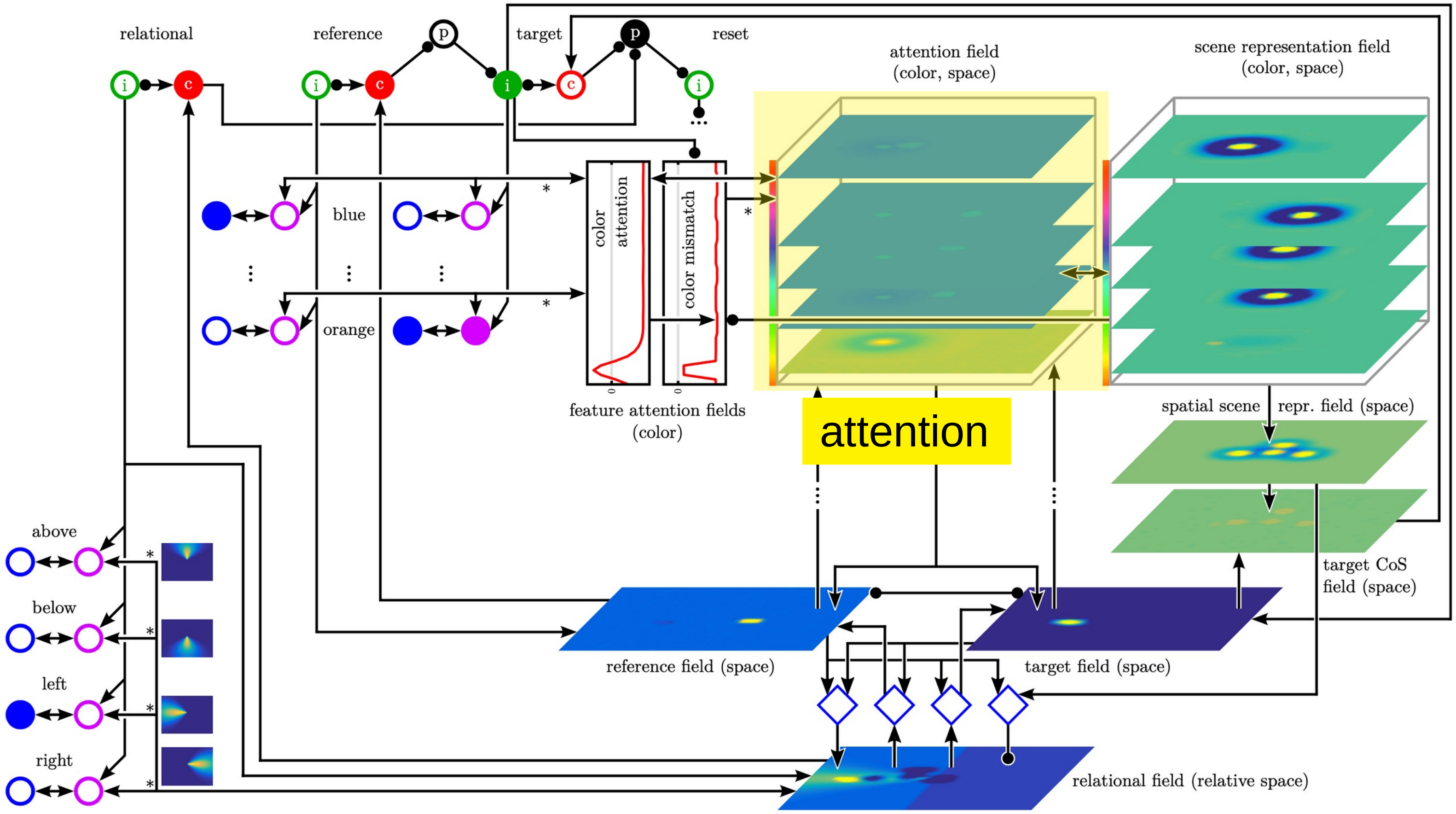


Kounatidou et al. (2018)



