Cognition in embodied and situated nervous systems. Lecture 2: toward higher cognition

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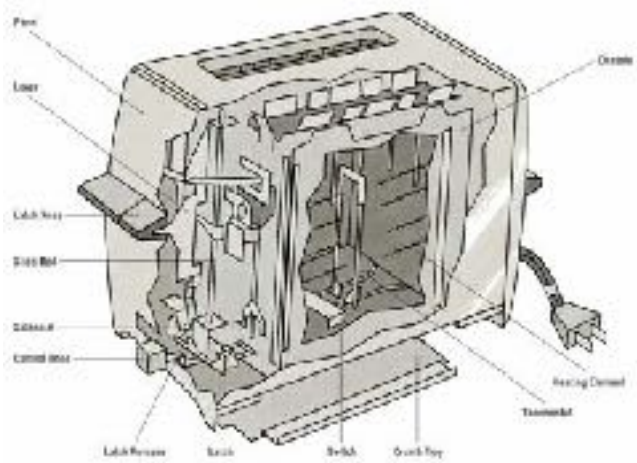
- embodied cognition
- multi-dimensional fields for operations
  - association
  - coordinate transforms
- sequential operation
- architectures
- higher cognition

Is soccer a cognitive?

- see and recognize the ball and the other players, estimate their velocities (perception, scene representation)
- select a visual target, track it, controlling gaze (attention)
- use working memory when players are out of view to predict where you need to look to update (working memory)
- plan and control own motion, initiate and control kick, update movement plans any time (planning)
- get better at playing (learning)
- know goal of the game/rules, how hard the ball is, how fast players are (background knowledge)

Repairing a toaster is cognition but also still embodied

- explore scene, recognize screws, while keeping track of spatial arrangement (scene representation, coordinate transforms)
- plan action, find tools, apply them to remembered locations, updated by current pose of toaster (working memory, scene representation)
- manipulating cover, taking it off, recognizing spring, re-attaching it (goal-directed action plan)
- mounting cover back on, generating the correct action sequence (sequence generation)
- get better at this (learning)
- know about cover, screws, hard to turn (background knowledge)



[image: HowStuffWorks]

[image: mystery fandom theater 3000]

“embodied cognition”

- active perception for a purpose through which perceptual objects are grounded: sensory autonomy
- cognitive processes continuously updated and continuously linkable to motor processes: stability
- invariance and abstraction must retain this linkage to the sensory and motor surfaces
- cognition is sensitive to behavioral history, environmental context: learning, adaptation
- (cognition arises from neural systems)
- build in “back-ground knowledge” (Searle)

The embodiment hypothesis

- there is no particular boundary up to which, cognition is embodied and beyond which cognition is “truly higher cognition and loses the properties of embodiment
- => all cognition shares properties of embodied cognition

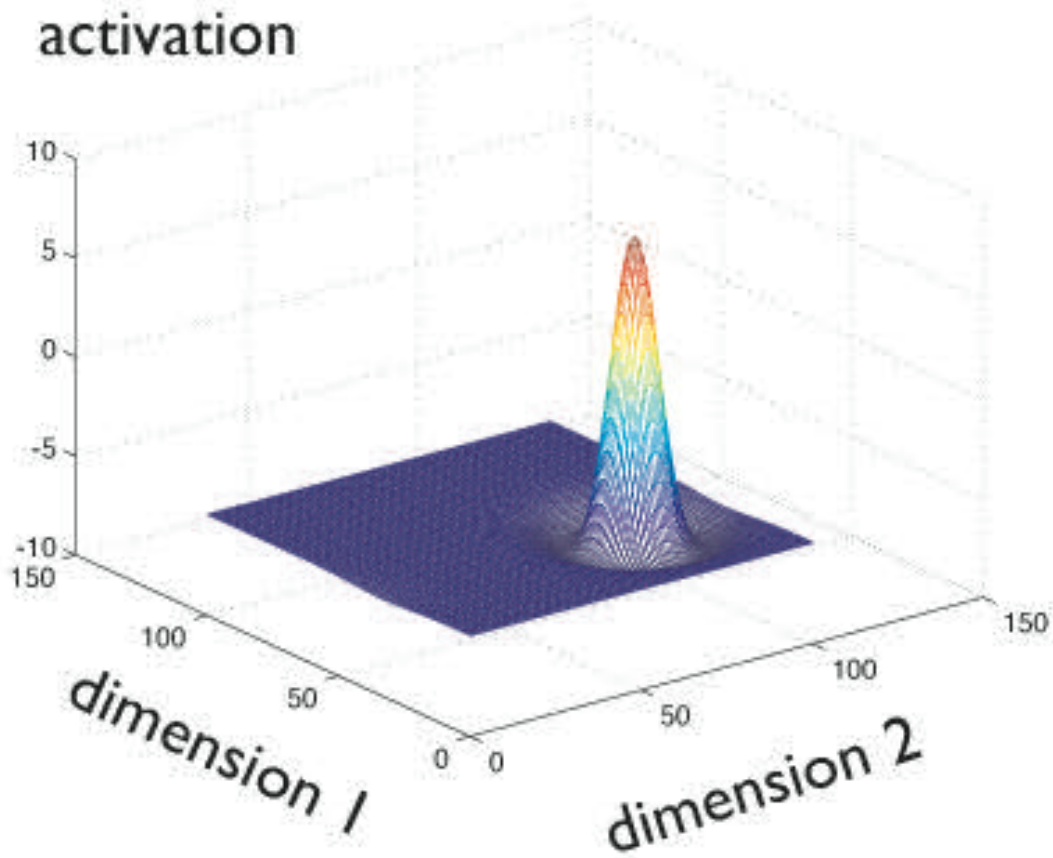
Neural dynamics hypothesis

- because embodied cognition unfolds in time, in interaction among processes, often including interaction (loop) between organisms and their environment
- => embodied cognition requires dynamics...

The goal of this second lecture is to show how the neural dynamic principles of DFT and embodied cognition may reach to higher cognition.

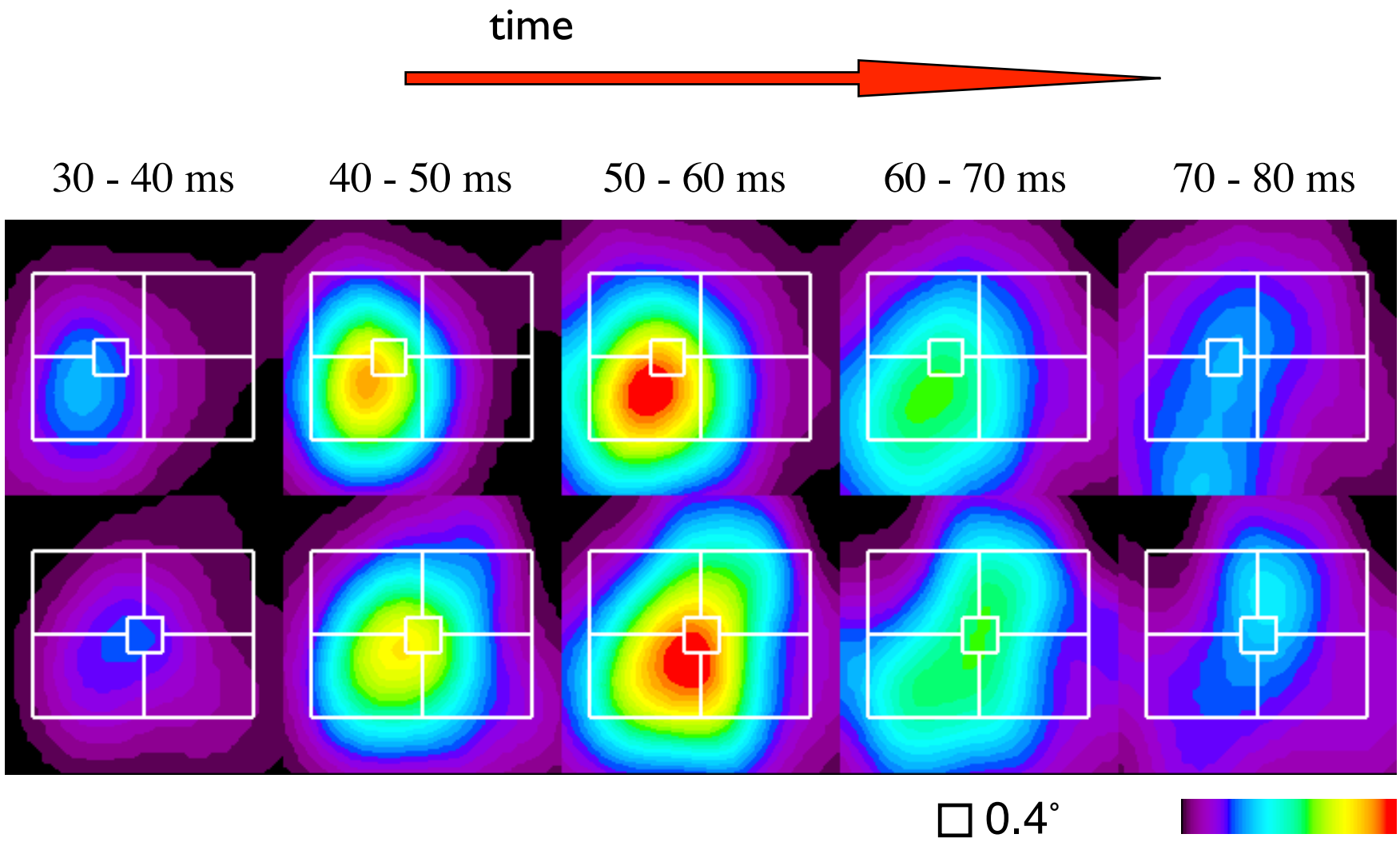
Higher dimensional fields

- no problem ... self-stabilized peaks work just fine...



DPA in higher dimension

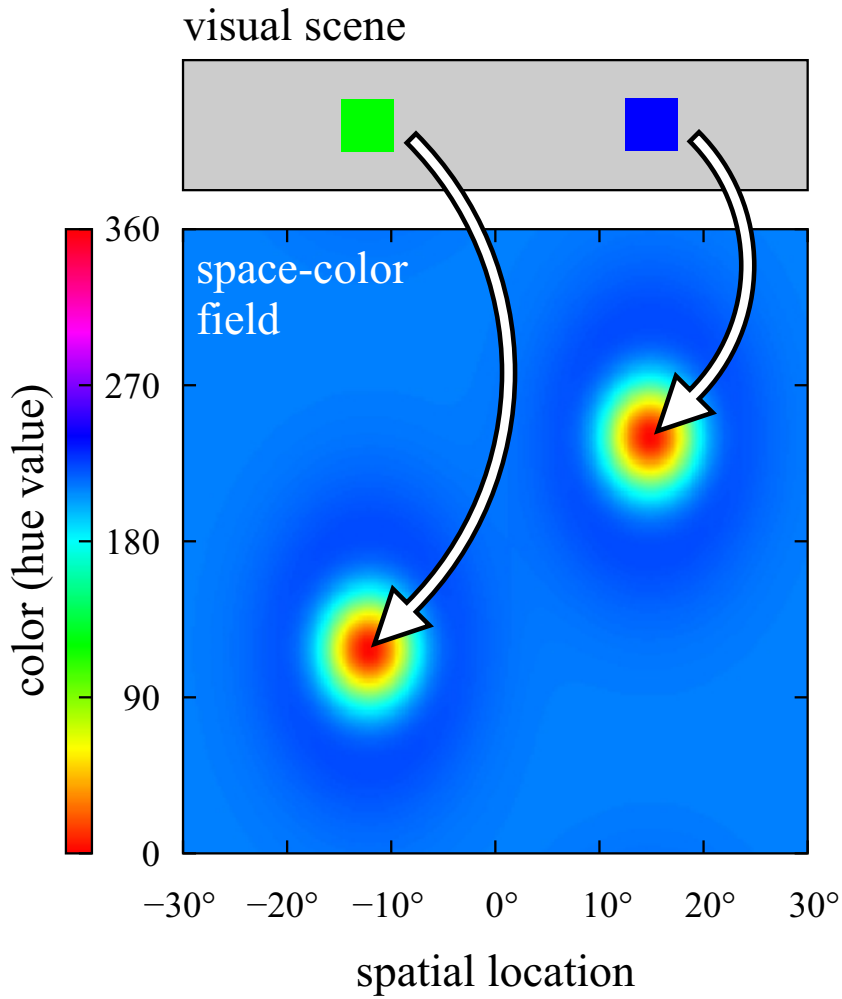
- for example, 2D retinal space



[Jancke et al., 1999]

