RUHR-UNIVERSITÄT BOCHUM

NEURAL PROCESS MODELS OF LANGUAGE GROUNDING

Daniel Sabinasz – IK 2023

MOTIVATION

- Towards understanding the biological neural processes that give rise to the language competence

THEORETICAL STARTING POINT

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

RESEARCH PROGRAM

- Build models of how the language competence may emerge from the neural principles postulated in DFT

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- Build models of how the language competence may emerge from the neural principles postulated in DFT
- … possibly using and extending the same neural architectures as more primitive sensory-motor processes
  - Neural fields with their instabilities (detection, selection, short-term memory)
  - Visual search
  - Categorization
  - Coordinate transformations

PERCEPTUAL GROUNDING

- Language understanding requires associating language with perceptual representations

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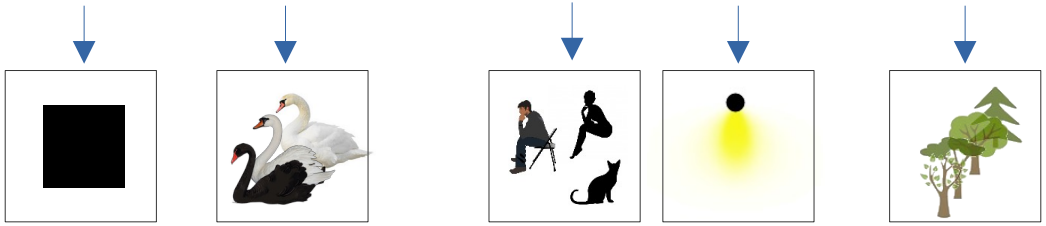
the black swan that sits below a tree



GOAL

- Towards a neural process model that perceptually grounds language

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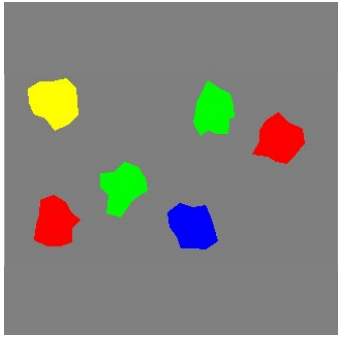
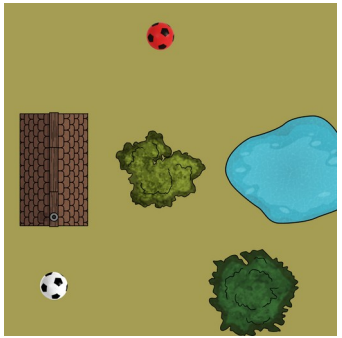
- Need to approach this in small steps

DFT MODELS OF LANGUAGE GROUNDING

- **Today: Simple visuo-spatial language grounding**
  - e.g., “the red to the right of the green”
  - Lipinski et al. (2012), Richter et al. (2014)

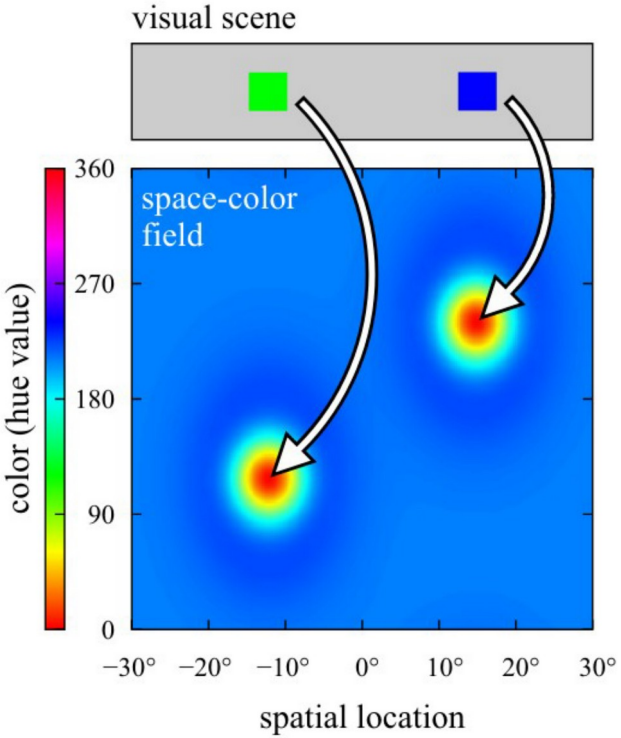


- Outlook:
  - Movement relations
    - e.g., “the red that moves towards the green”
    - Richter, Lins, & Schöner (2021)
  - Compositional visuo-spatial language grounding
    - e.g., “the red ball that moves towards the big tree, which is to the left of the lake and to the right of the house”
    - Sabinasz & Schöner (2021)



Preliminaries

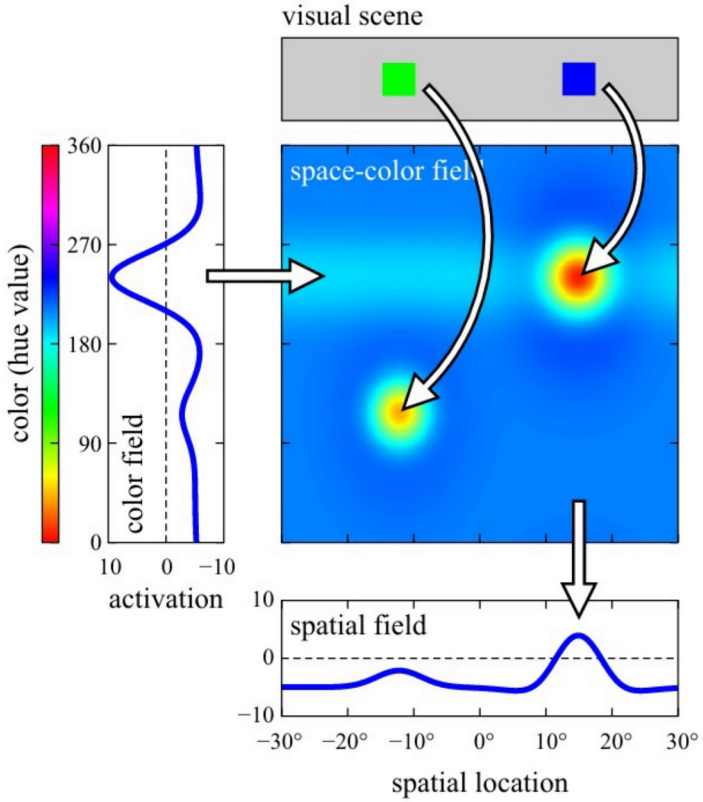
- Higher-dimensional fields enable binding dimensions



(Schneegans et al., 2016a)

Preliminaries

- Ridge input along one dimension can be used to extract bound information



(Schneegans et al., 2016a)