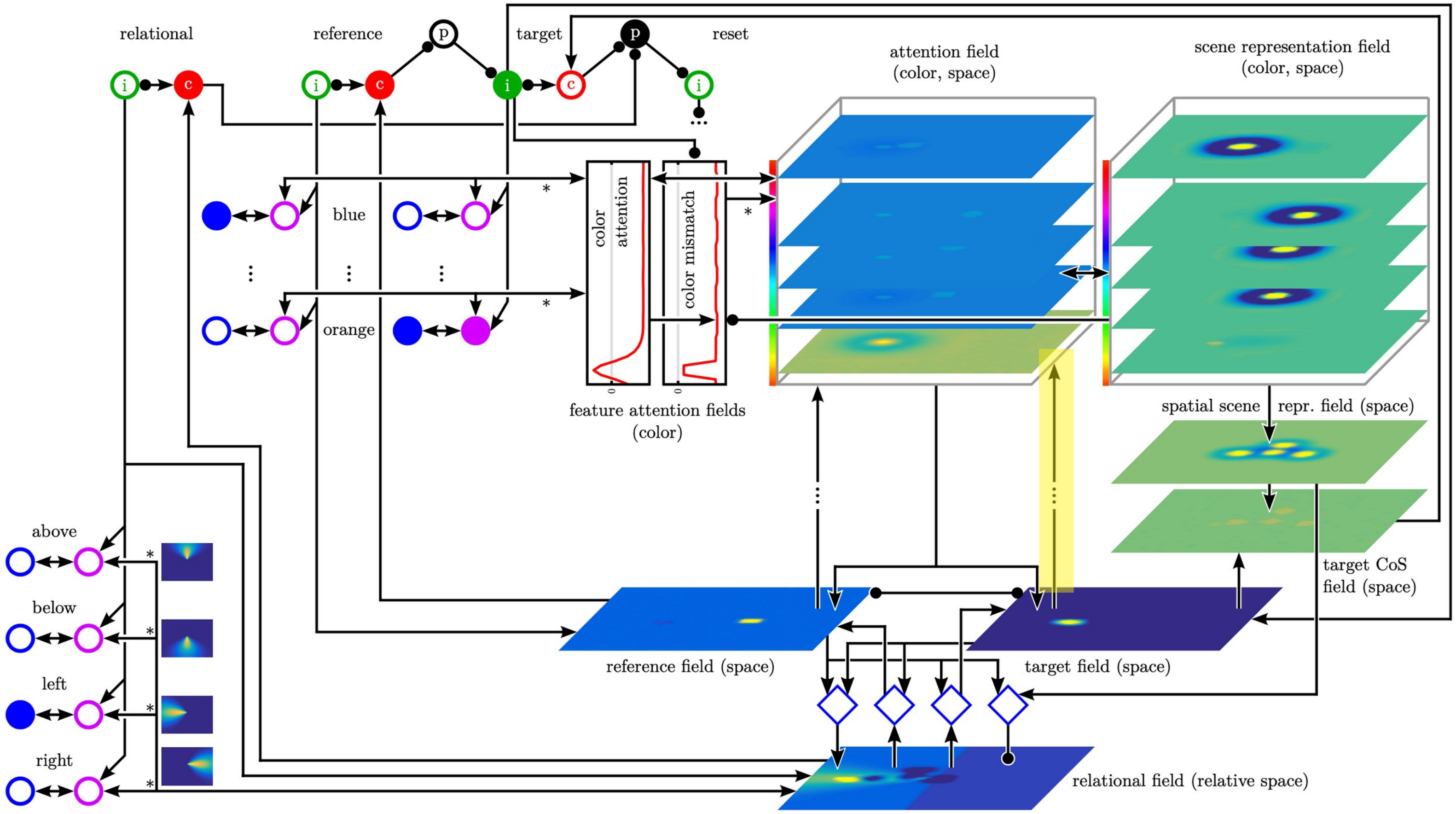
Kounatidou et al. (2018)

RUHR UNIVERSITÄT BOCHUM RUB

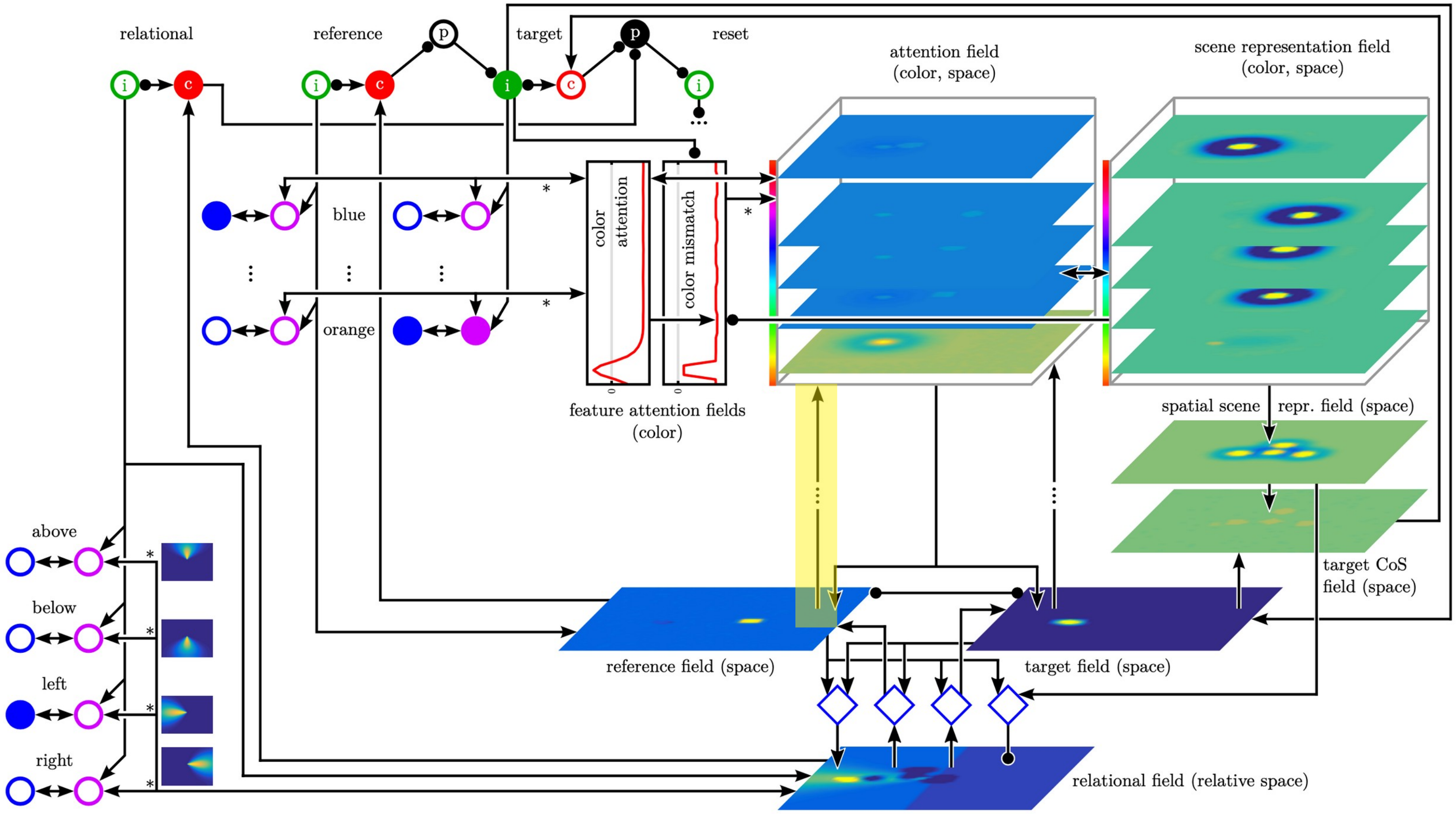


Kounatidou et al. (2018)