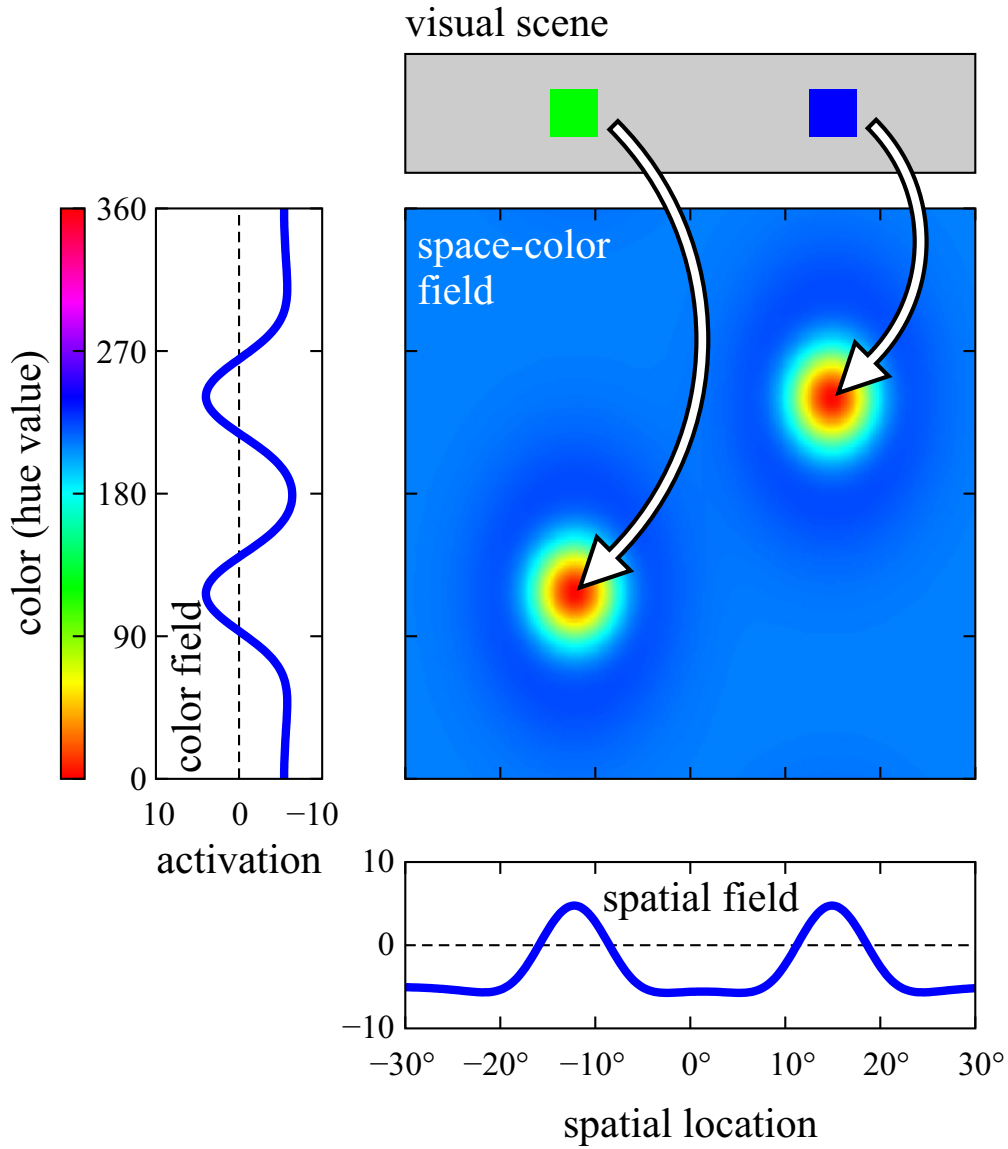
New functions become available in higher dimensional fields

- example: color-space field
  - 1D spatial location (for illustration)
  - 1D color dimension (hue)
- visual input: 2D
- => 2D peaks



[Slides adapted from Sebastian Schneegans,
see Schneegans, Lins, Spencer, Chapter 5 of Dynamic Field Theory-A Primer, OUP, 2015]

- separate fields for 1D spatial location
- and 1D color dimension (hue)
- => combined (bound) vs. separate representations



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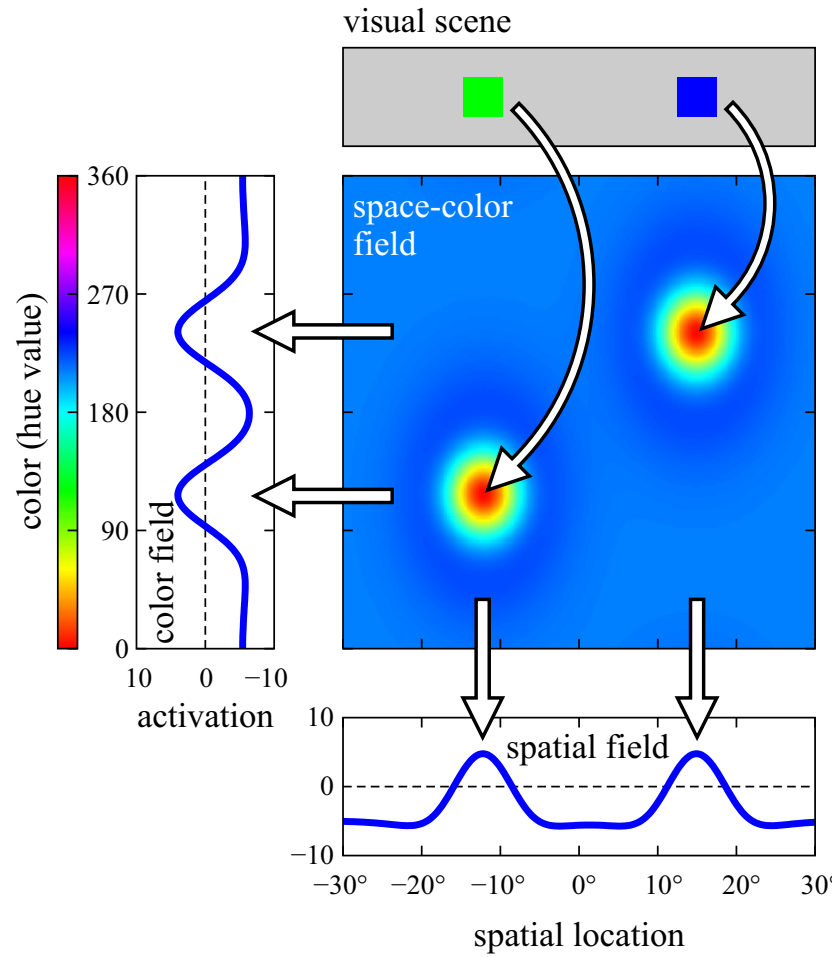
From 2D to 1D: projection

- summing along the other dimension (marginalization)
- or taking the (soft)max



[Slides adapted from Sebastian Schneegans,
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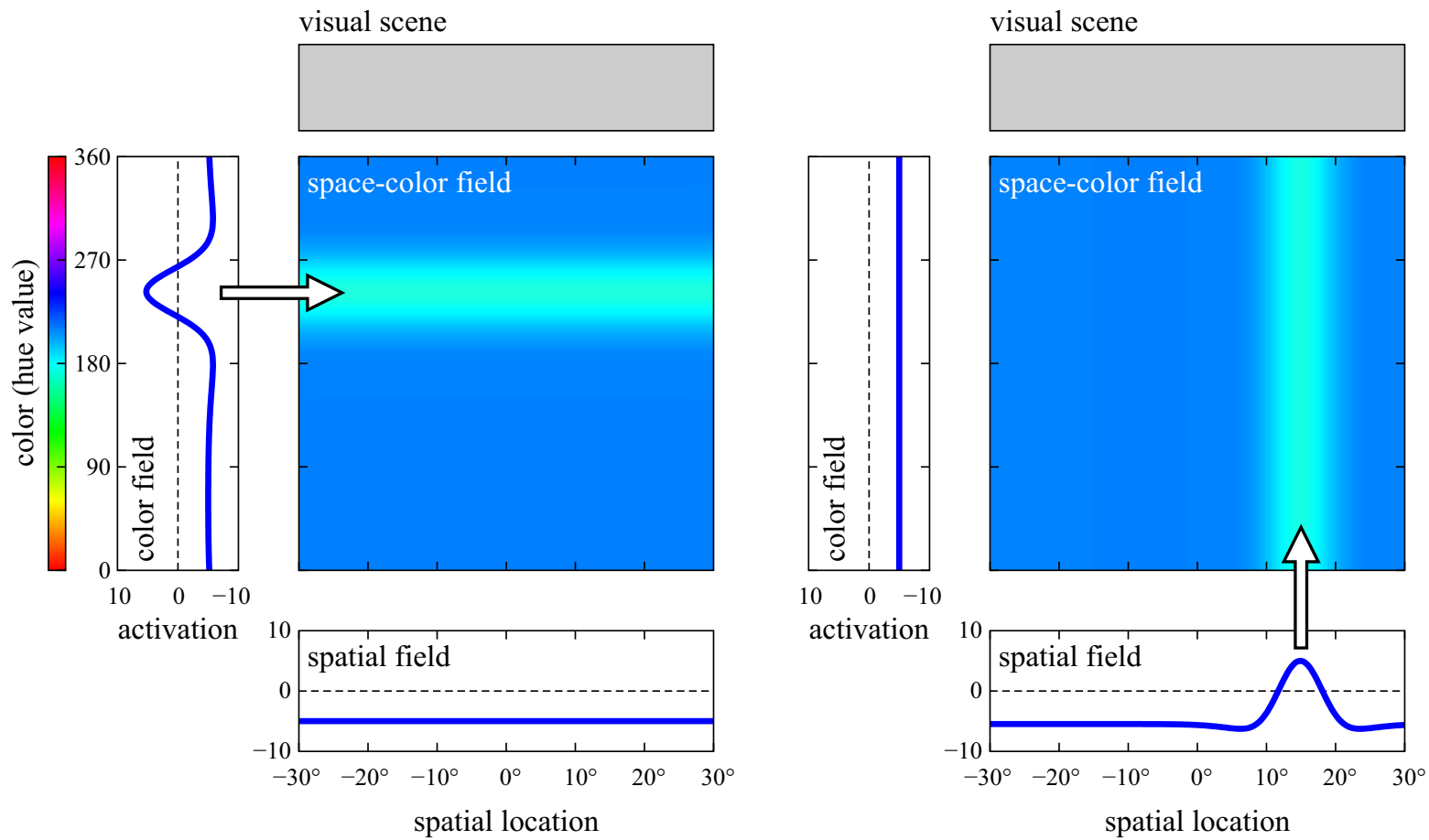
from 1D to 2D: ridges