Preliminaries

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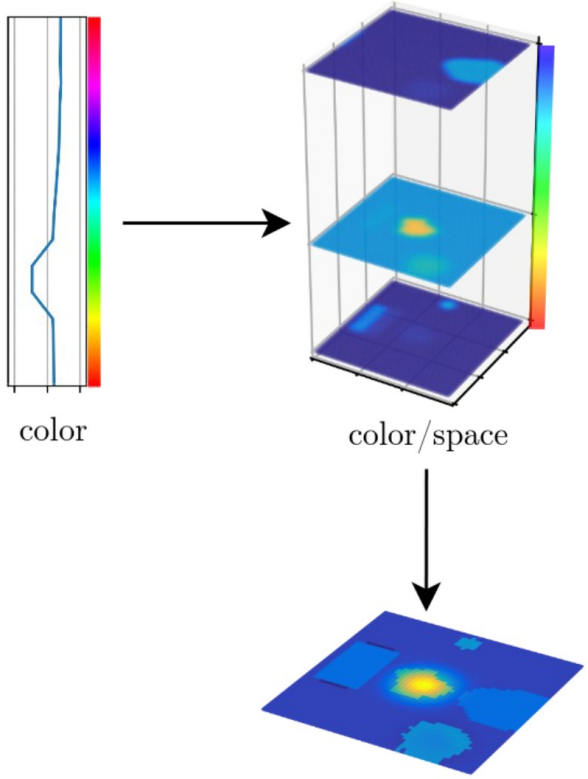
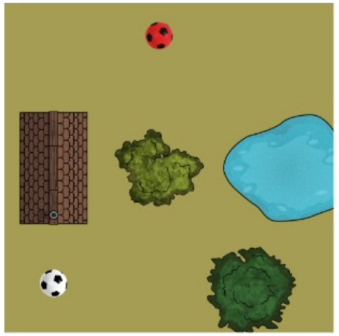
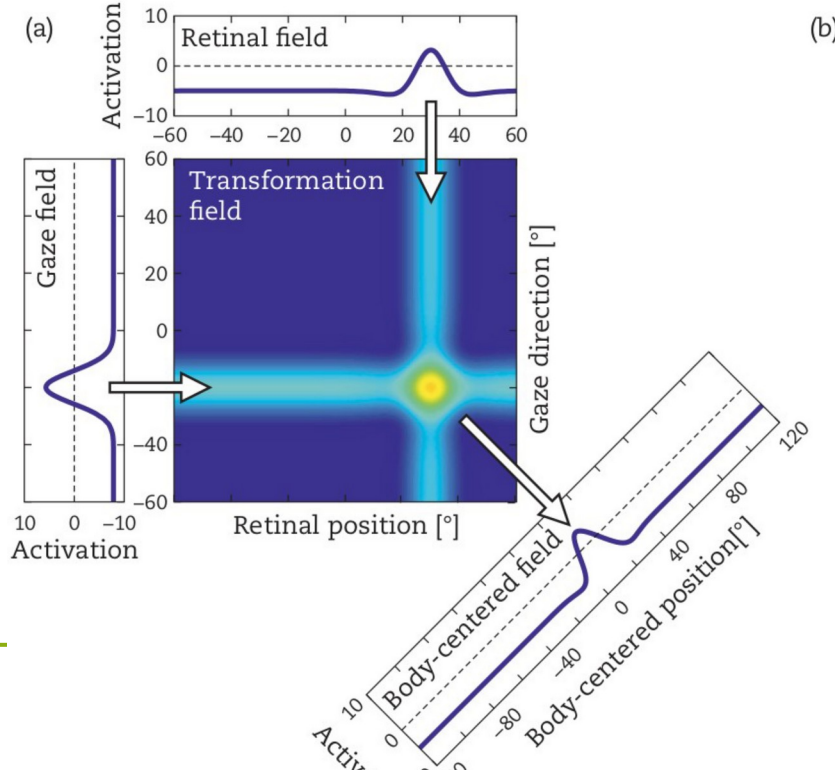
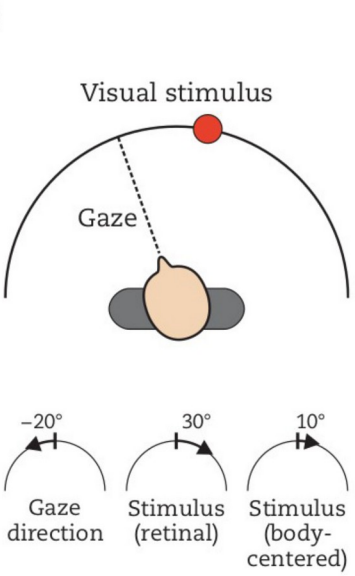




Preliminaries

- 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 & Schöner, 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

Lipinski et al. (2012)

SPATIAL COMPARISON: REQUIRED OPERATIONS

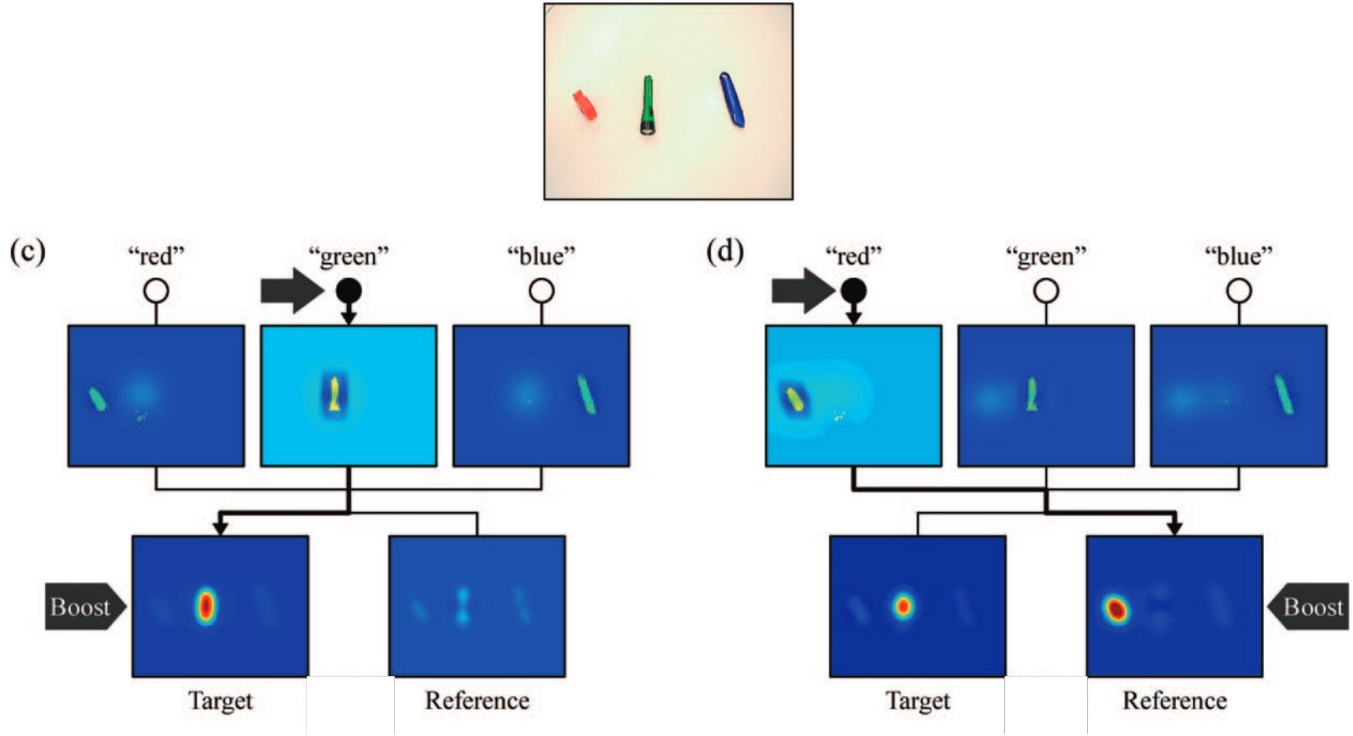
(Following a computational analysis by Logan & Sadler, 1996)

- 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

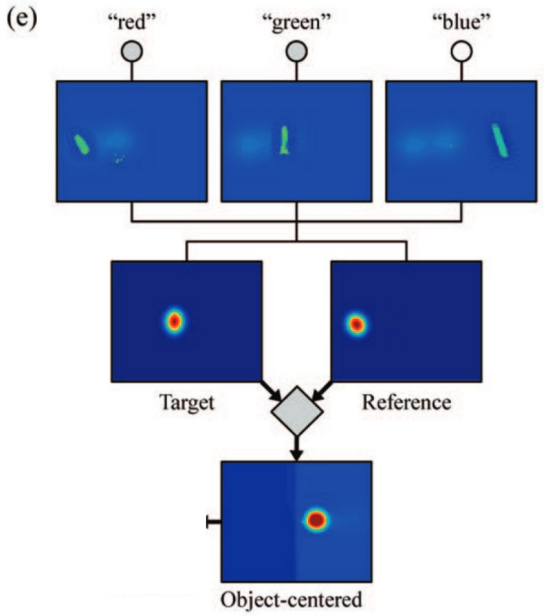
Lipinski et al. (2012)

FINDING OBJECTS IN THE PERCEPTUAL INPUT



Lipinski et al. (2012)