RUHR UNIVERSITÄT BOCHUM RUB

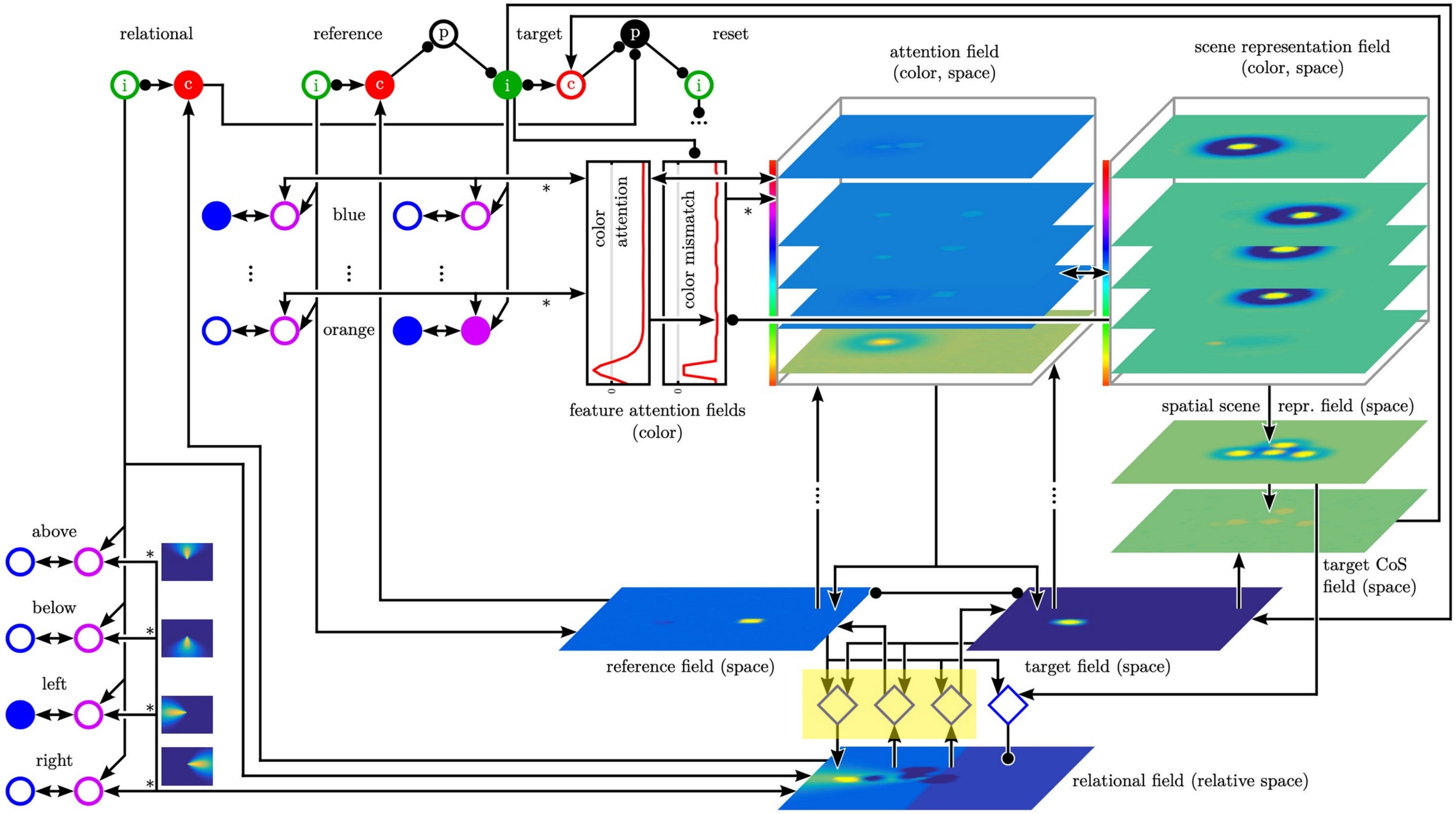


Kounatidou et al. (2018)