- ridge localized along one dimension, constant along the other dimension



[Slides adapted from Sebastian Schneegans,
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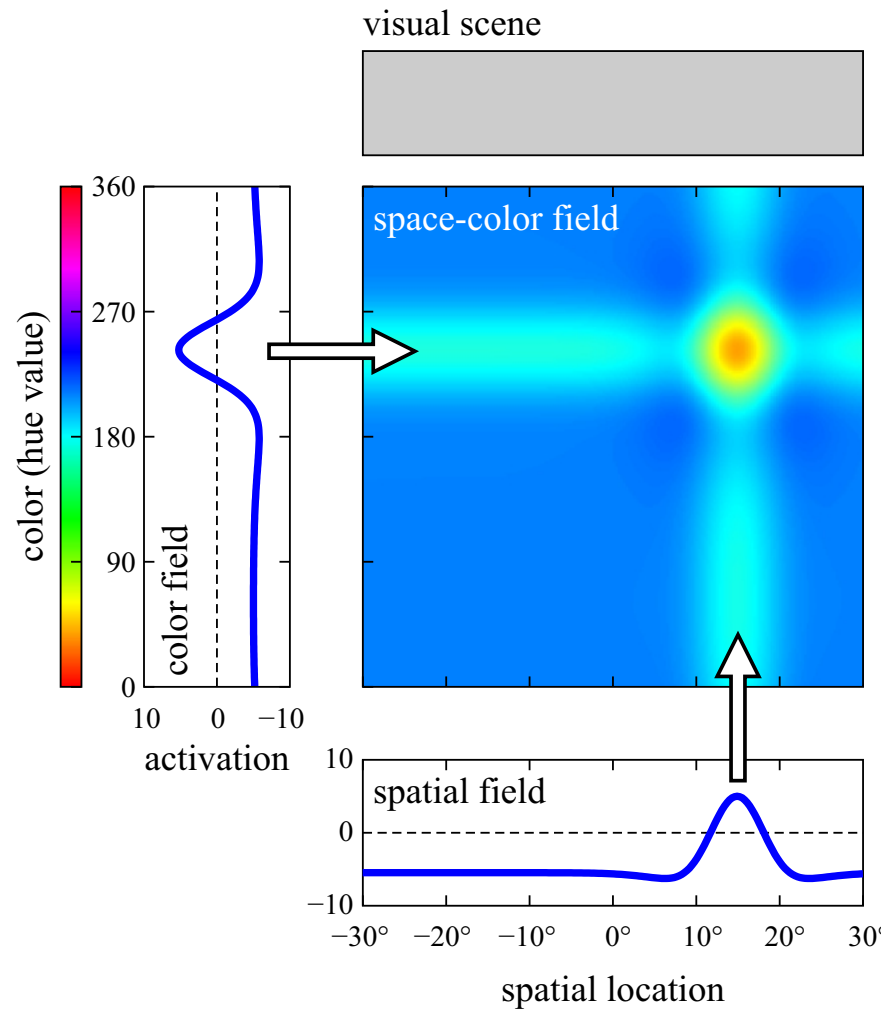
from 1D to 2D: ridges

- peaks at intersections of ridges: bind two dimensions



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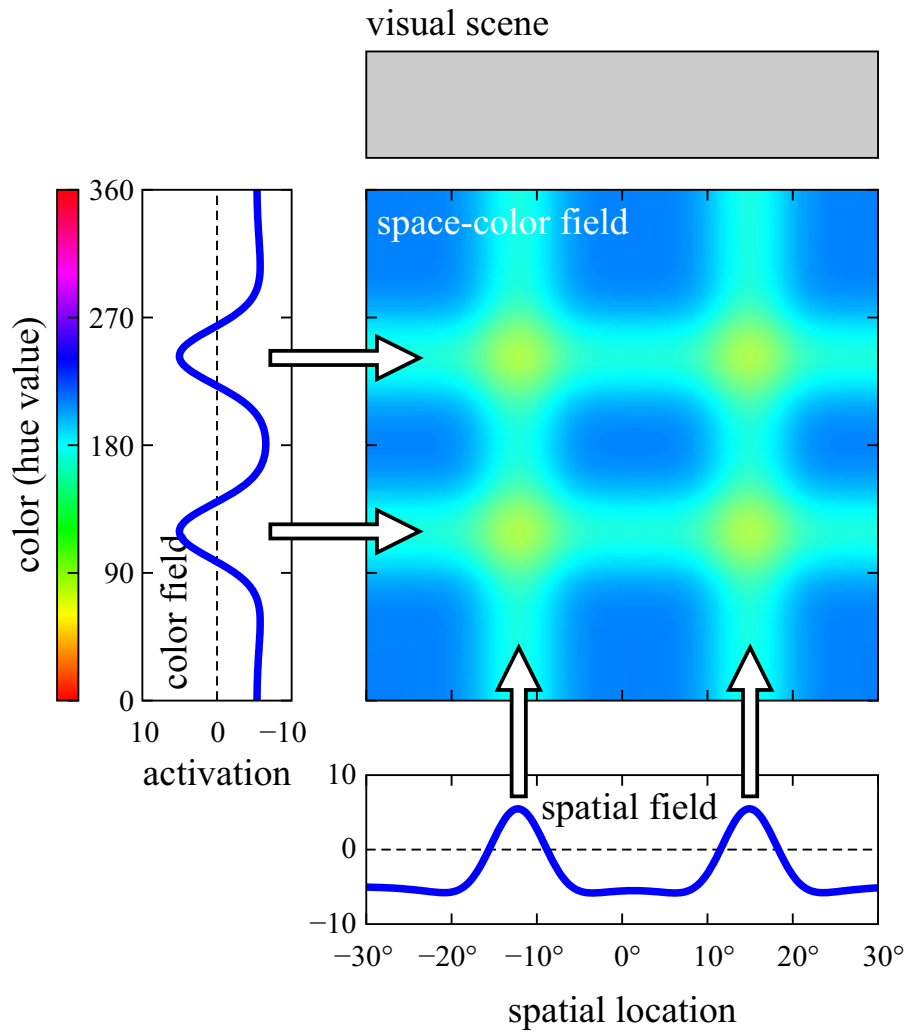
feature-binding

- multiple ridges lead to binding problem = correspondence problem



[Slides adapted from Sebastian Schneegans,
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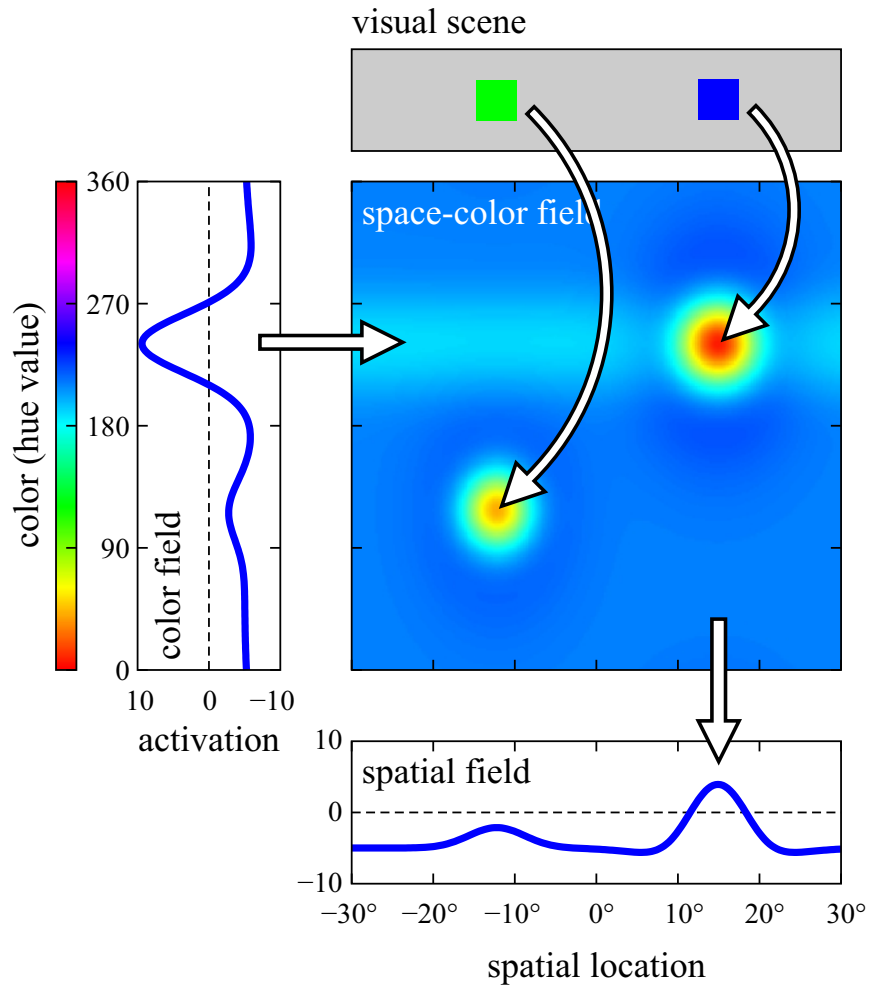
visual search

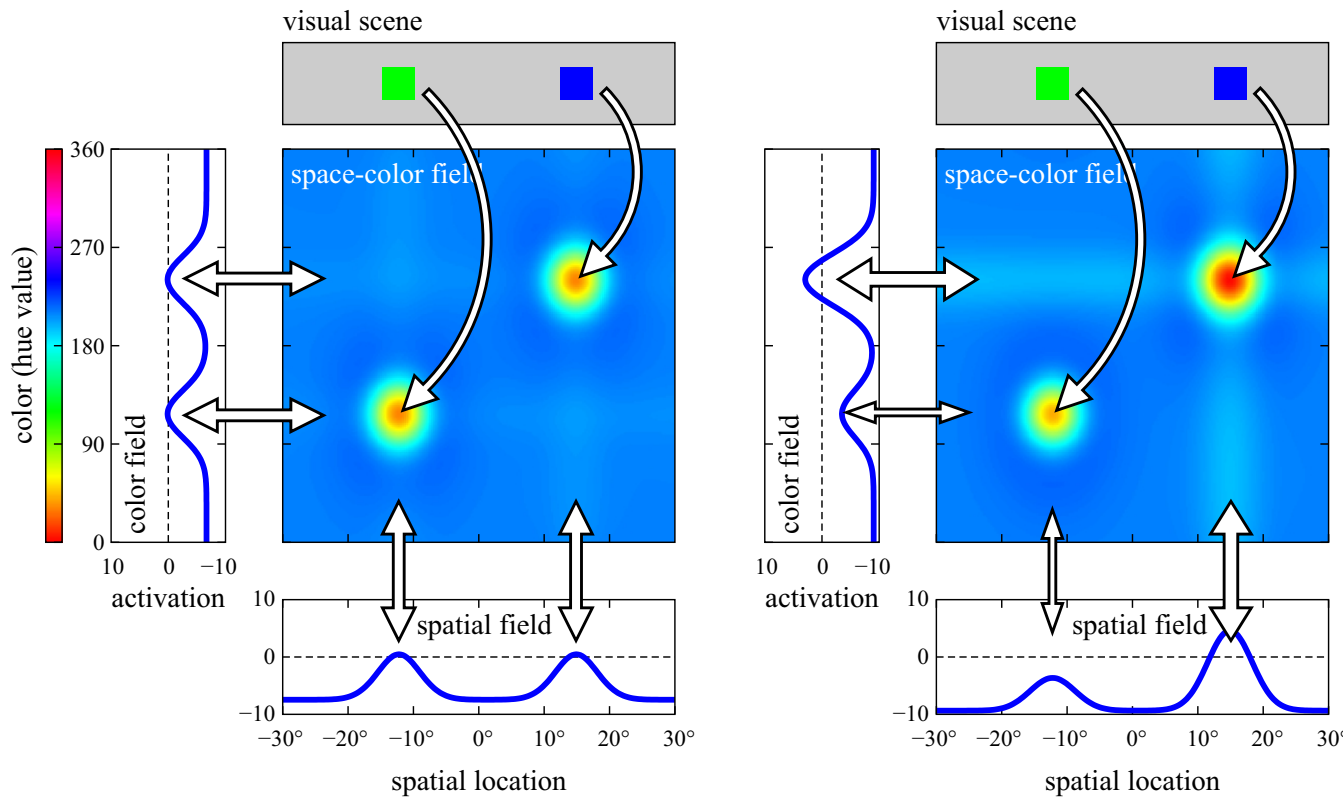
- combine ridge input with 2D input..