COORDINATE TRANSFORMATION

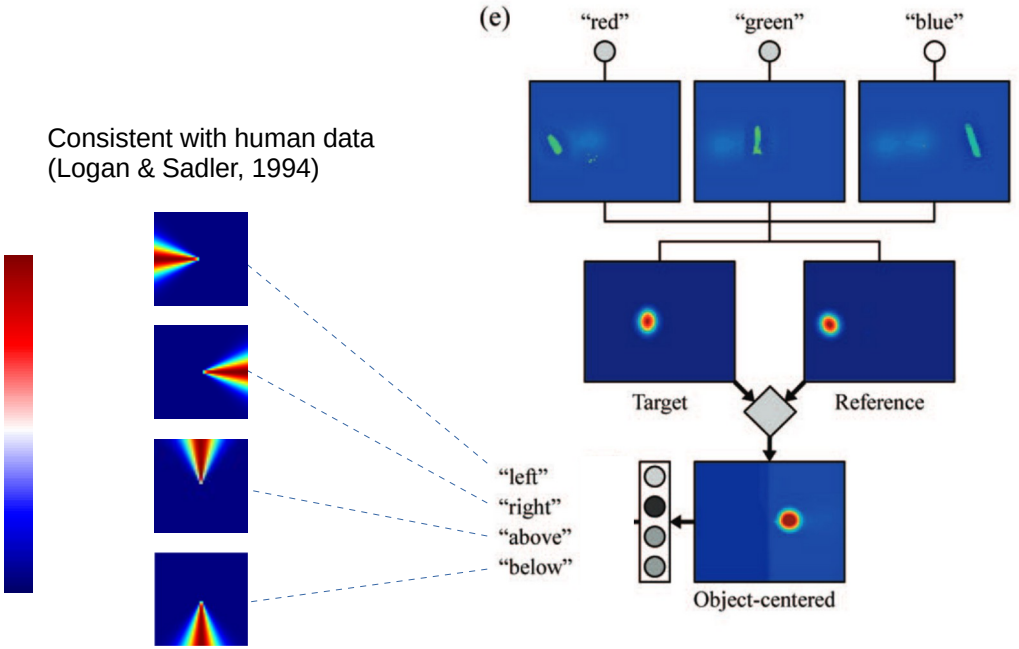


Lipinski et al. (2012)

COMPARING TO A SPATIAL TEMPLATE

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

Consistent with human data
(Logan & Sadler, 1994)



Lipinski et al. (2012)

COMPARING TO A SPATIAL TEMPLATE

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

Lipinski et al. (2012)

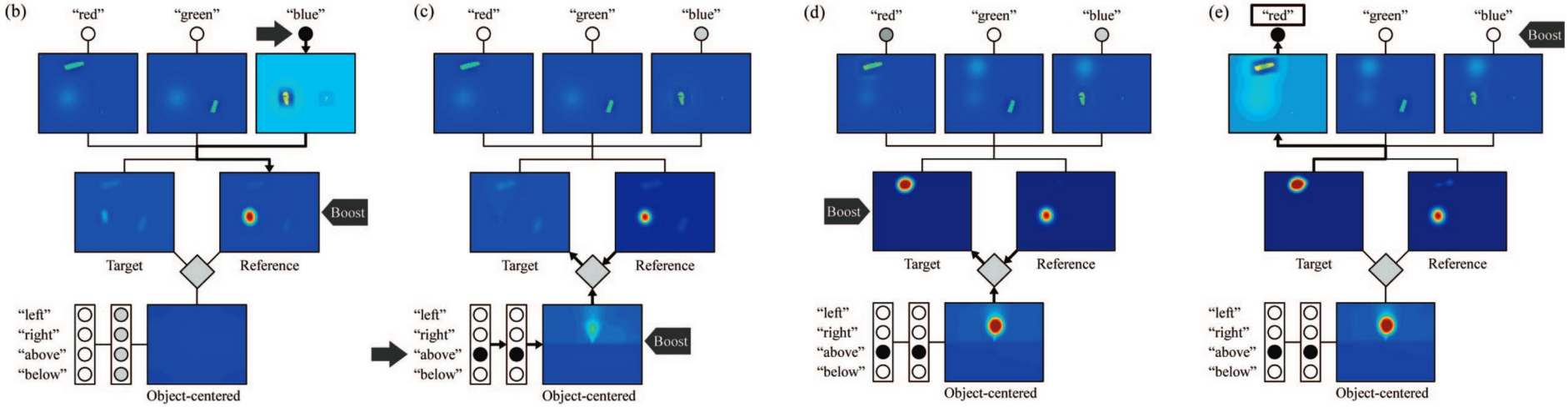
TARGET IDENTIFICATION

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

Lipinski et al. (2012)

TARGET IDENTIFICATION

- “Which object is above the blue object?”



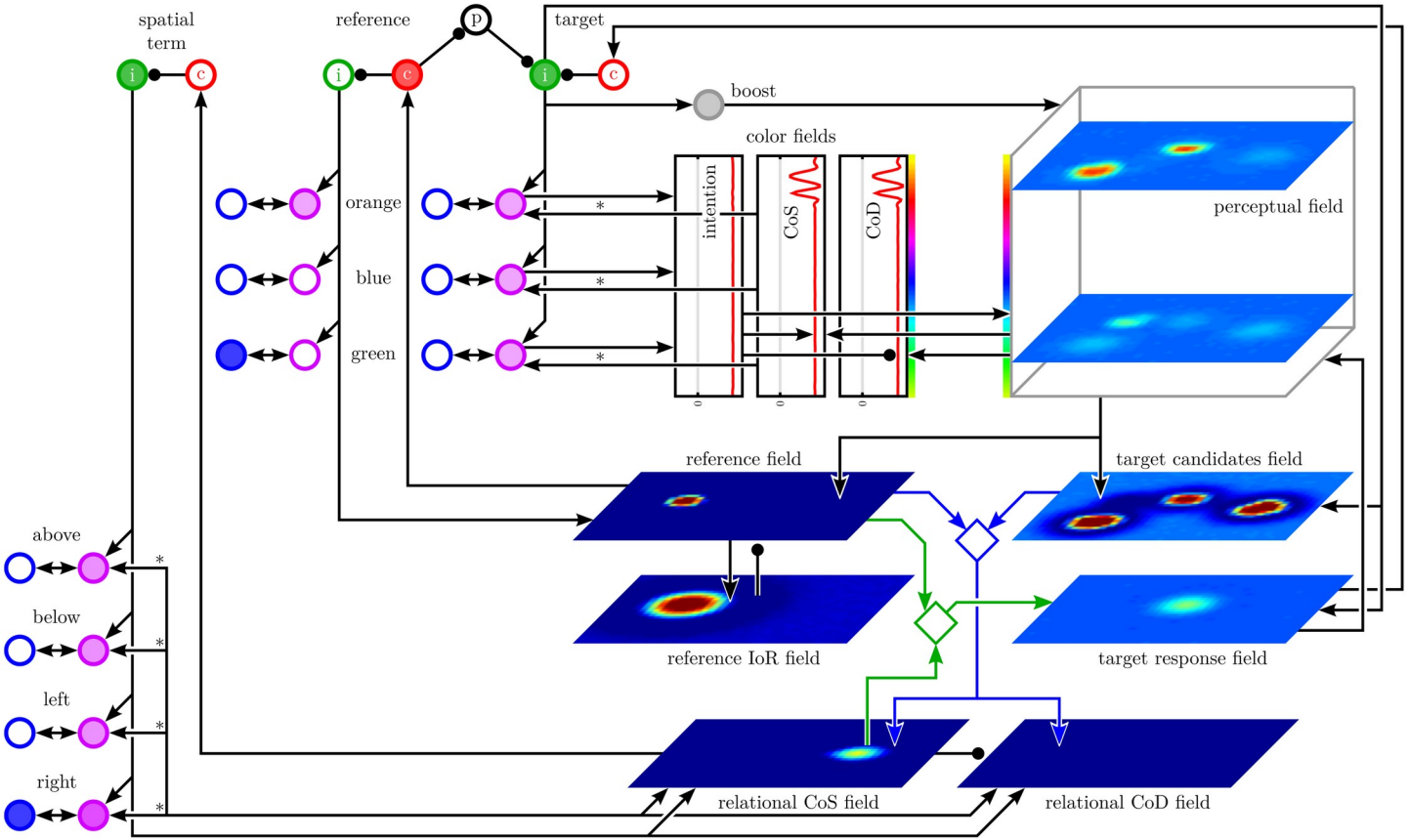
Lipinski et al. (2012)

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

Richter et al. (2014)