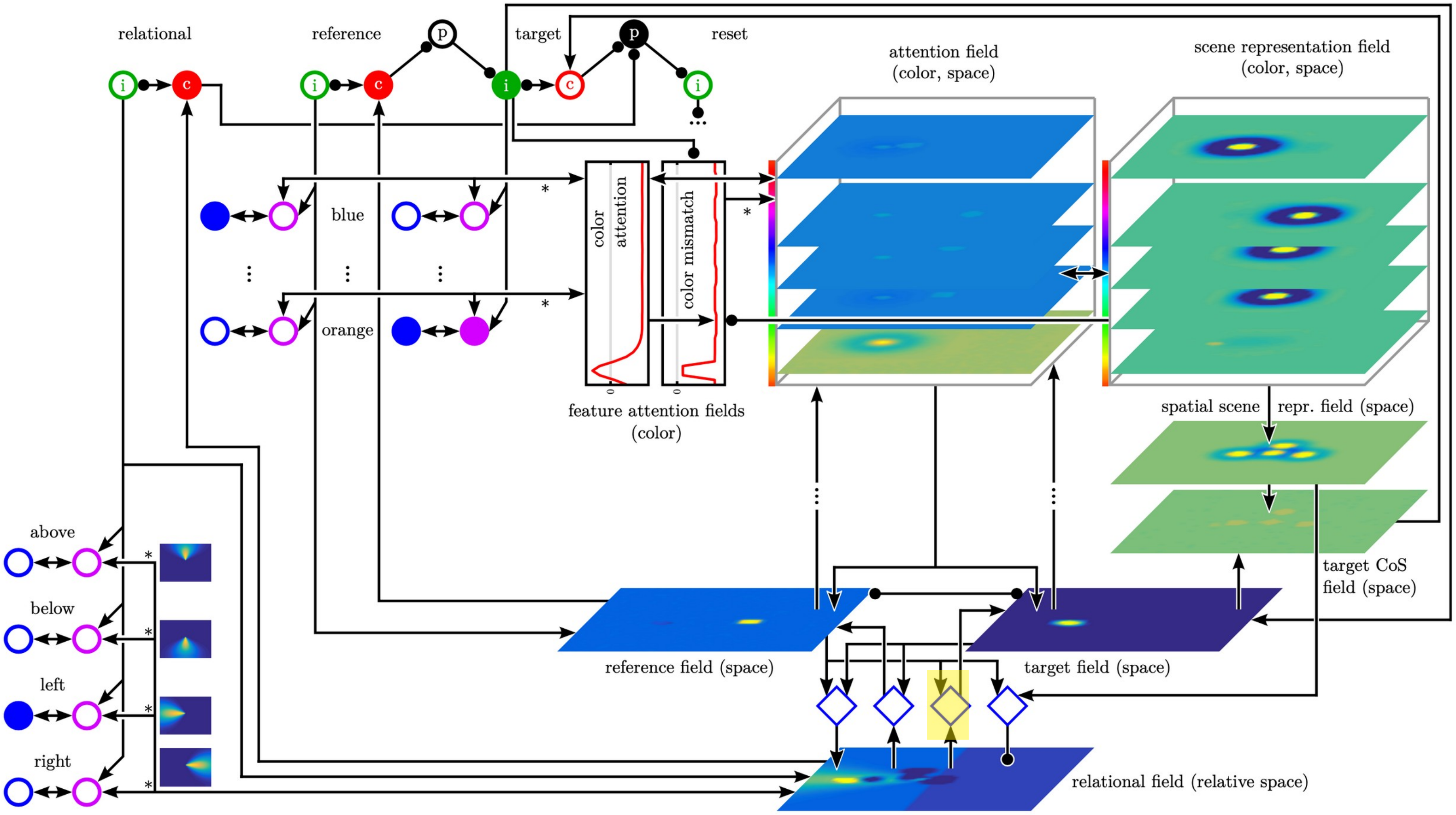


Kounatidou et al. (2018)