[Slides adapted from Sebastian Schneegans,
see Schneegans, Lins, Spencer, Chapter 5 of Dynamic Field Theory-A Primer, OUP, 2015]

Example: Color-Space field

- joint selection in 2 1D fields, that are coupled across 2D field



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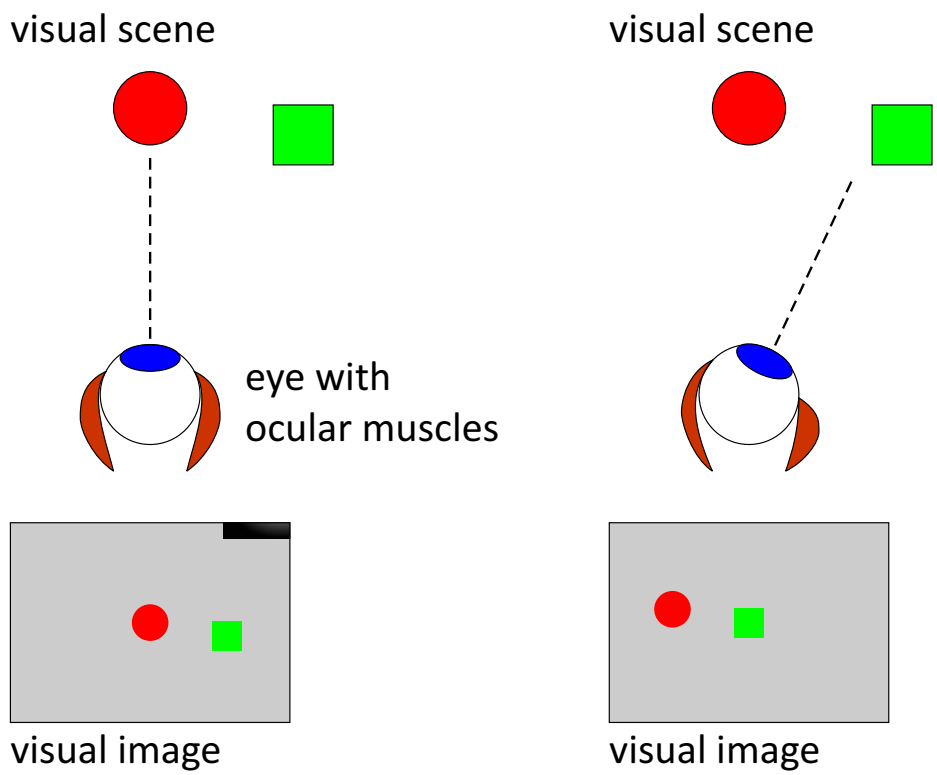
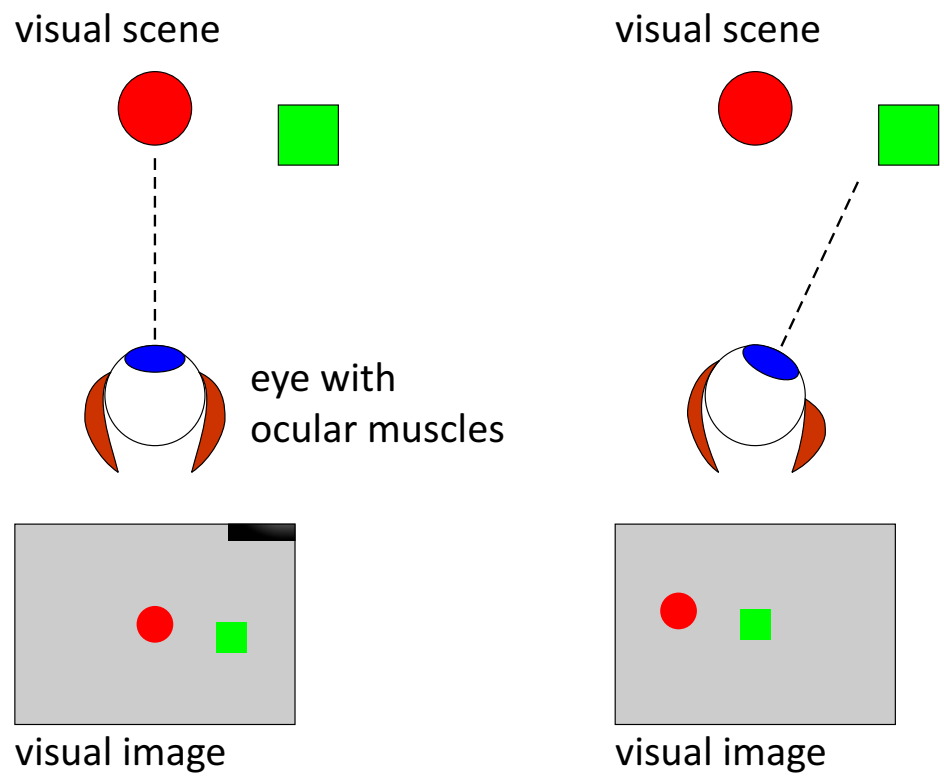
Coordinate transformations

- eye movement: visual target from retinal representation to head-centered representation for reaching



[Slides adapted from Sebastian Schneegans,
see Schneegans, Chapter 7 of Dynamic Field Theory-A Primer, OUP, 2015]

- every gaze shift changes the spatial reference frame of the visual perception
- how to memorize locations when the reference frame keeps shifting?
- => transformation to gaze-invariant reference frame



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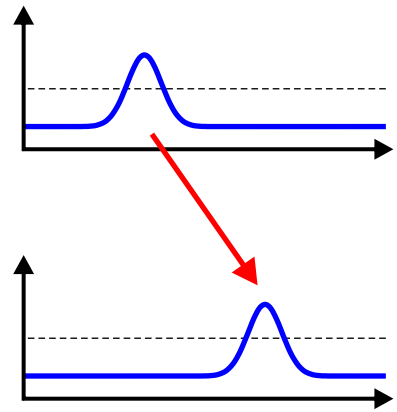
coordinate transformations

- need mapping between different reference frame: retinocentric (moving with the eye) to body-centered (gaze-invariant)
- mapping is a variable shift, depends on current gaze direction
- as a formula x body = x retinal + x gaze
- but how to implement this in DNFs, using space code representations?

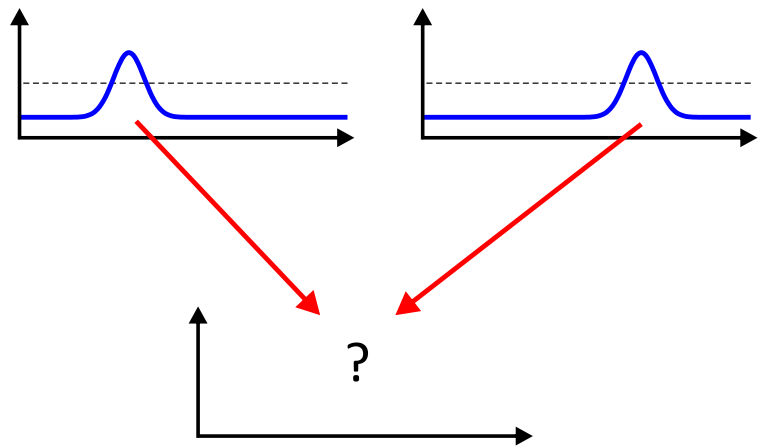
[Slides adapted from Sebastian Schneegans,
see Schneegans, Chapter 7 of Dynamic Field Theory-A Primer, OUP, 2015]

coordinate transformations

- fixed mapping: neural projection in a neural network



- steerable mapping that depends on gaze/eye position: that's the challenge



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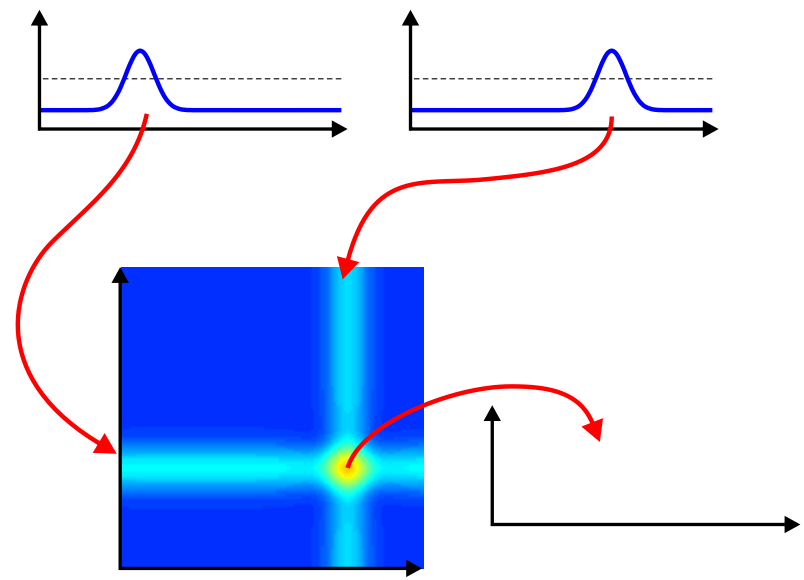
coordinate transformations

- expand into a 2D field
- free output connectivity to implement any mapping



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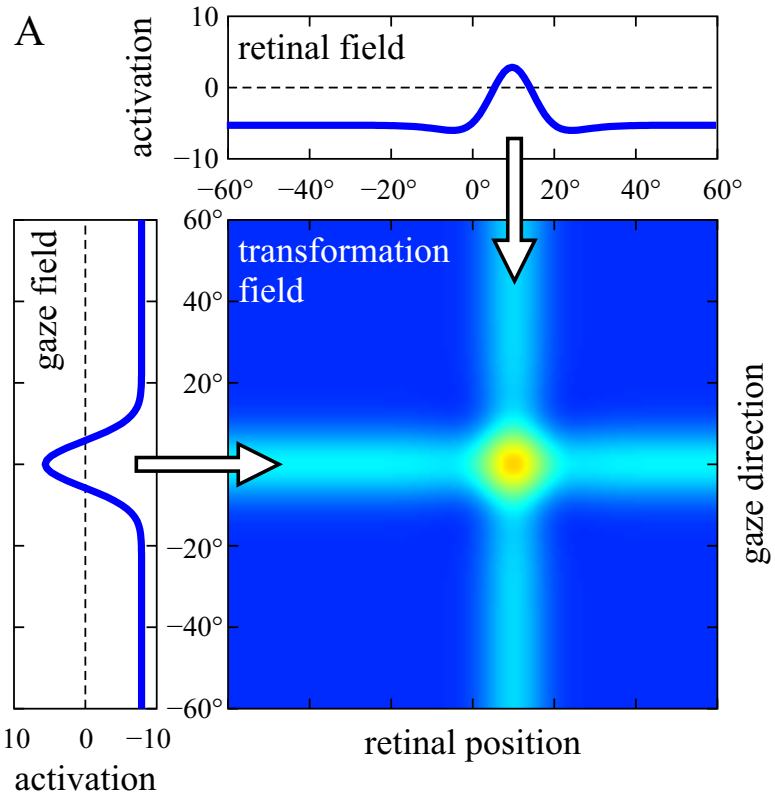
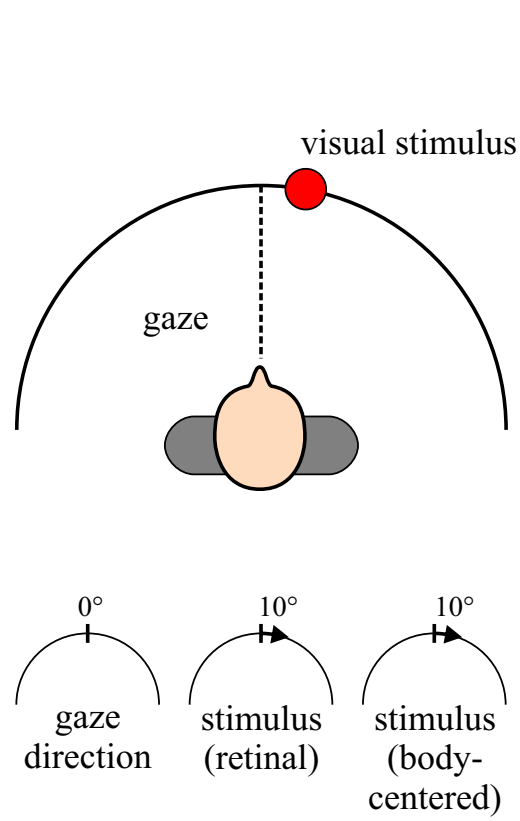
coordinate transformations