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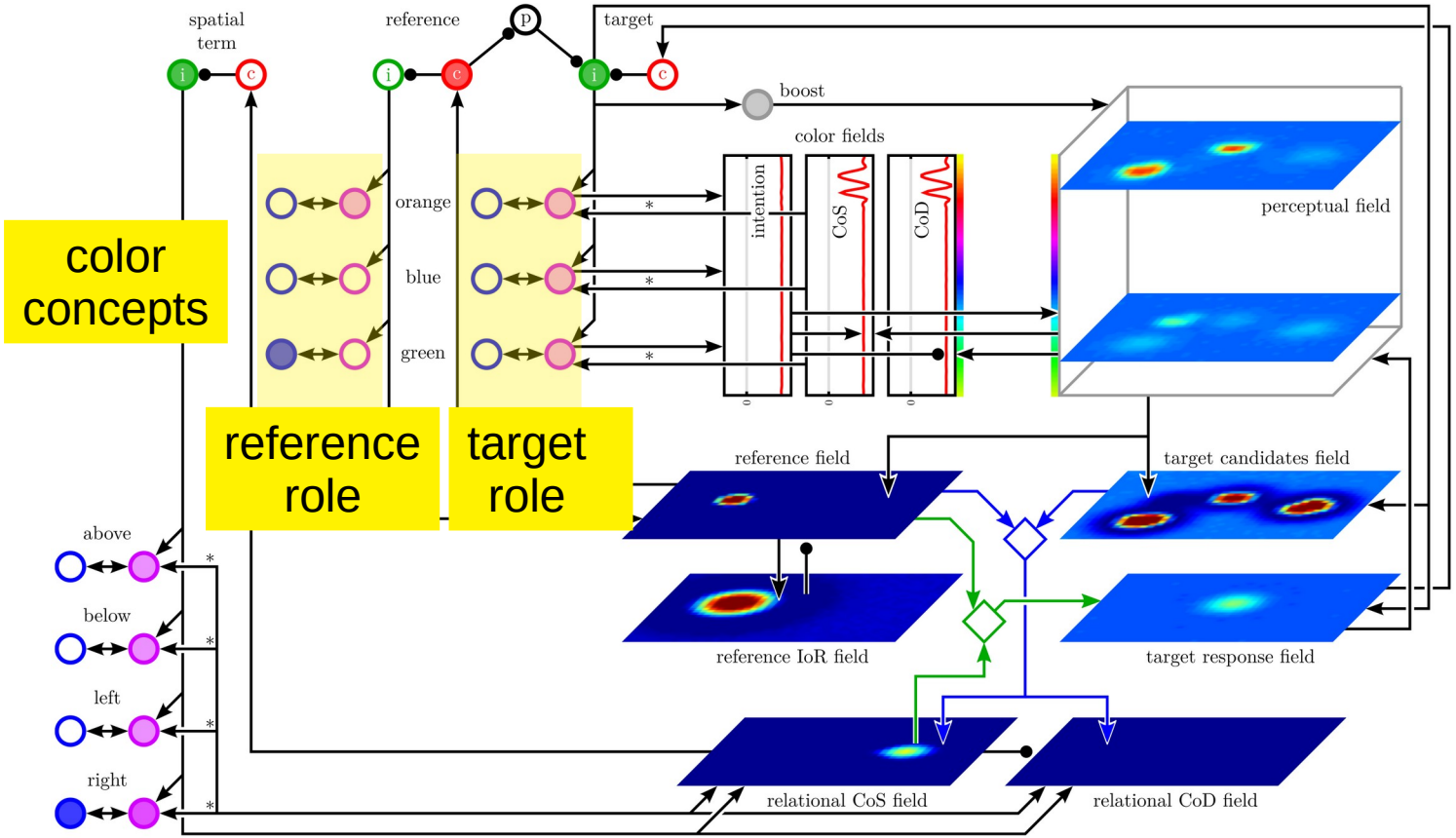

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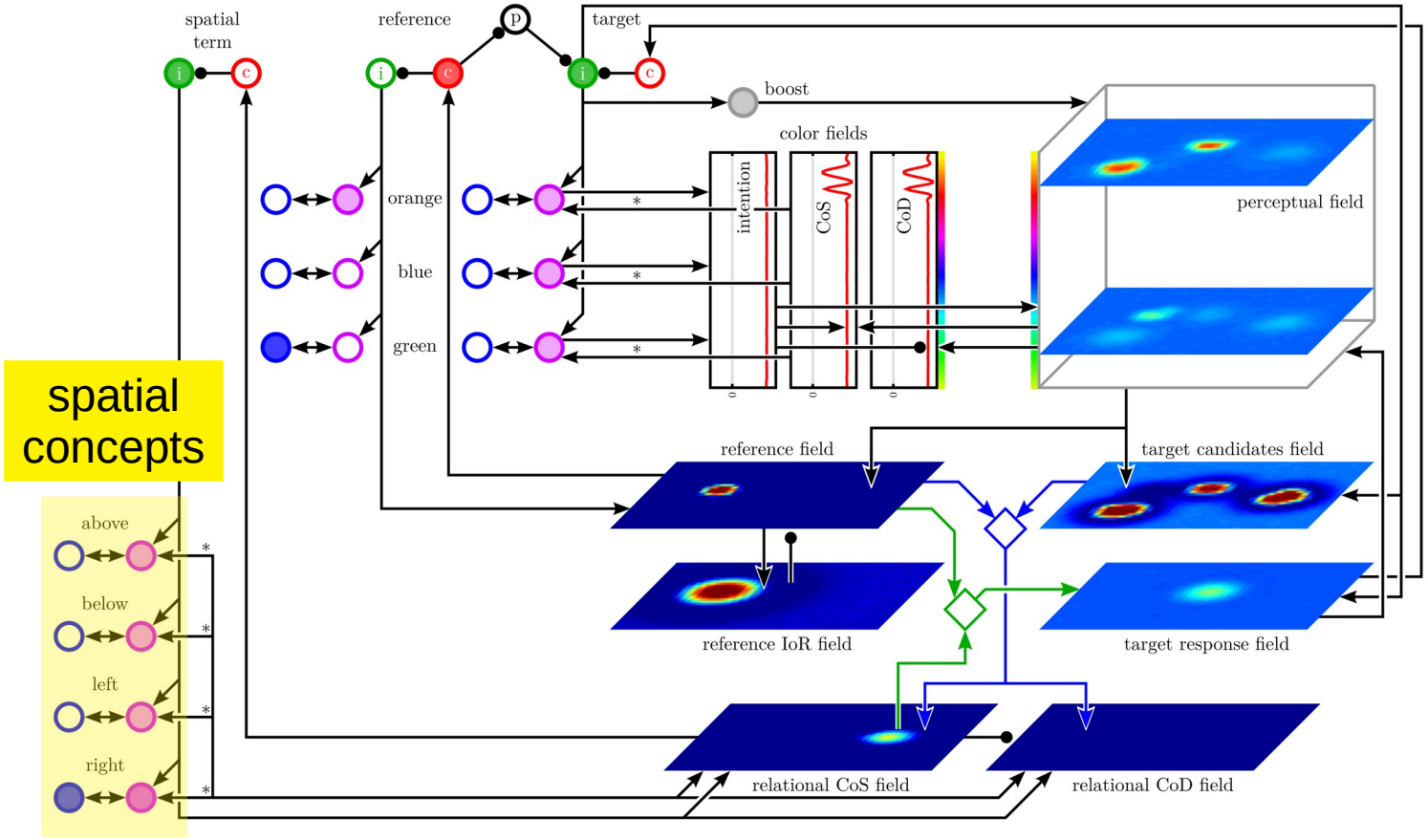