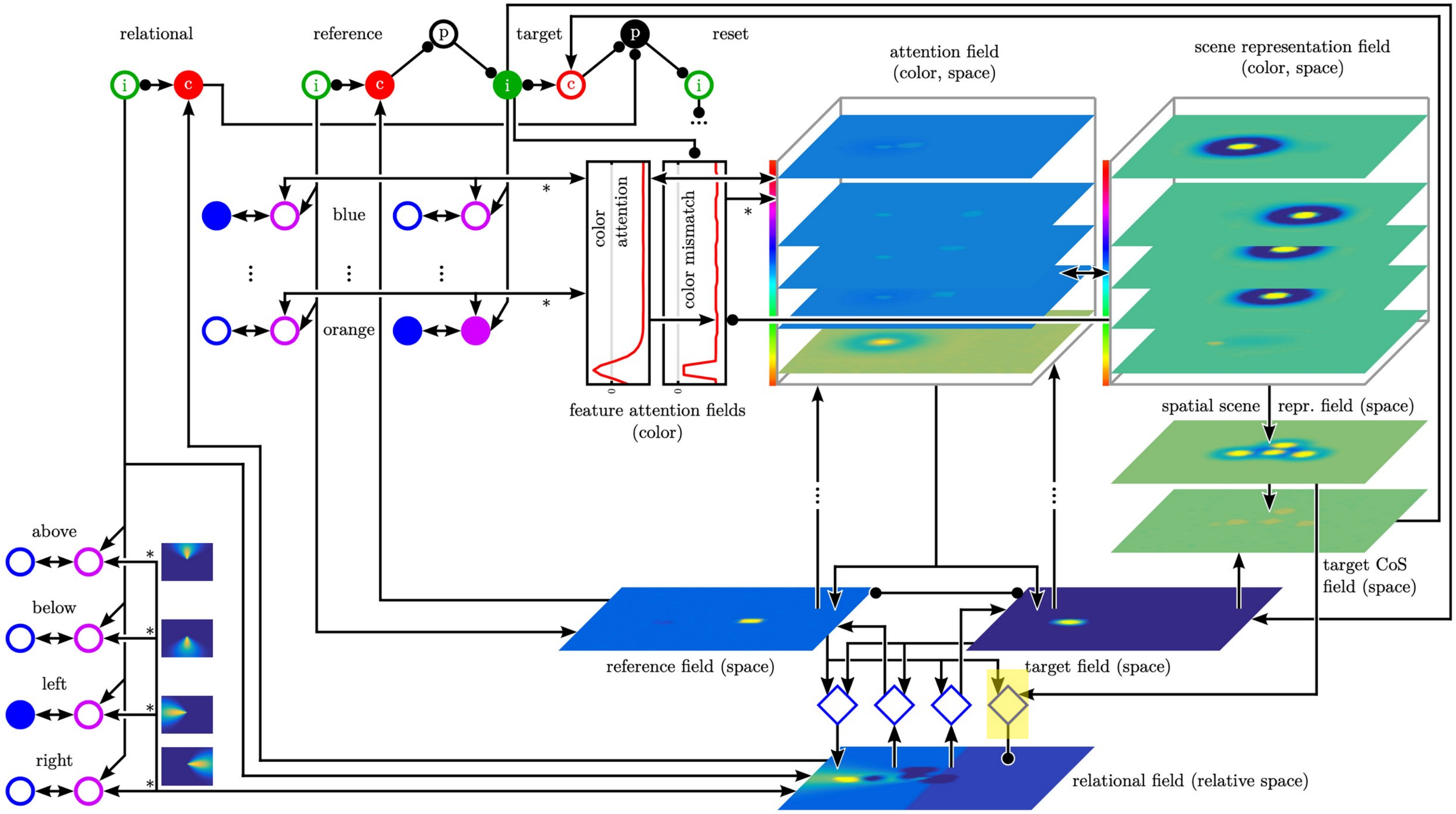
RUHR UNIVERSITÄT BOCHUM RUB



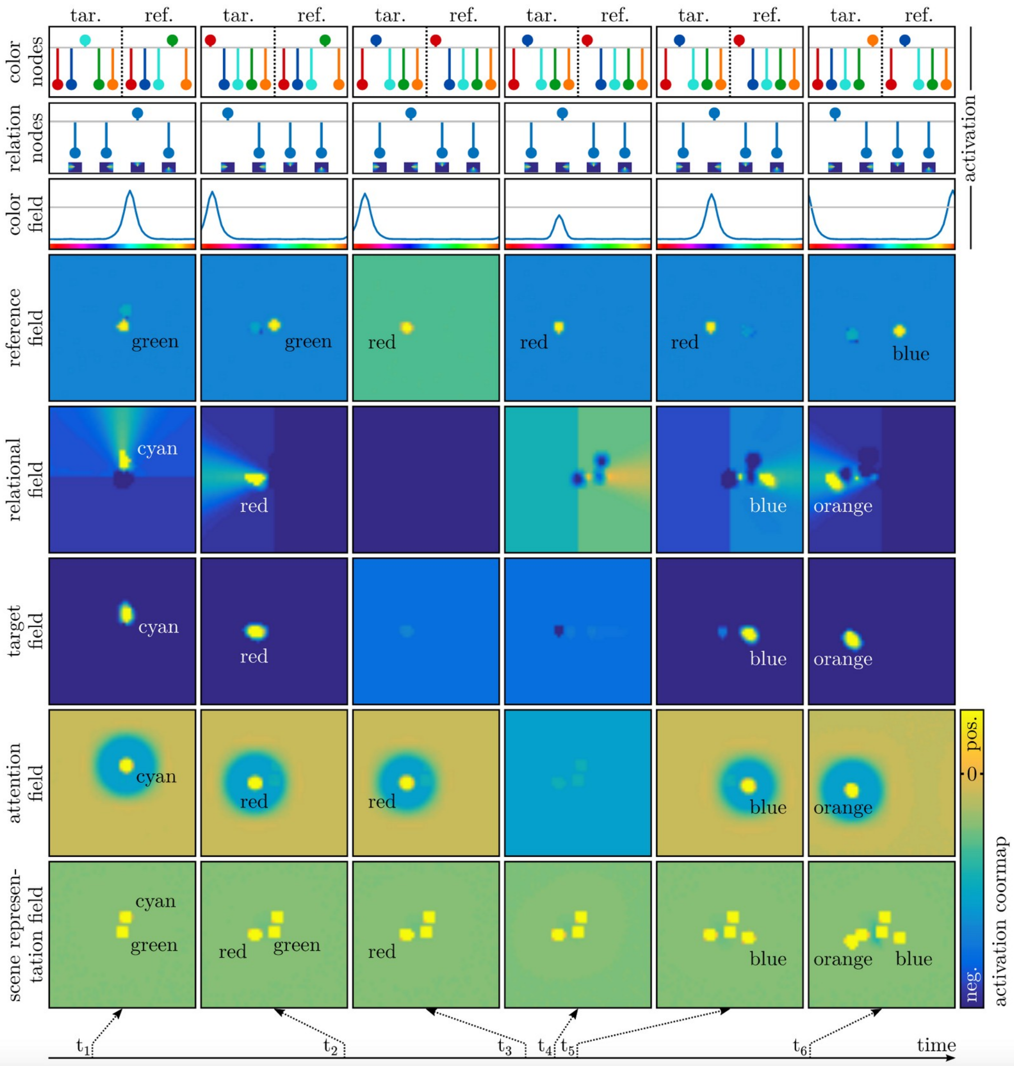
Kounatidou et al. (2018)



Kounatidou et al. (2018)

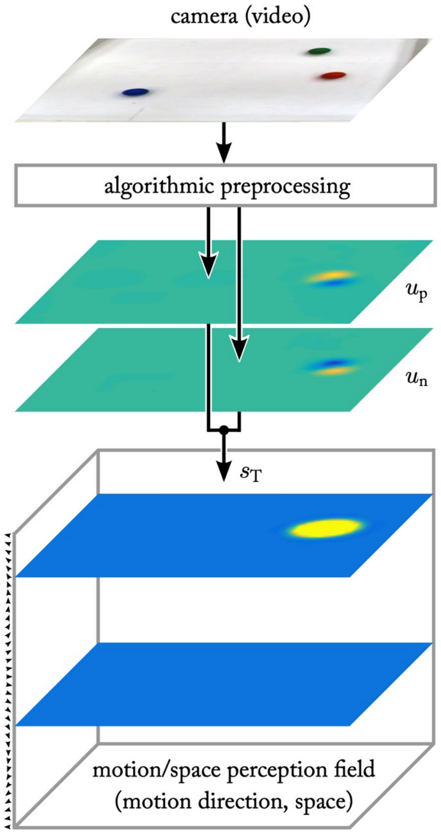


Kounatidou et al. (2018)