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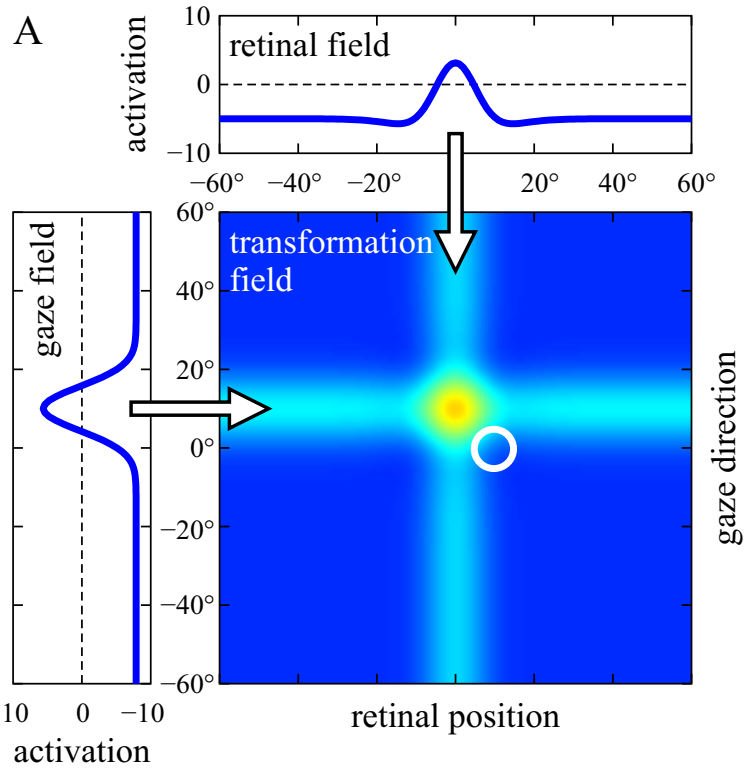
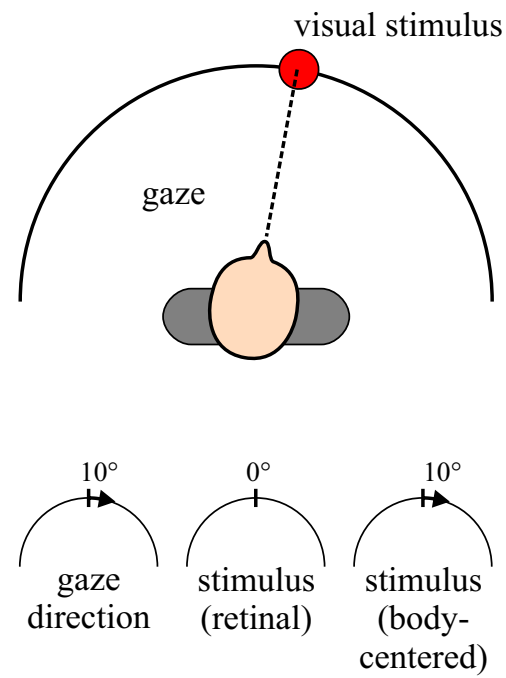
coordinate transformations





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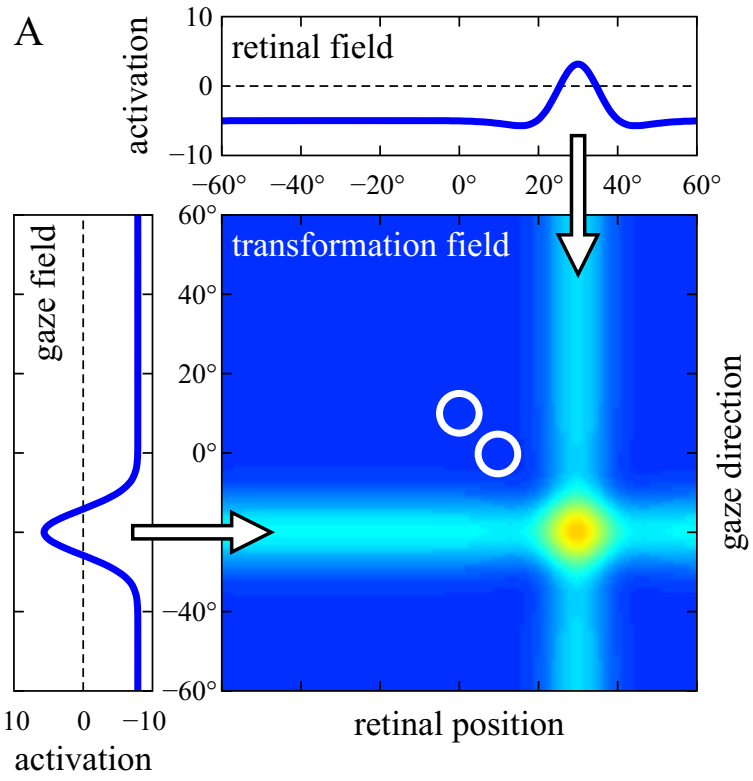
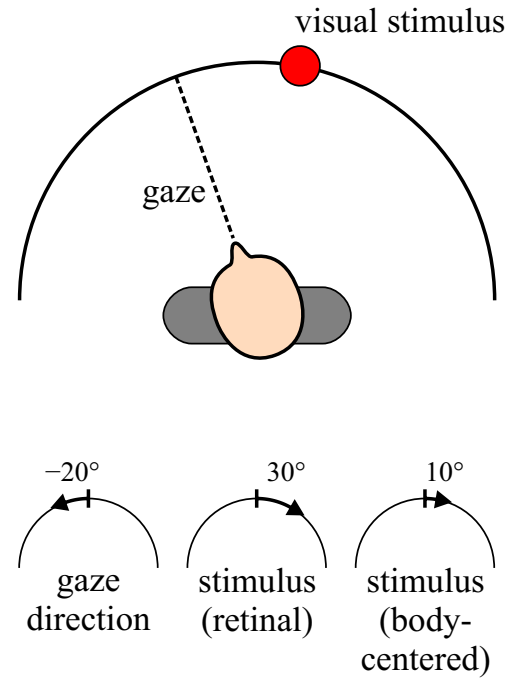
coordinate transformations





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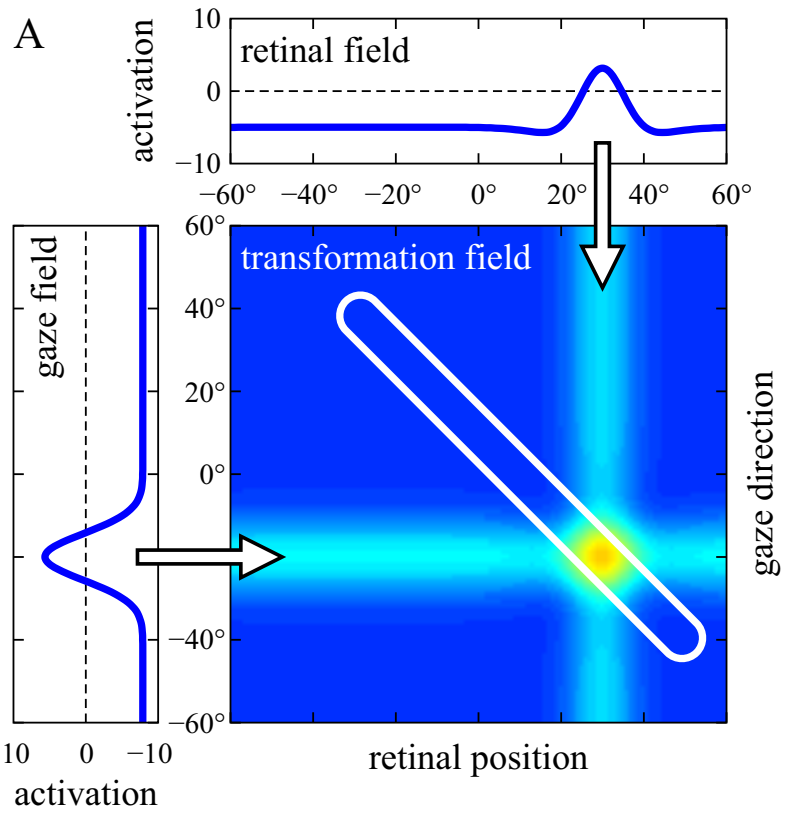
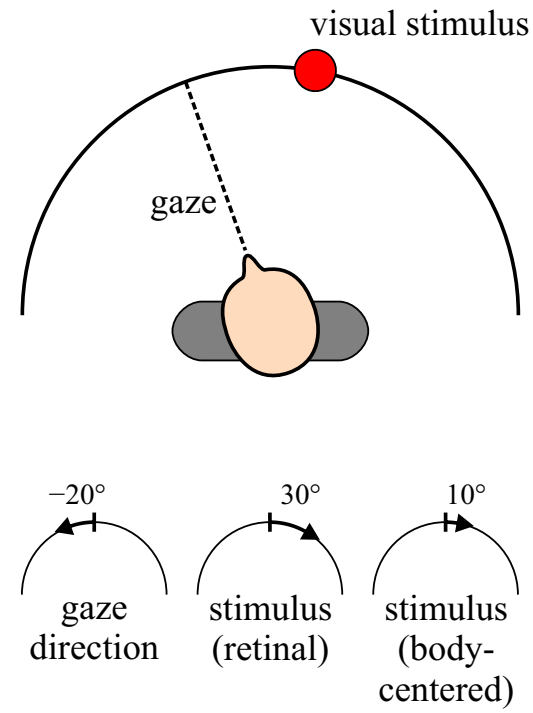
coordinate transformations





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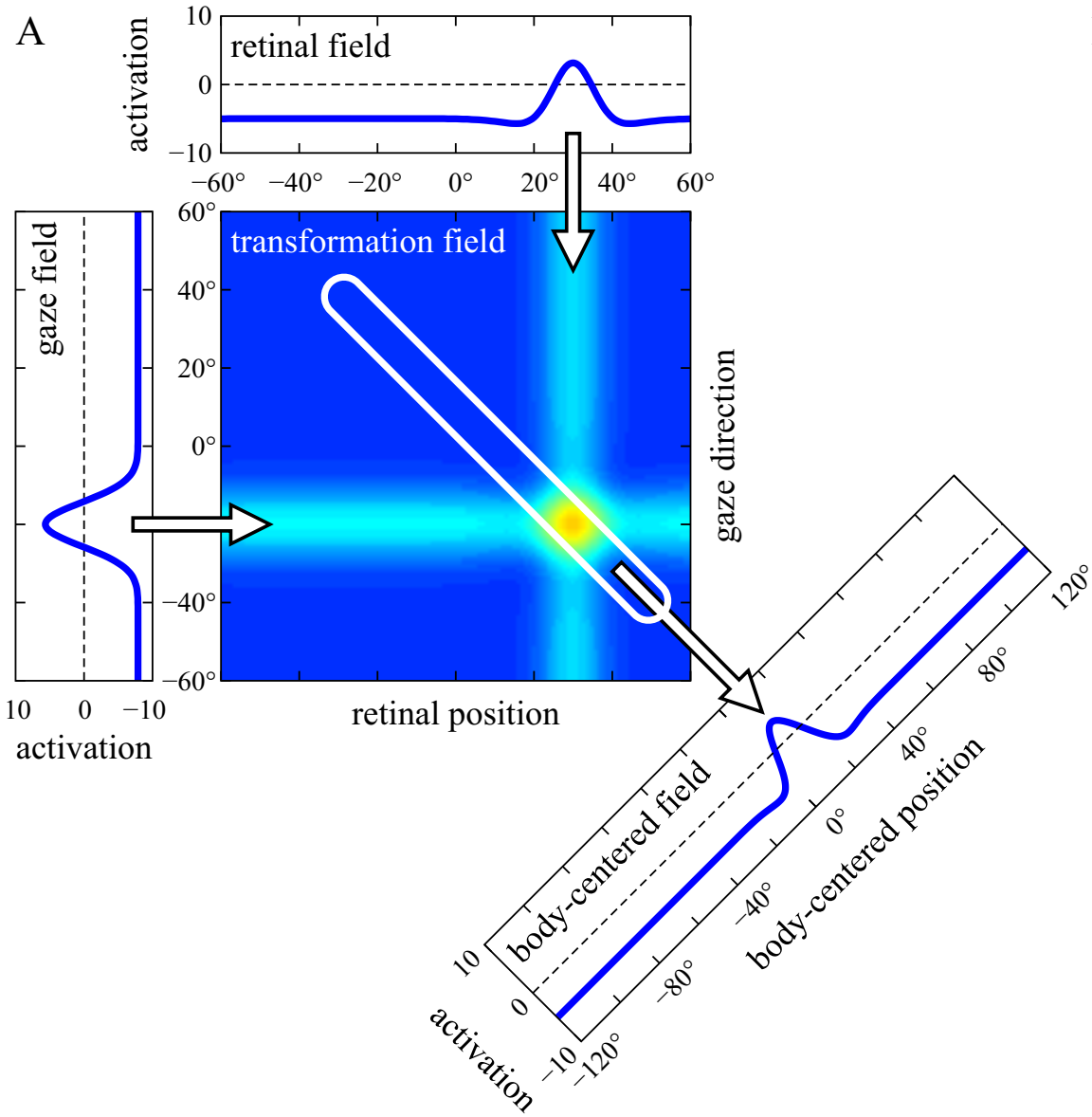
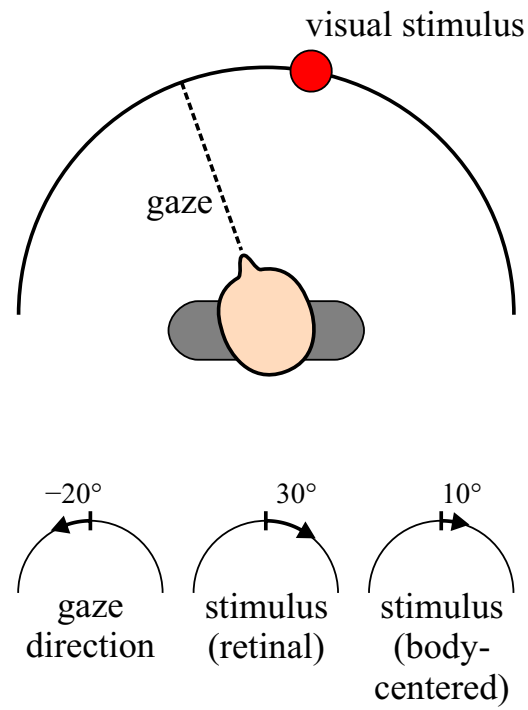
coordinate transformations