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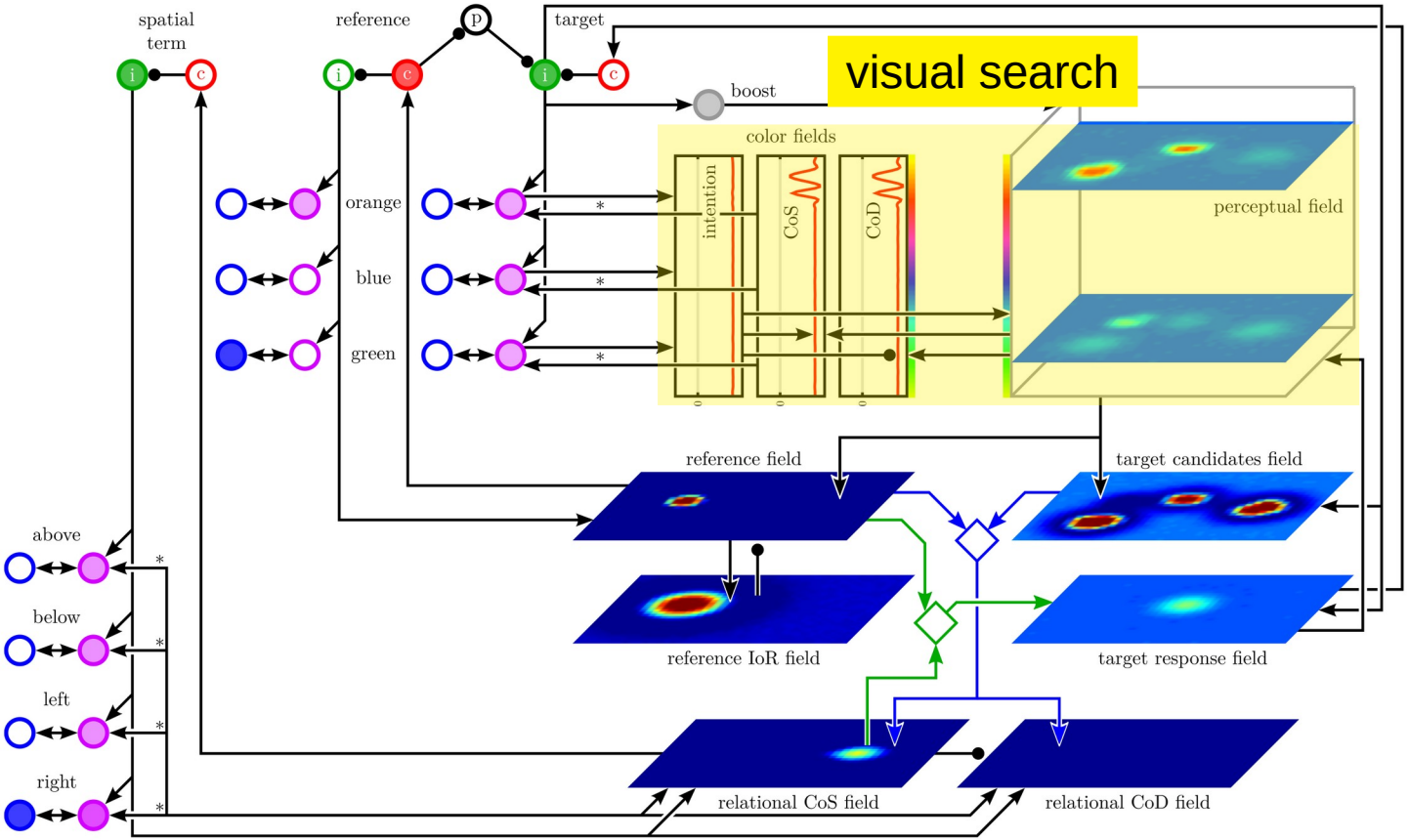
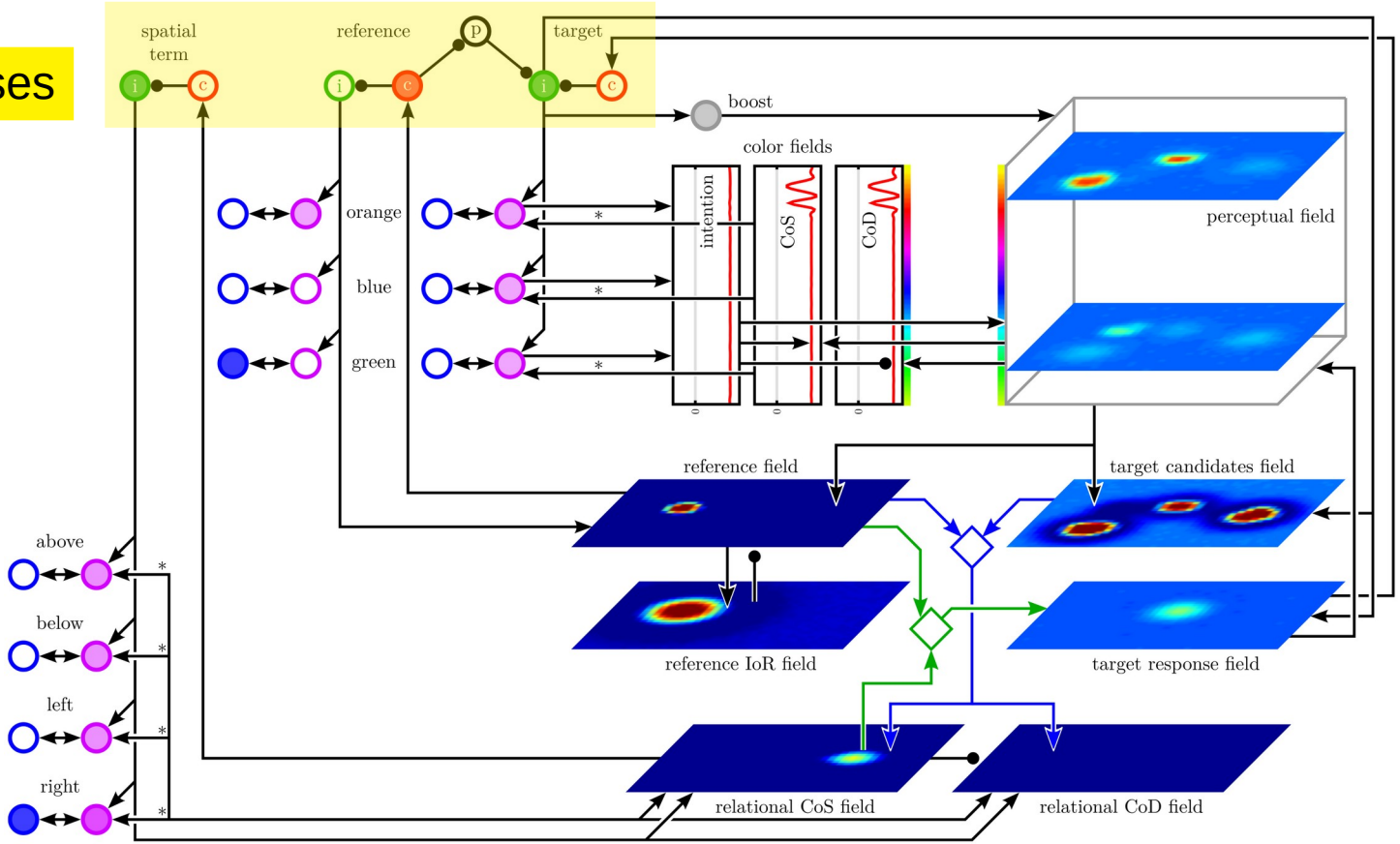


Richter et al. (2014)

processes



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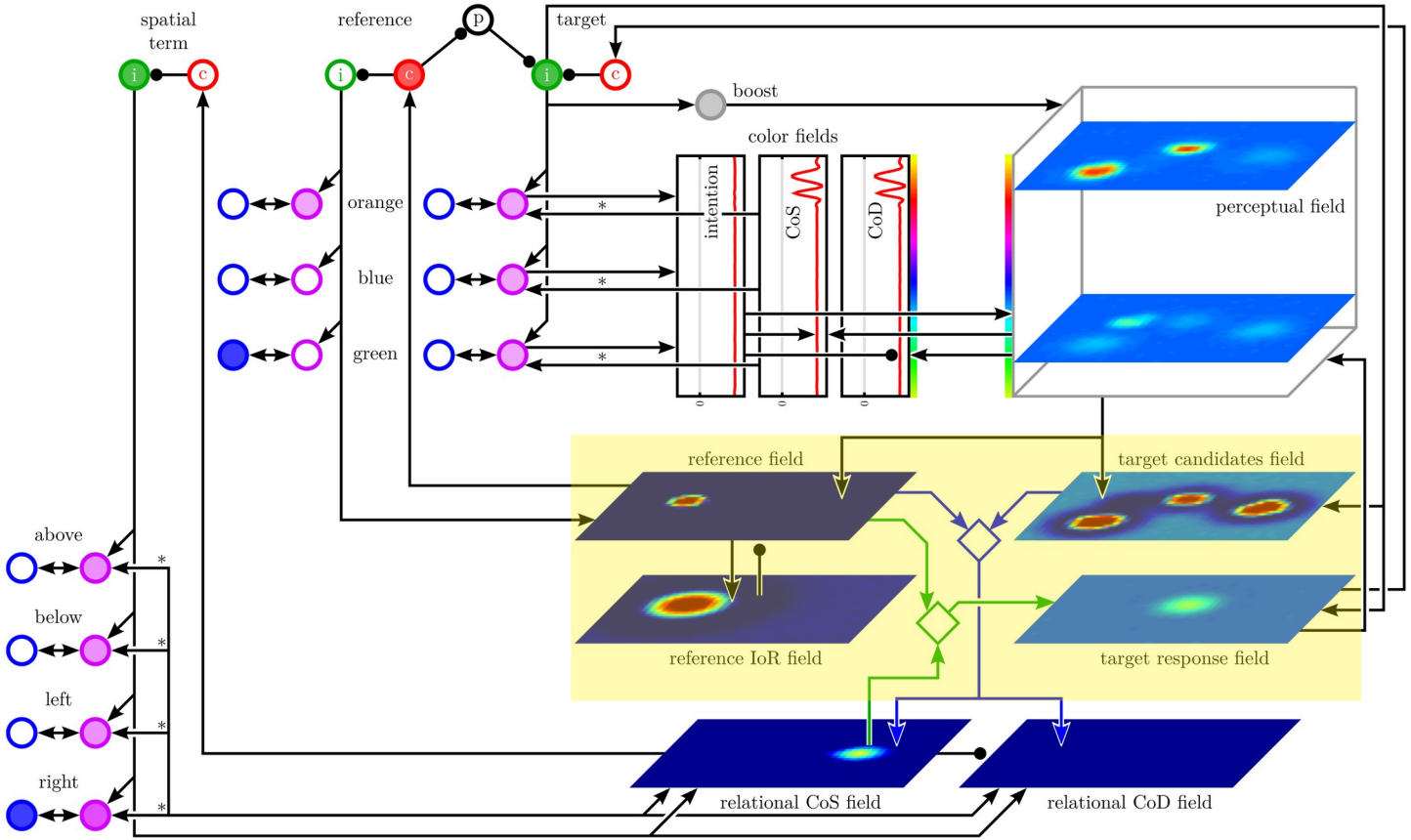