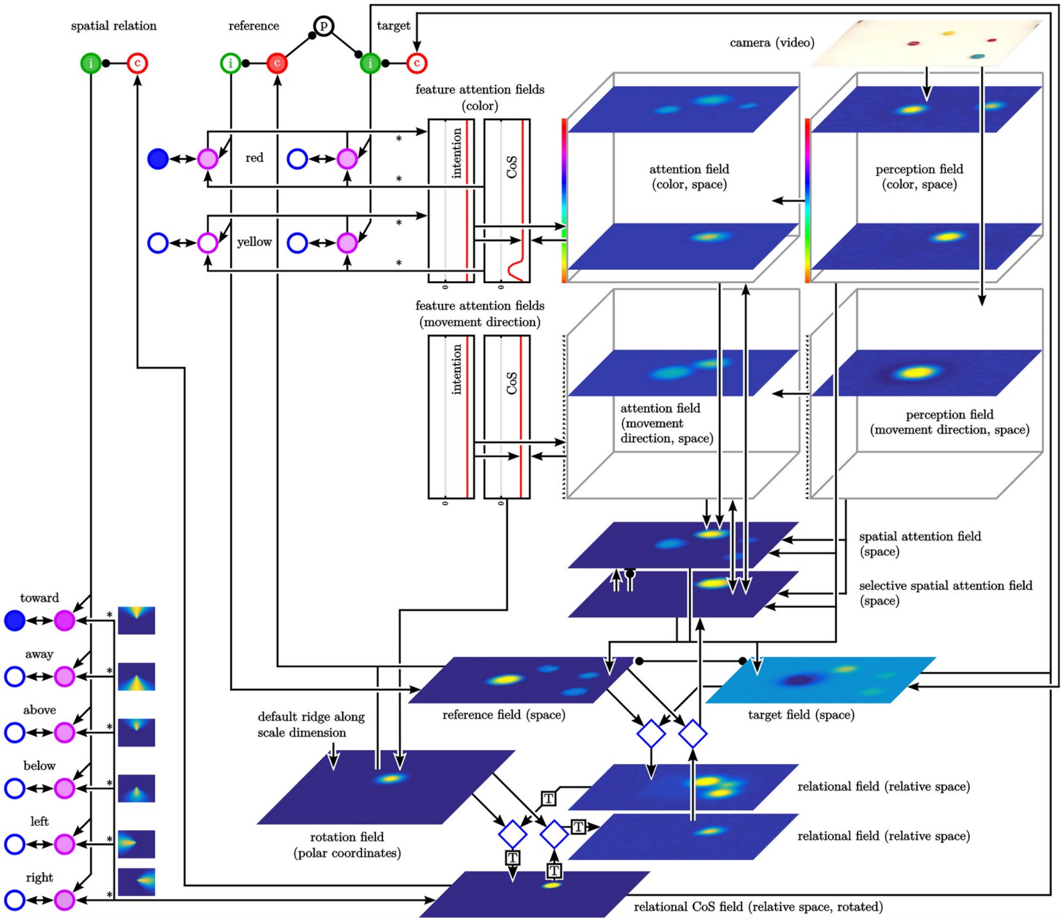


 Kounatidou et al. (2018)

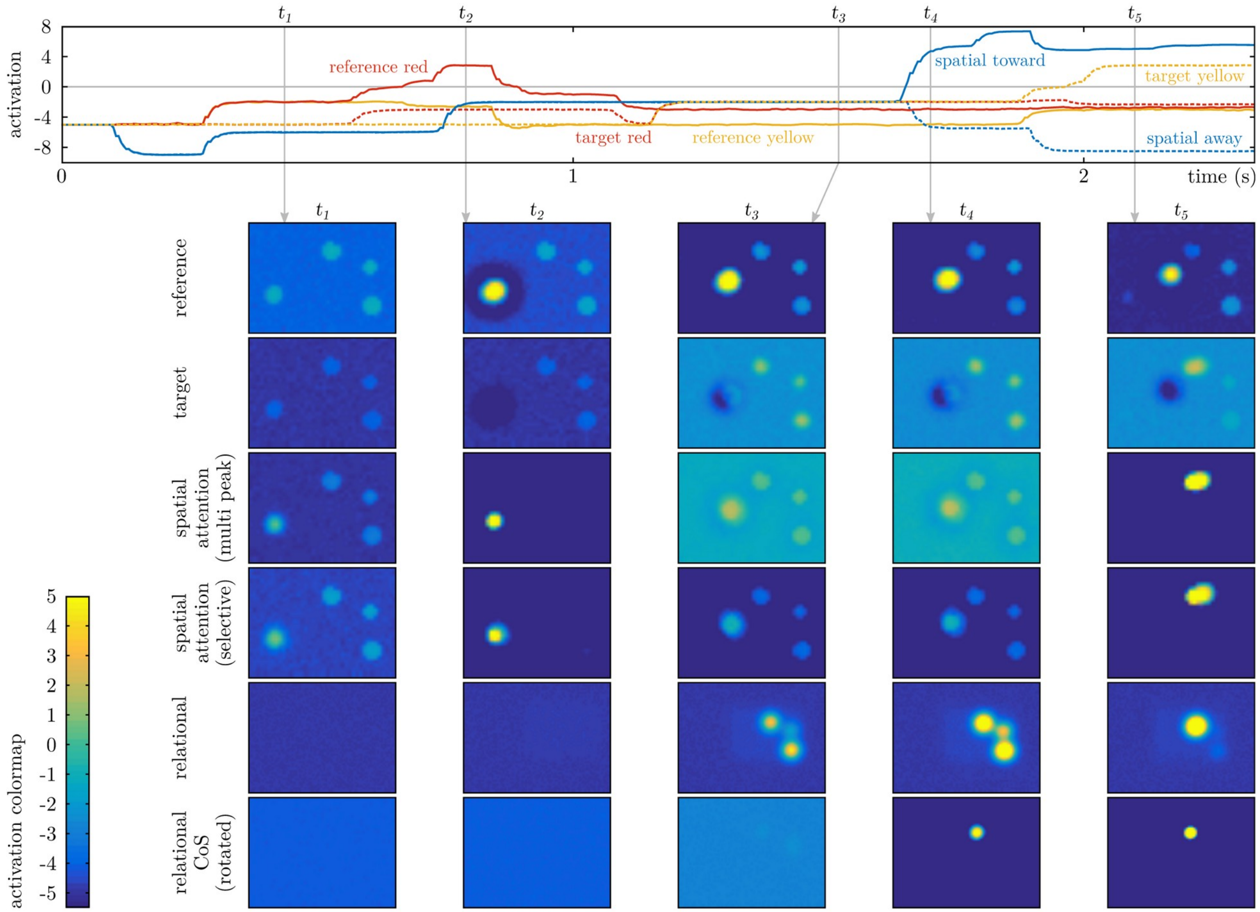
MOVEMENT RELATIONS



Richter et al. (2017)