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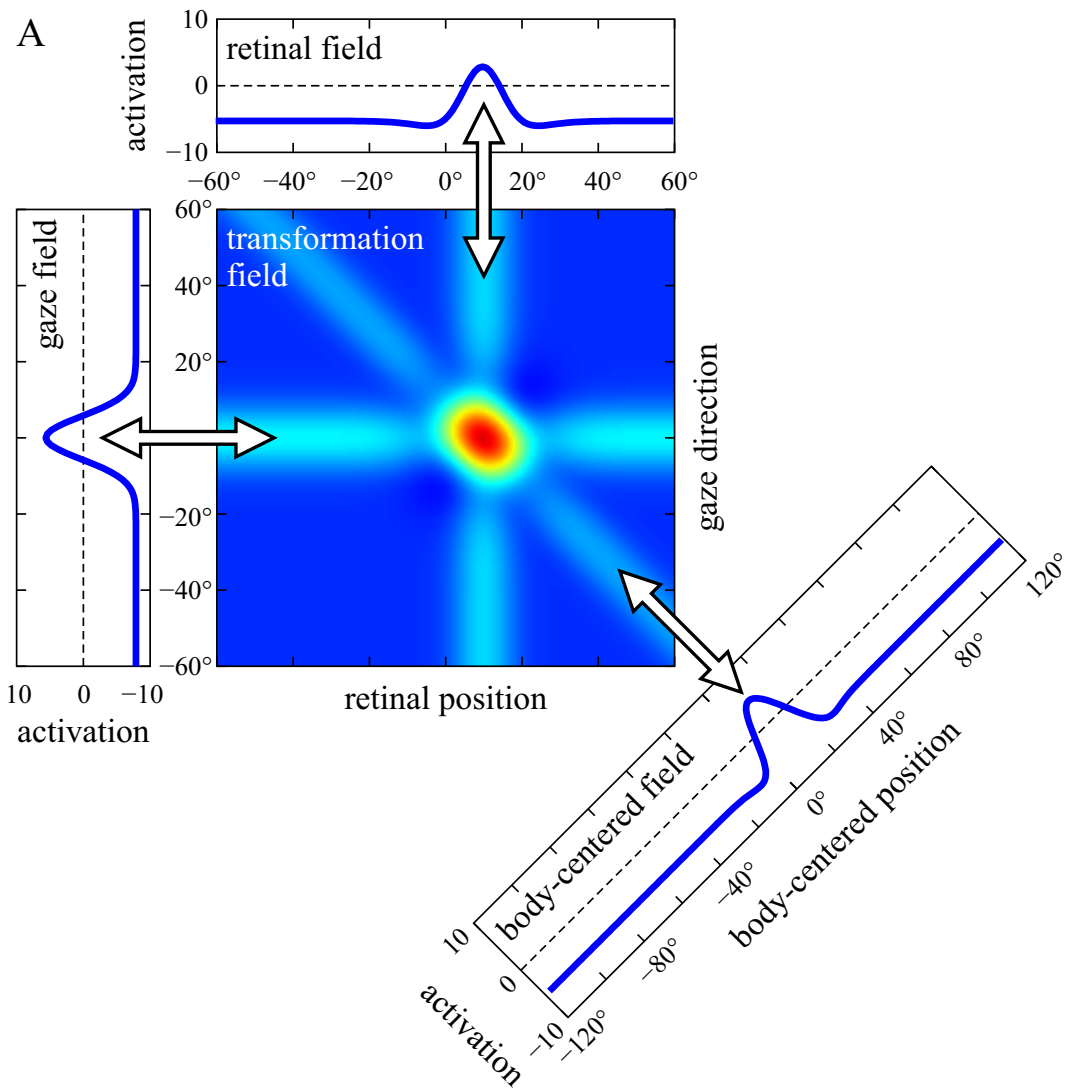
coordinate transformations

- bi-directional coupling: reversing the transformations



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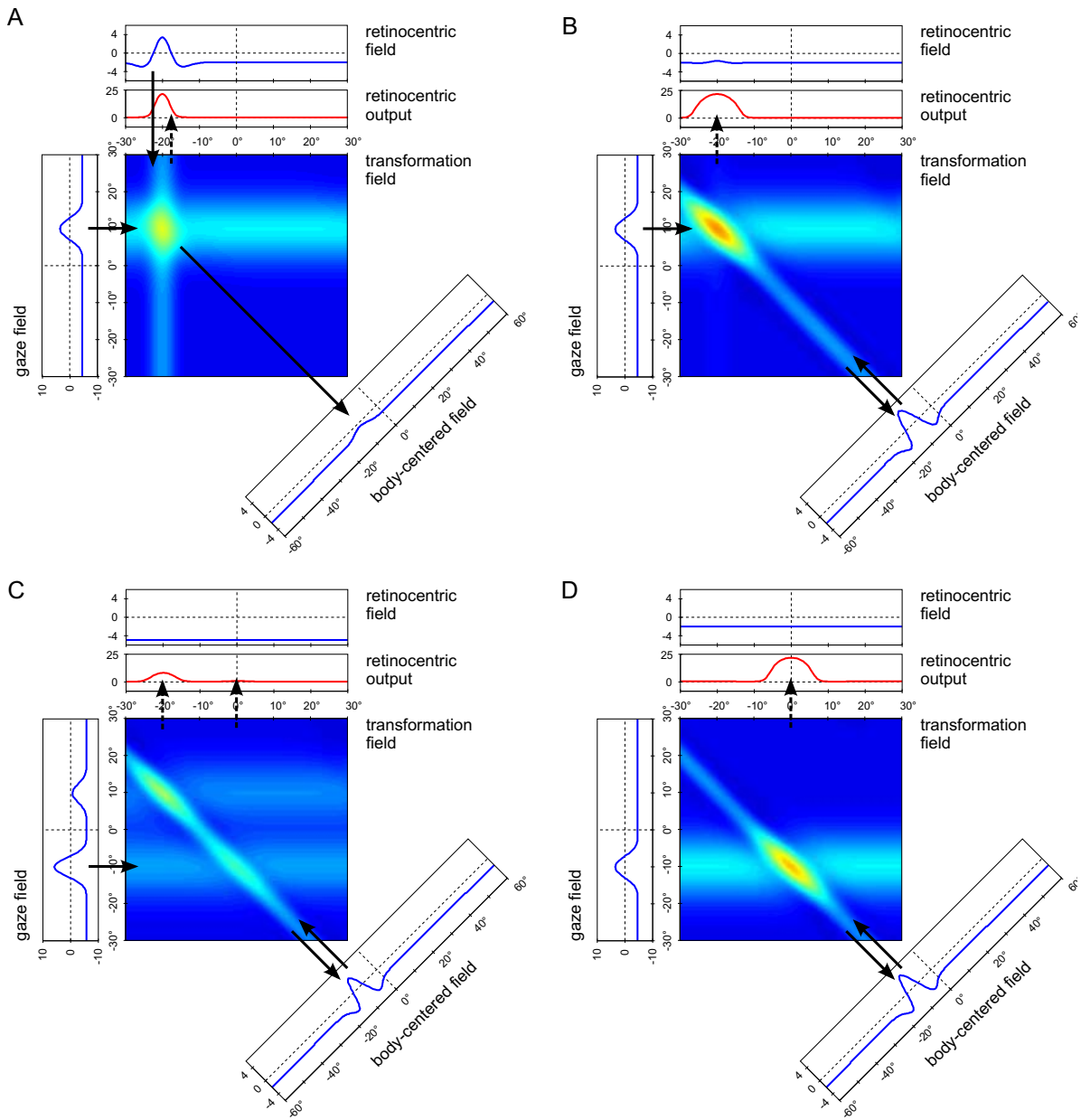
spatial remapping during saccades