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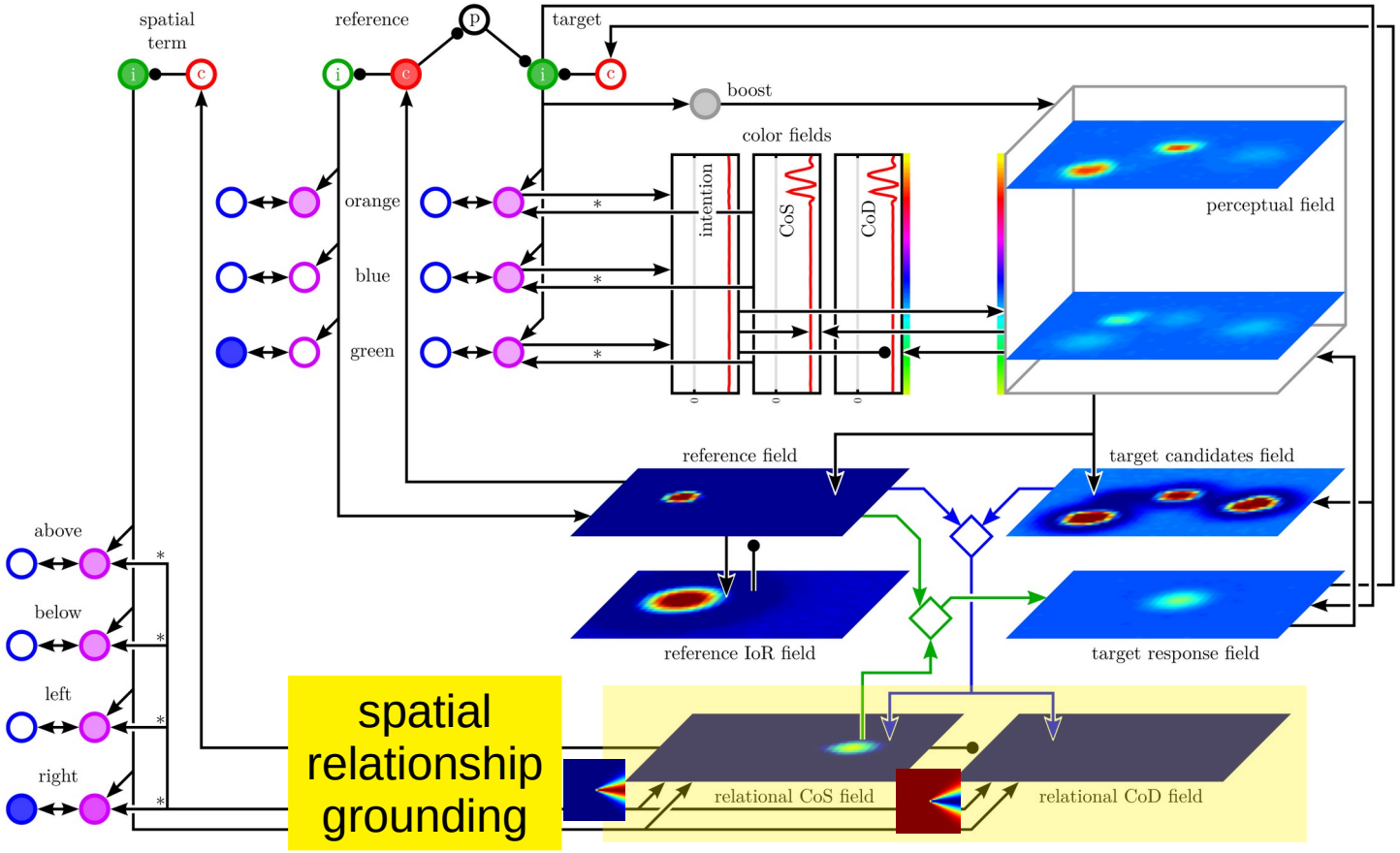

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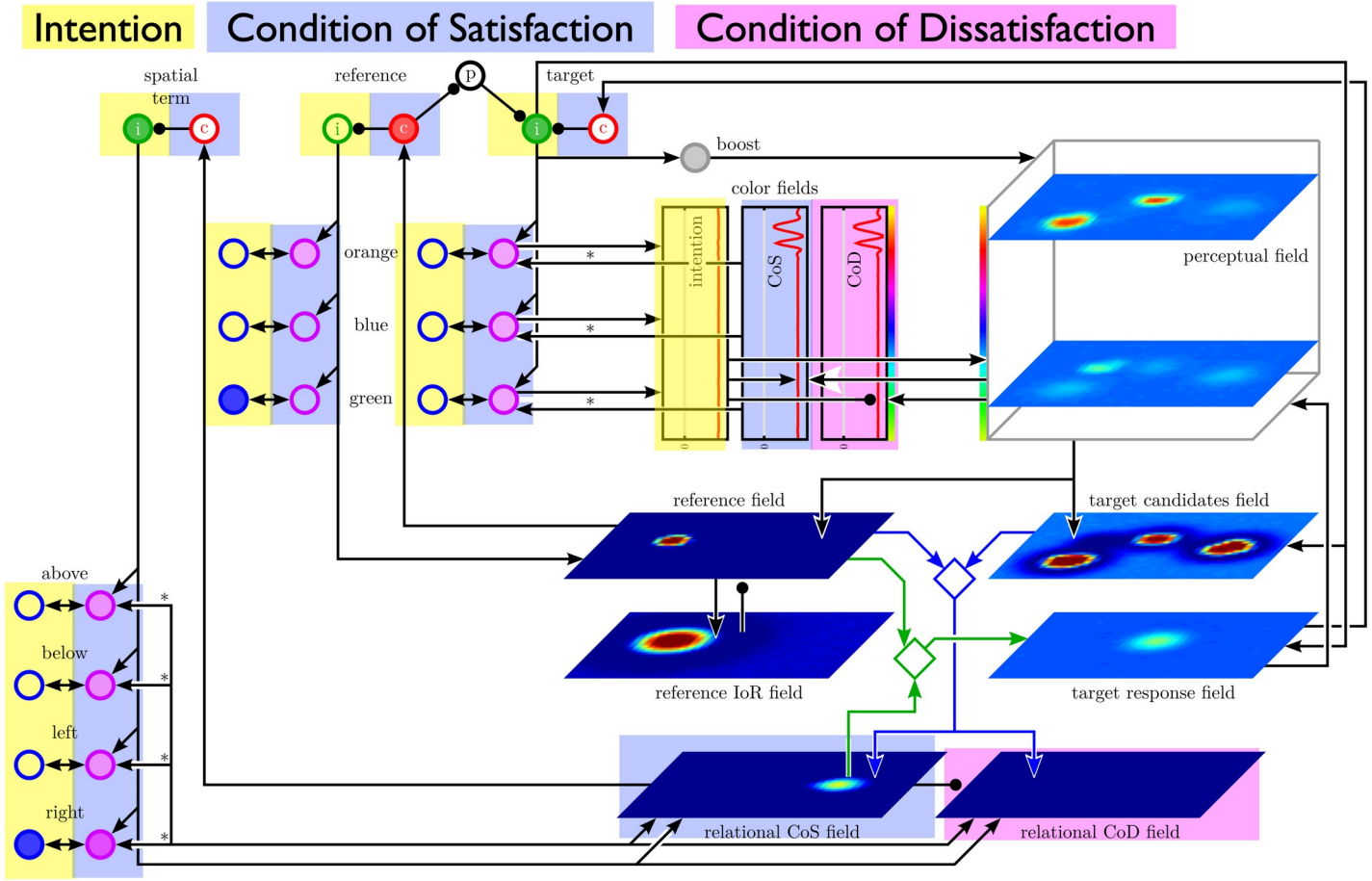
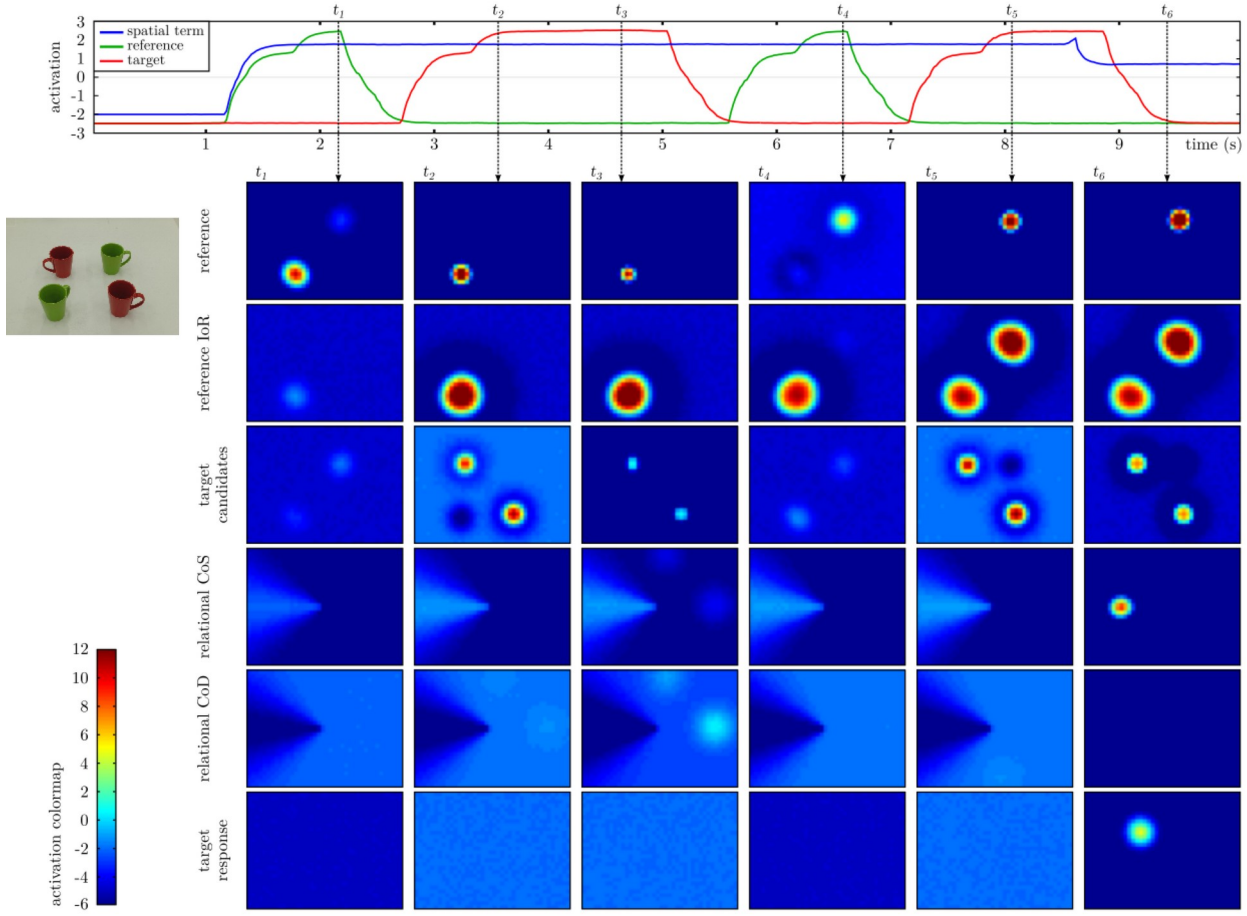