Richter et al. (2017)

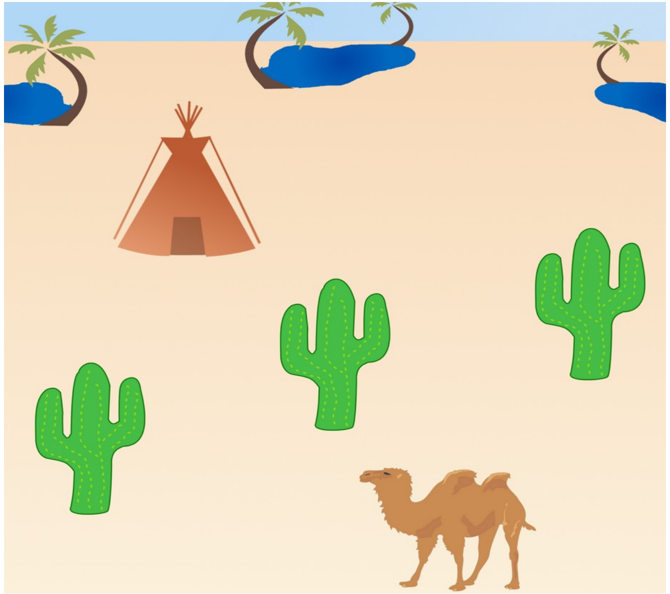


Richter et al. (2017)