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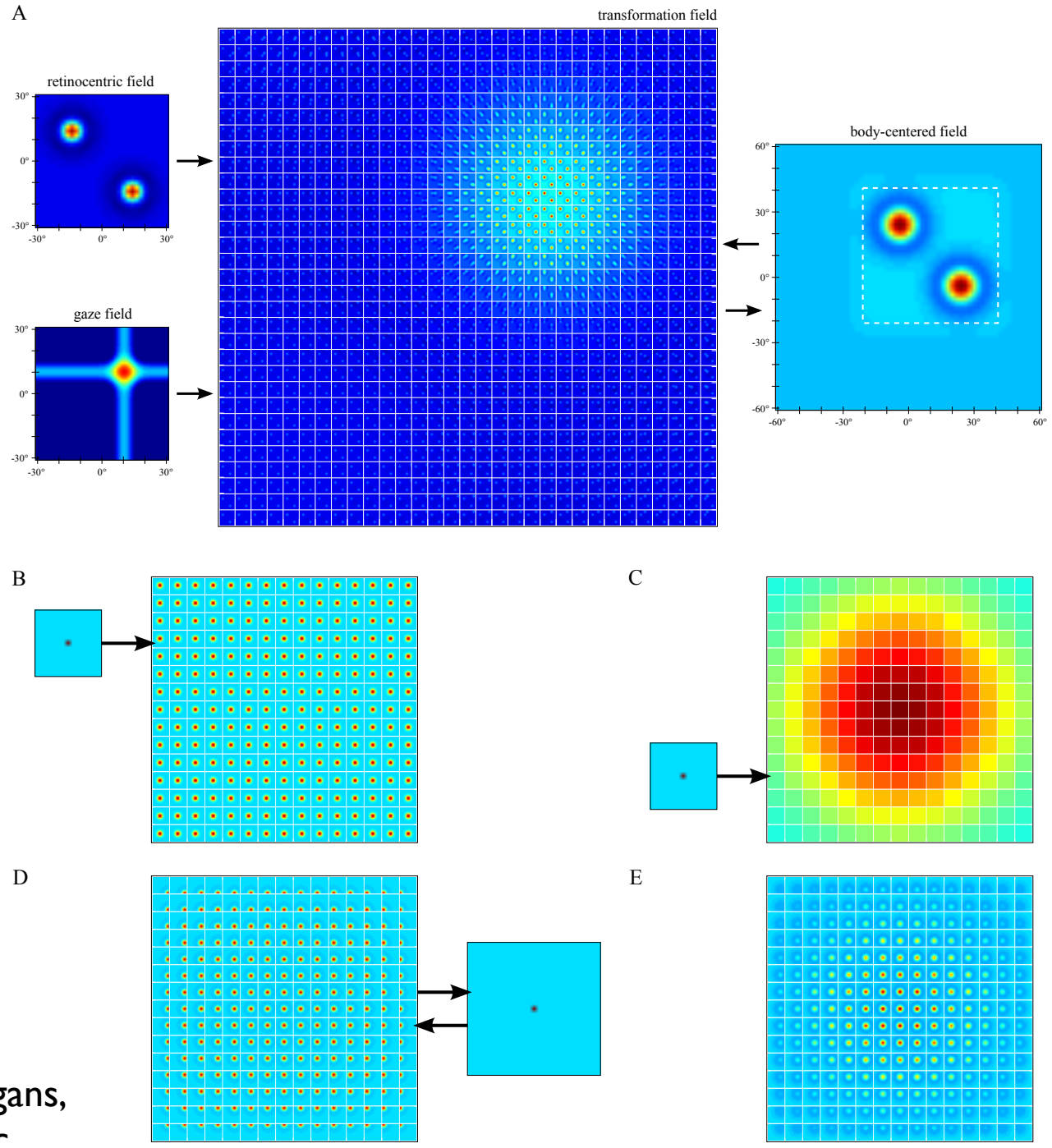
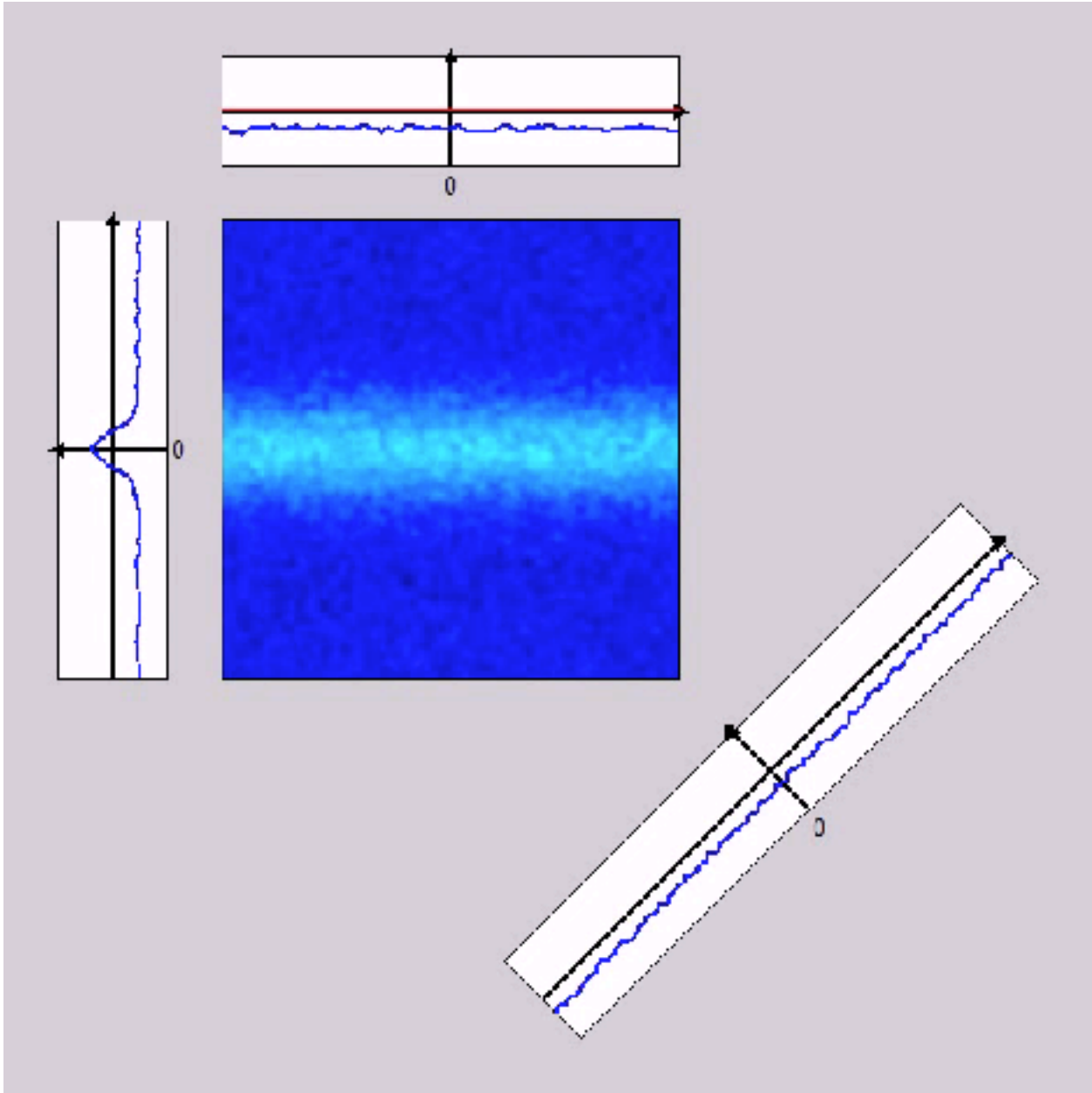


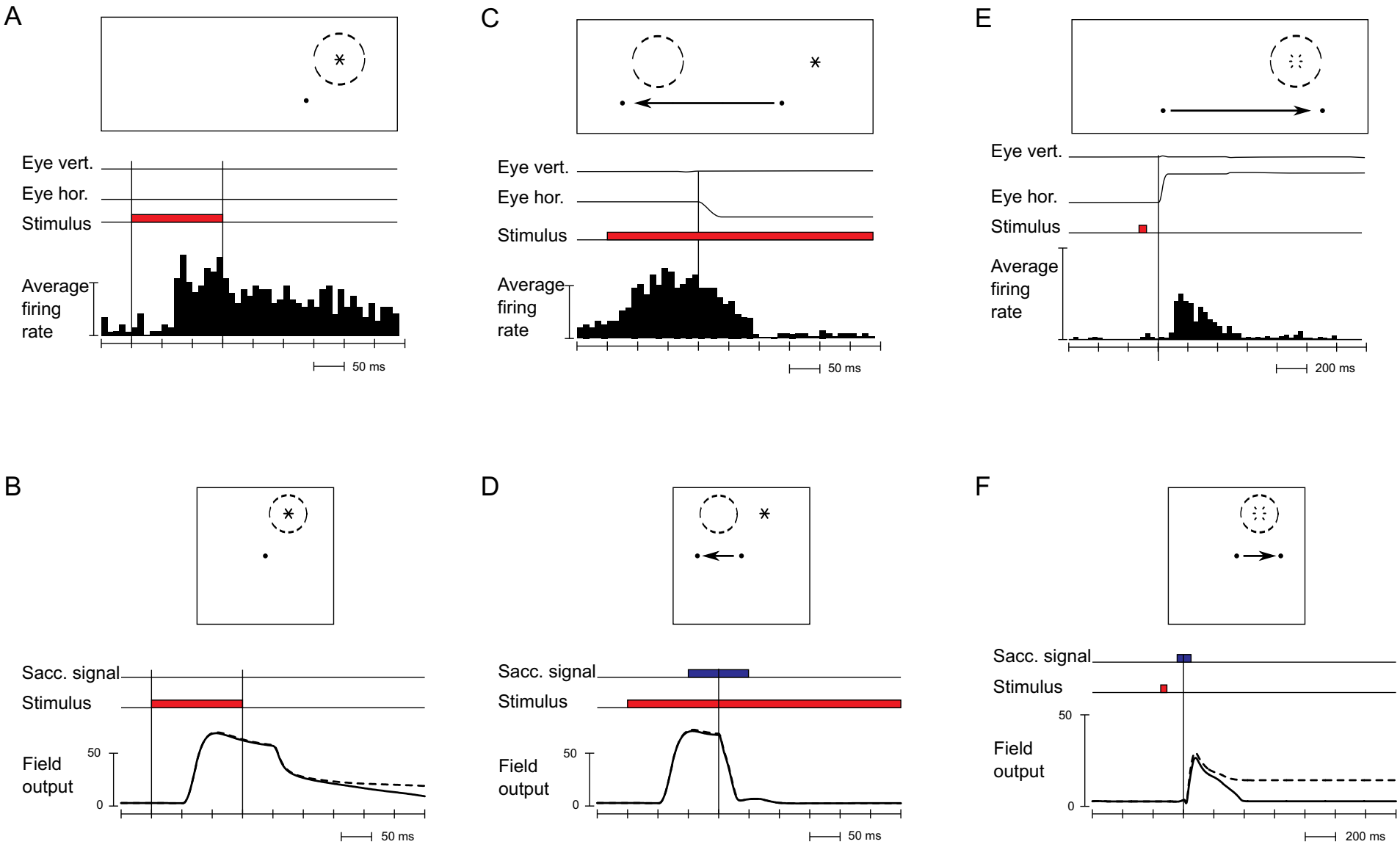
[Slides adapted from Sebastian Schneegans, see Schneegans, Chapter 7 of Dynamic Field Theory-A Primer, OUP, 2015]

Coordinate transformations

- predict retinal location following gaze shift



[Schneegans, Schöner, BC 2012]

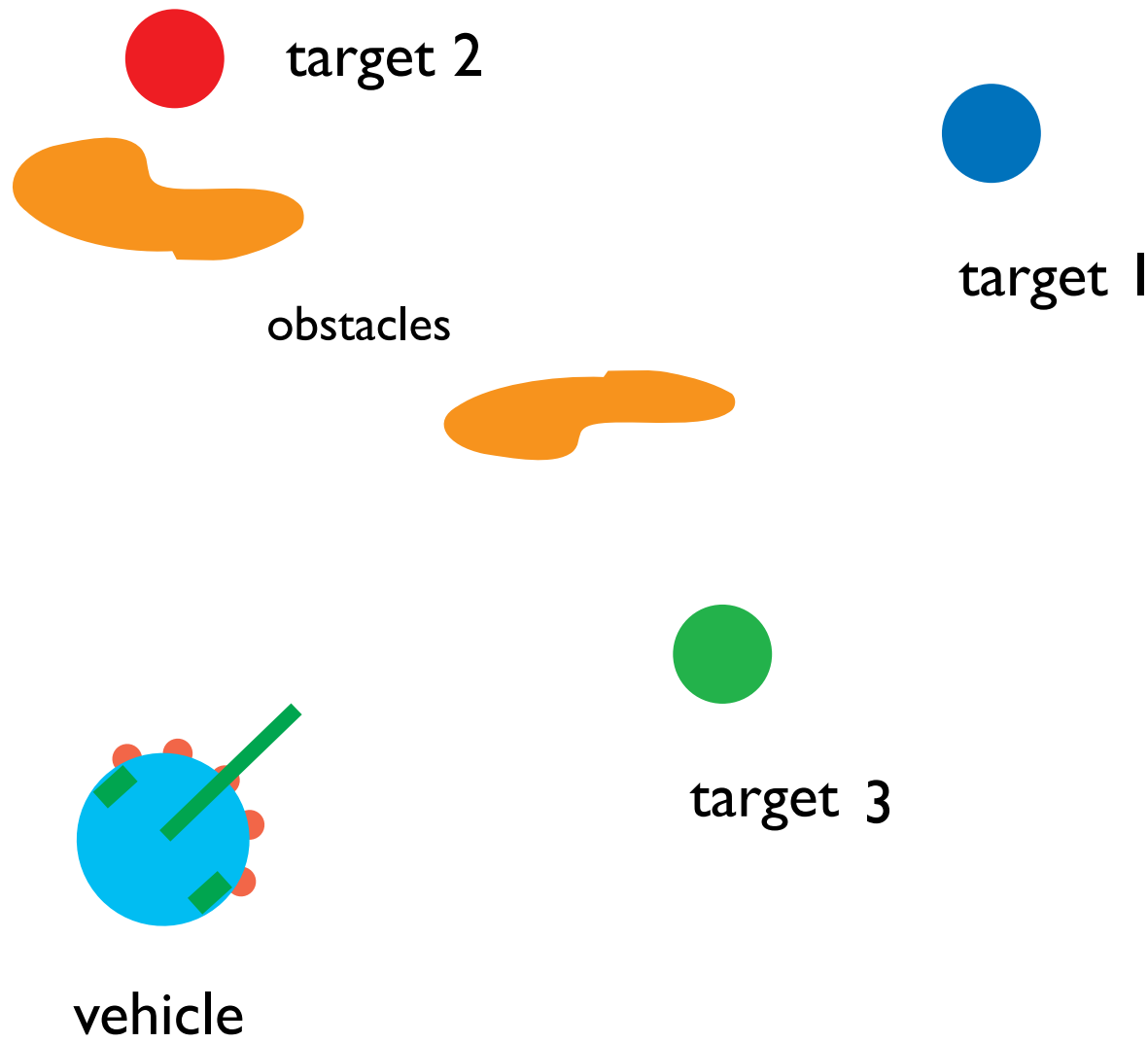


=> accounts for predictive updating of retinal representation

[Schneegans, Schöner, BC 2012]