Richter et al. (2014)

EXAMPLE

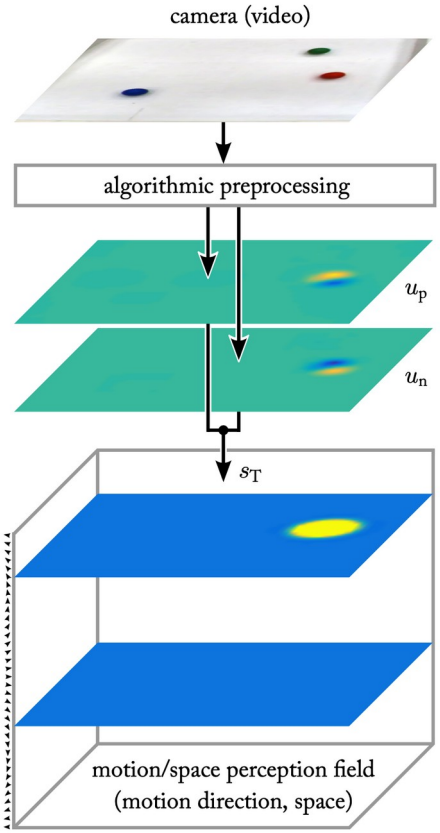
“The red object to the left of the green object”

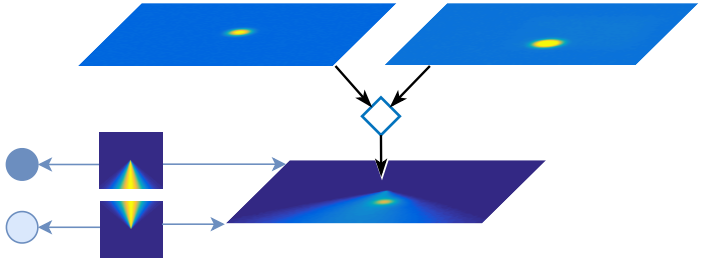
Richter et al. (2014)



Richter et al. (2014)

MOVEMENT RELATIONS





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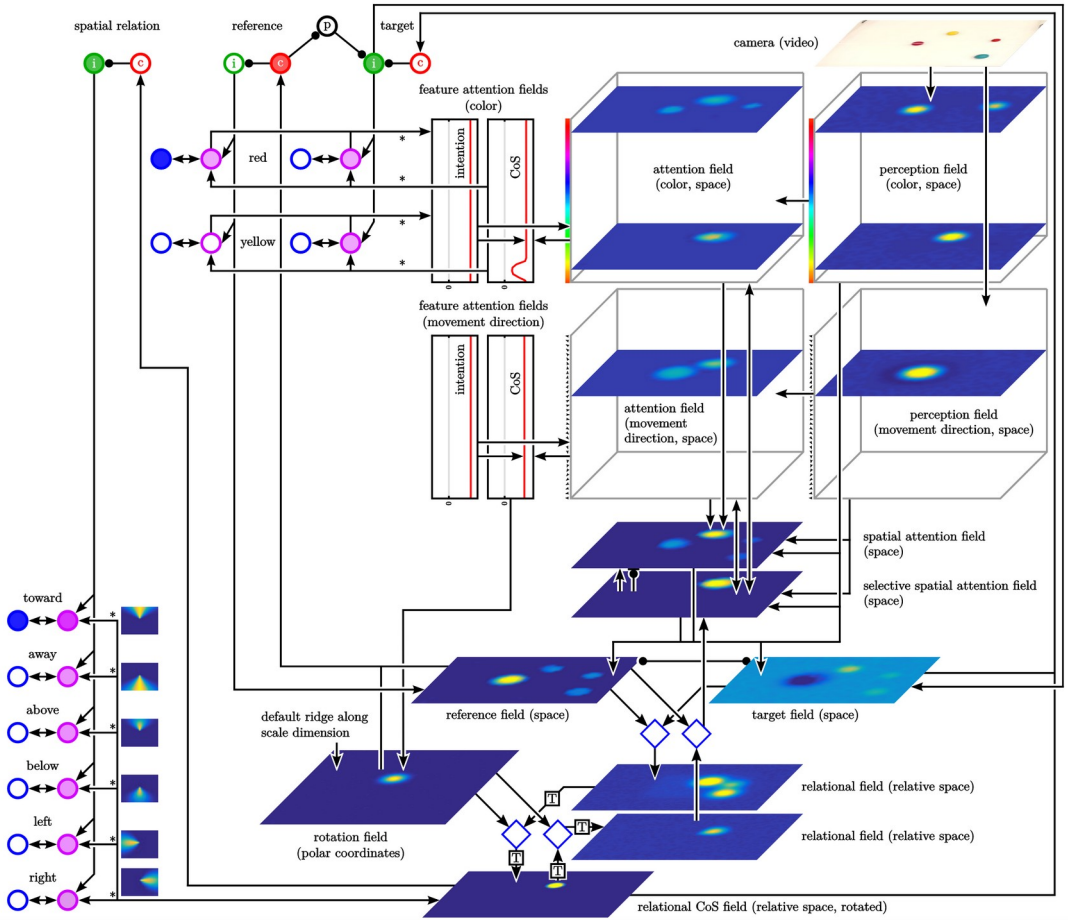