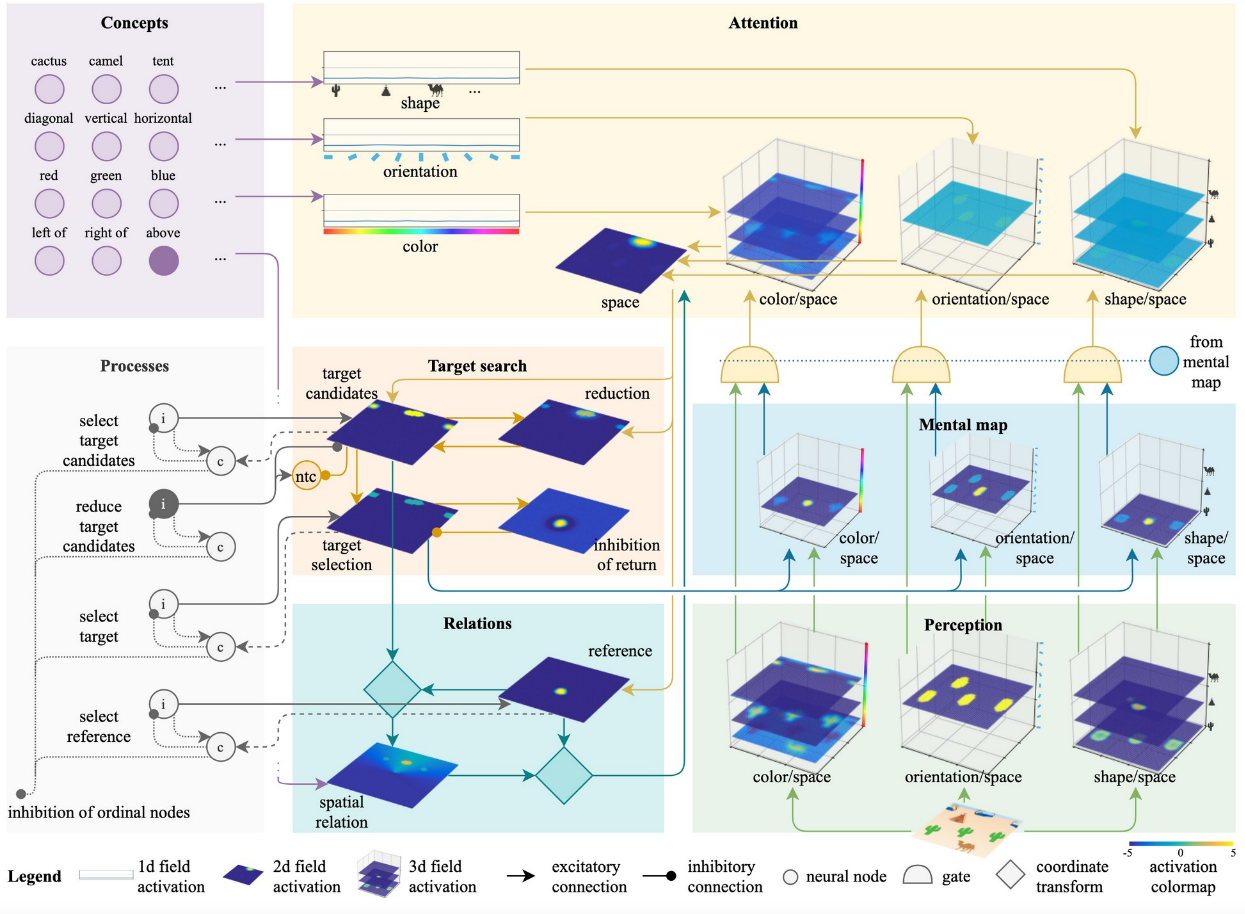
TOWARDS COMPOSITIONALITY

COMPOSITIONALITY

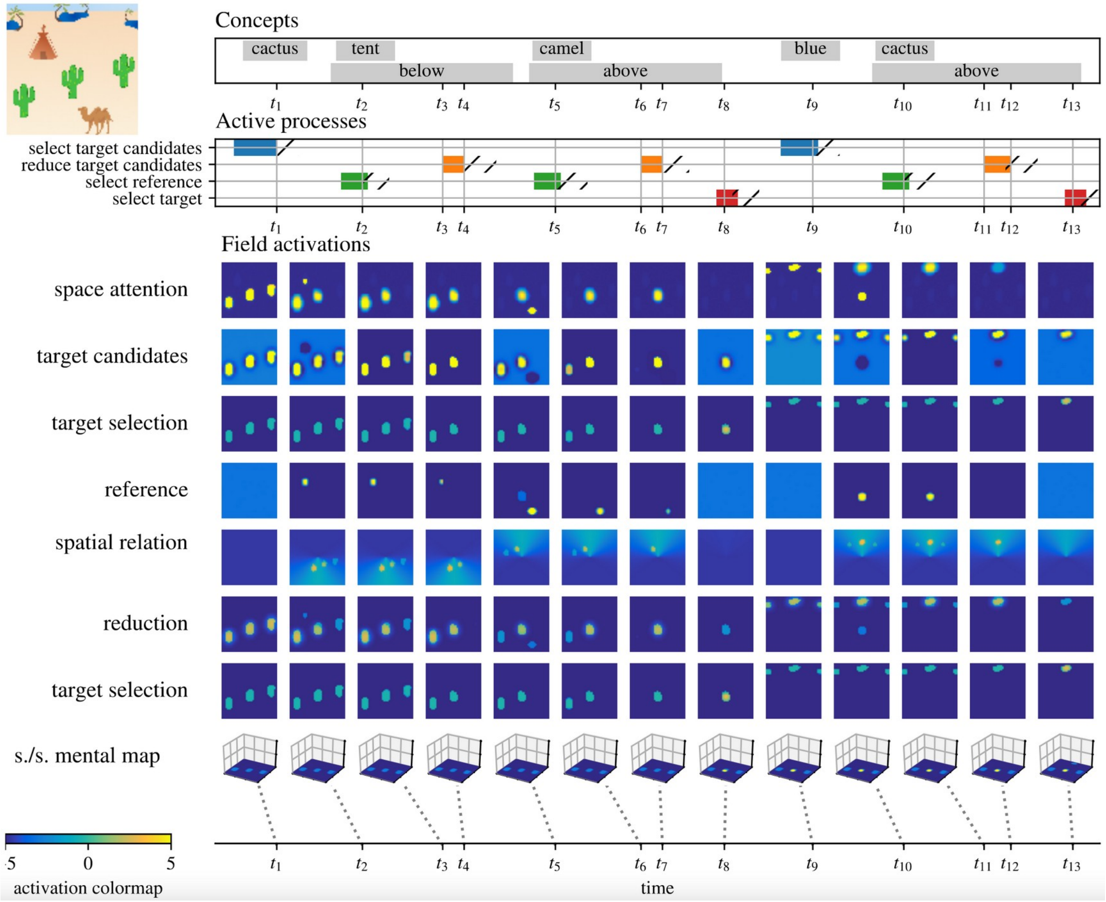
- "There's a blue object above a cactus (which is) below a tent and above a camel"



Sabinasz et al. (2020)



Sabinasz et al. (2020)



Sabinasz et al. (2020)

REFERENCES

- Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences, 22*(4), 577–609.
- Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology*, 59, 617–645.
- Fodor, J. A. & Pylyshyn, Z. W. (1988). Connectionism and cognitive architecture: A critical analysis. *Cognition, 28*(1-2), 3– 71.
- Gärdenfors, P. (2000). *Conceptual spaces: The geometry of thought*. Cambridge, MA: MIT Press.
- Gärdenfors, P. (2014). *The geometry of meaning: Semantics based on conceptual spaces*. Cambridge, MA: MIT Press.
- Harnad, S. (1990). The symbol grounding problem. *Physica D, 42*, 335–346.
- Hofstadter, D. R., & Sander, E. (2013). *Surfaces and essences: Analogy as the fuel and fire of thinking*. Basic Books.
- Lakoff, G., & Johnson, M. (1980). *Metaphors we live by*. University of Chicago press.
- Kounatidou, P., Richter, M., & Schöner, G. (2018). A neural dynamic architecture that autonomously builds mental models. *Proceedings of the 40th annual meeting of the cognitive science society*. Austin, TX: Cognitive Science Society.

REFERENCES

- Lipinski, J., Schneegans, S., Sandamirskaya, Y., Spencer, J. P., & Schöner, G. (2012). A neuro-behavioral model of flexible spatial language behaviors. *Journal of Experimental Psychology: Learning, Memory and Cognition, 38*(6), 1490–1511.
- Pulvermüller, F. (1999). Words in the brain's language. *Behavioral and Brain Sciences, 22*(2), 253–336.
- Pulvermüller, F. (2005). Brain mechanisms linking language and action. *Nature Reviews Neuroscience, 6*(July), 576–582.
- Ragni, M. & Knauff, M. (2013). A theory and a computational model of spatial reasoning with preferred mental models. *Psychological Review, 120*(3), 561–588
- Richter, M., Lins, J., Schneegans, S., Sandamirskaya, Y., & Schöner, G. (2014). Autonomous neural dynamics to test hypotheses in a model of spatial language. *Proceedings of the 36th annual meeting of the cognitive science society*. Austin, TX: Cognitive Science Society.
- Richter, M., Lins, J., & Schöner, G. (2017). A neural dynamic model generates descriptions of object-oriented actions. *Topics in Cognitive Science, 9*, 35–47.
- Sabinasz, D., Richter, M., Lins, J., & Schöner, G. (2020). Grounding Spatial Language in Perception by Combining Concepts in a Neural Dynamic Architecture. In *CogSci 2020*.