Richter et al. (2017)

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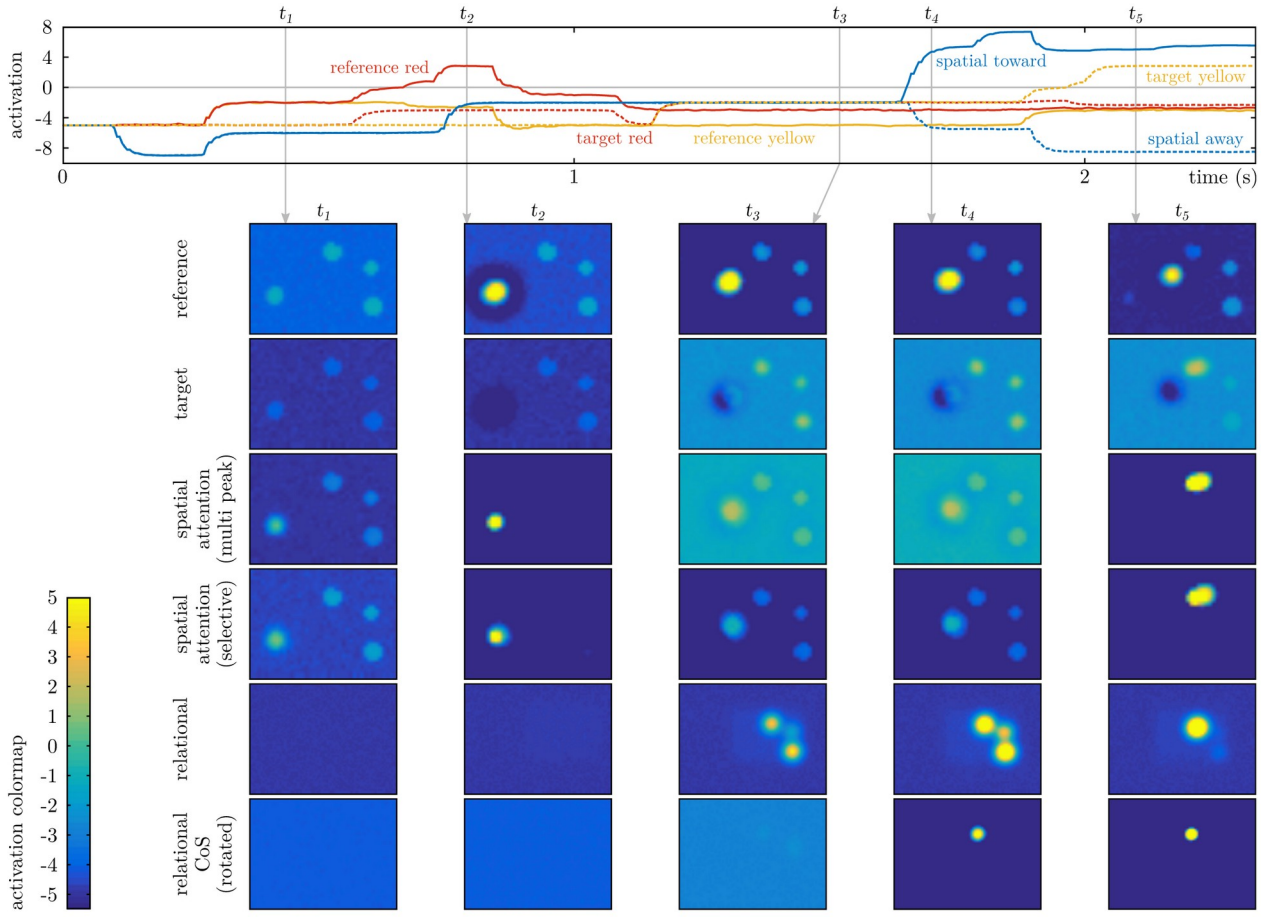
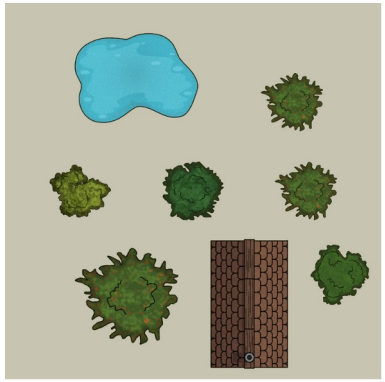
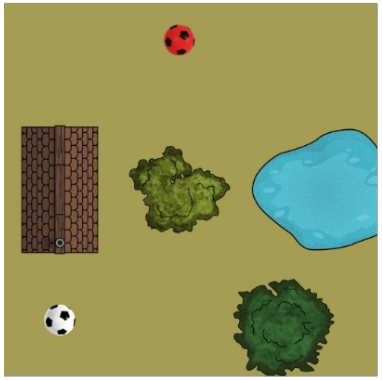


Richter et al. (2017)

TOWARDS COMPOSITIONALITY

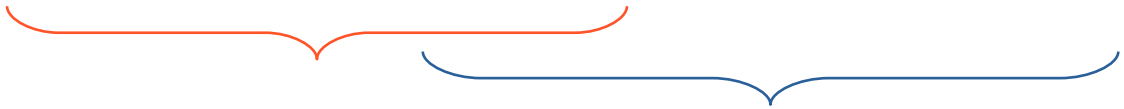
- the tree to the right of the tree below the lake
- the tree below the lake and above the house
- the red ball that moves towards the big tree, which is to the left of the lake and to the right of the house





TOWARDS COMPOSITIONALITY

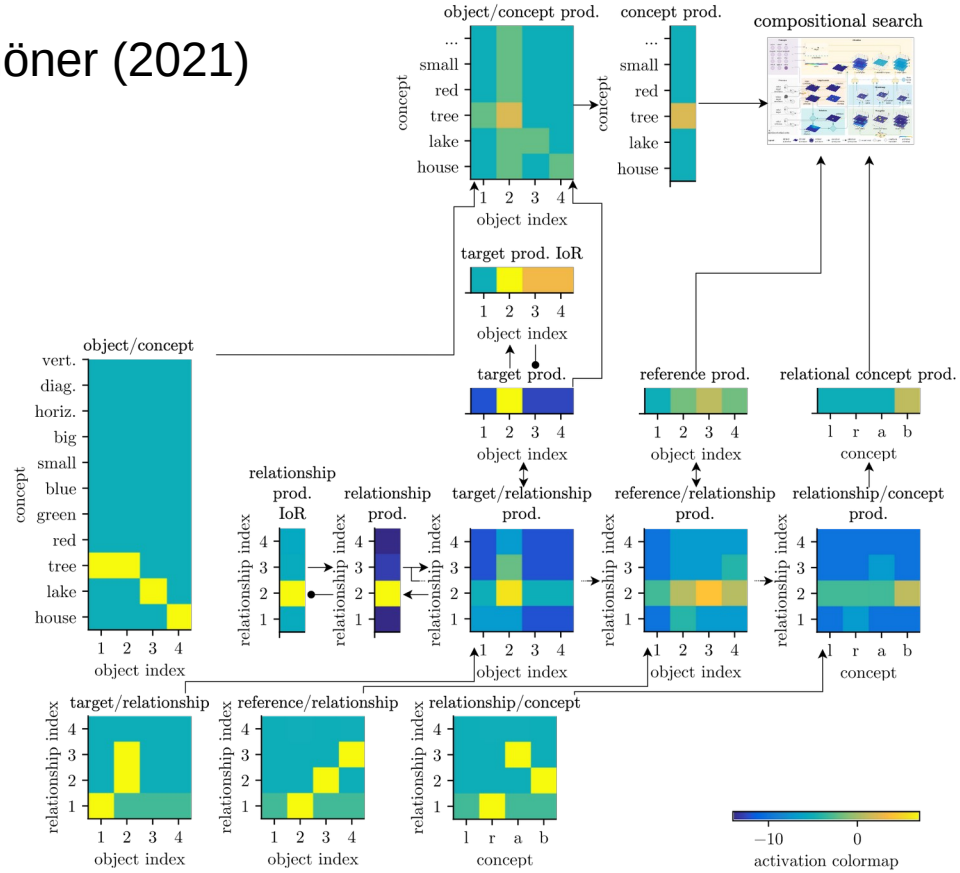
- The massiveness of the binding problem:
  e.g., "the lake above the tree above the house"



- The problem of 2:
  e.g., "the small tree above the big tree"

TOWARDS COMPOSITIONALITY

Sabinasz & Schöner (2021)



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