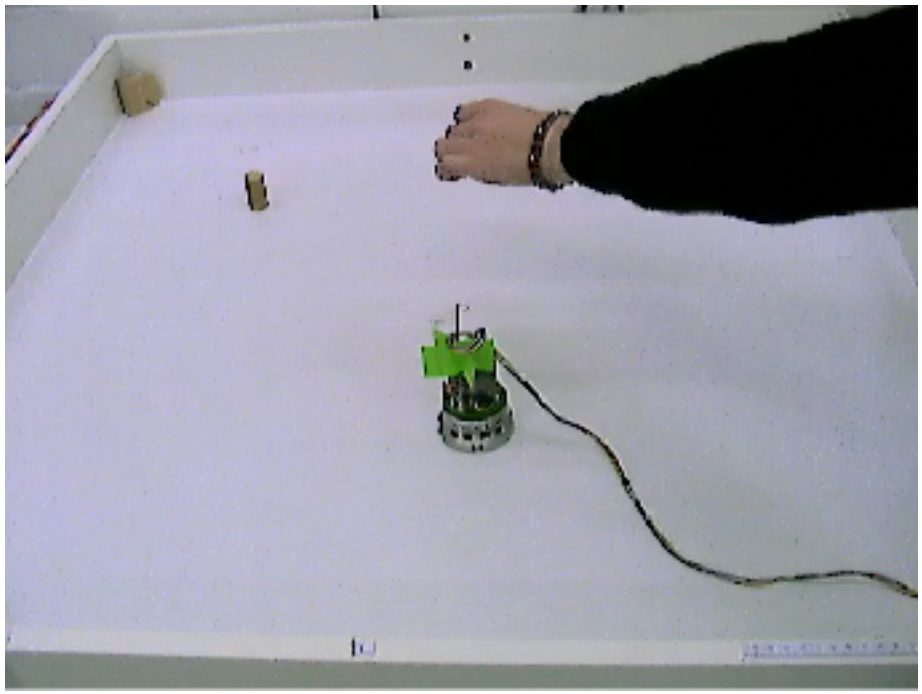
Neural dynamics of sequence generation

- Behavior and cognition consist of sequences of actions or thoughts



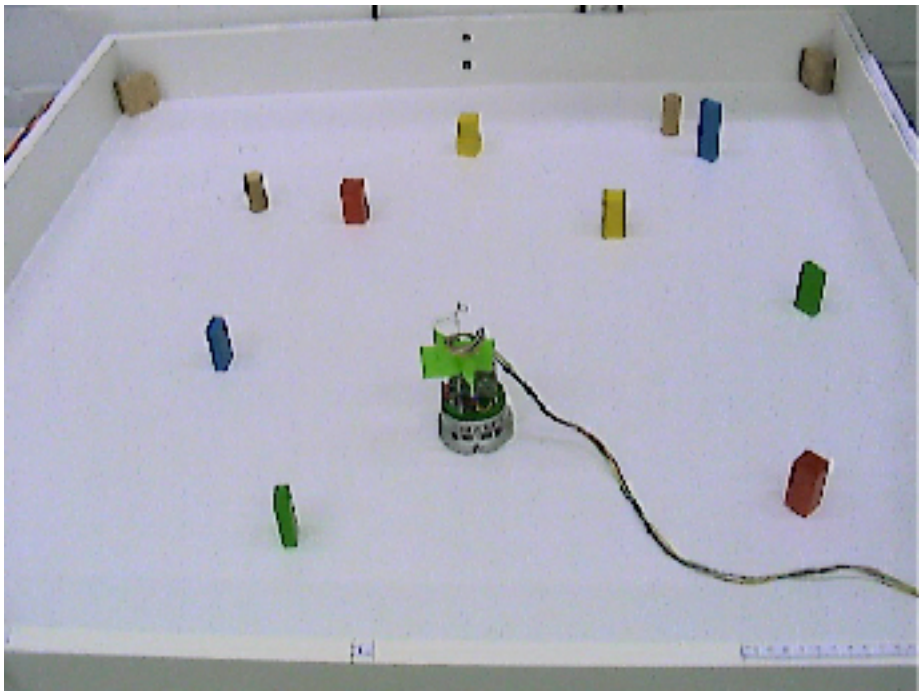
- learn a serially ordered sequence from a single demonstration

yellow-red-green-blue-red



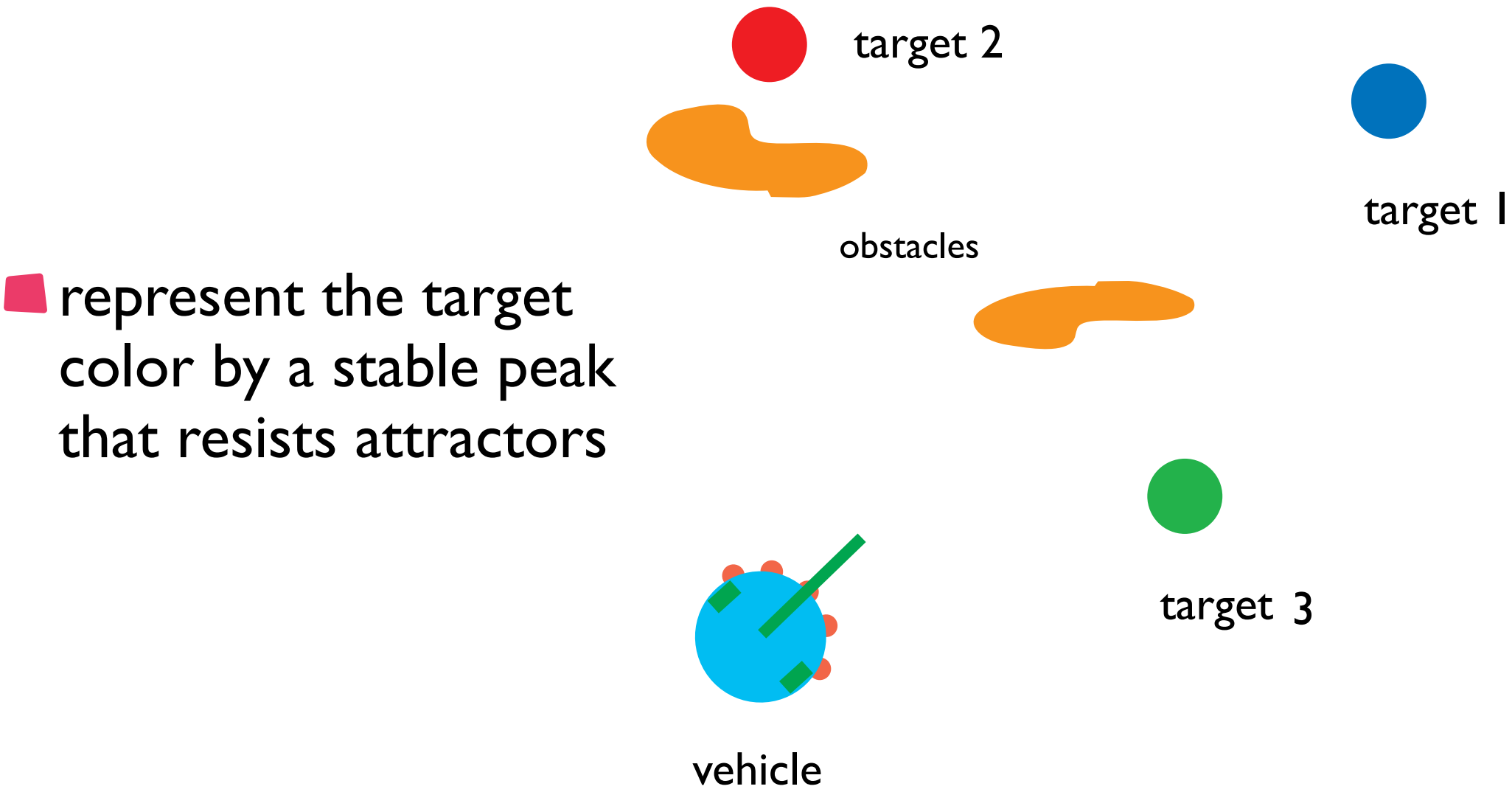
- perform a serially ordered sequence with new timing

yellow-red-green-blue-red

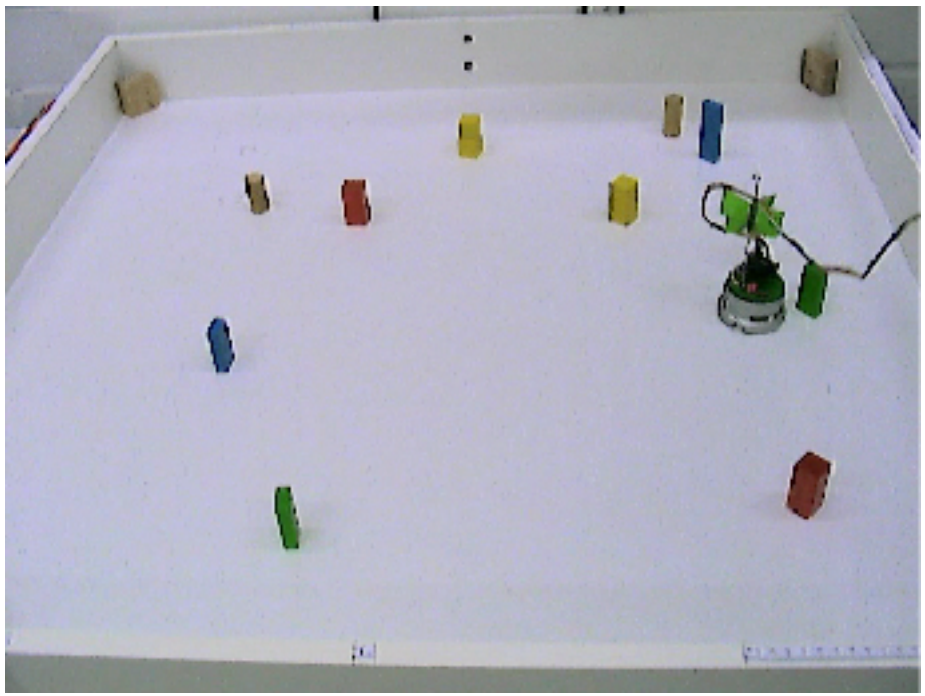


[Sandamirskaya, Schöner: Neural Networks 23:1163 (2010)]

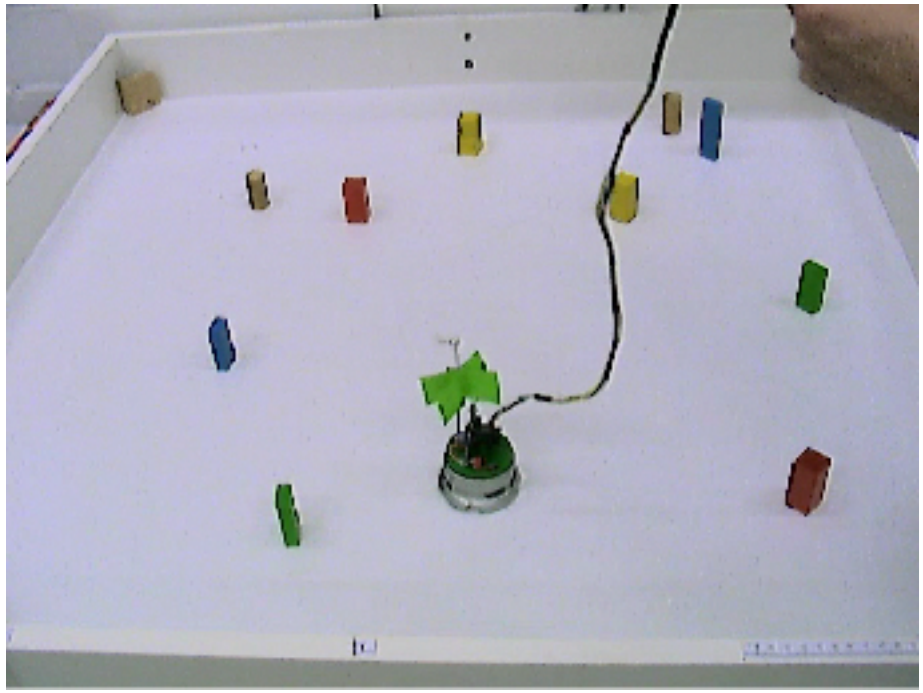
Neural dynamics of sequence generation



red a distractor



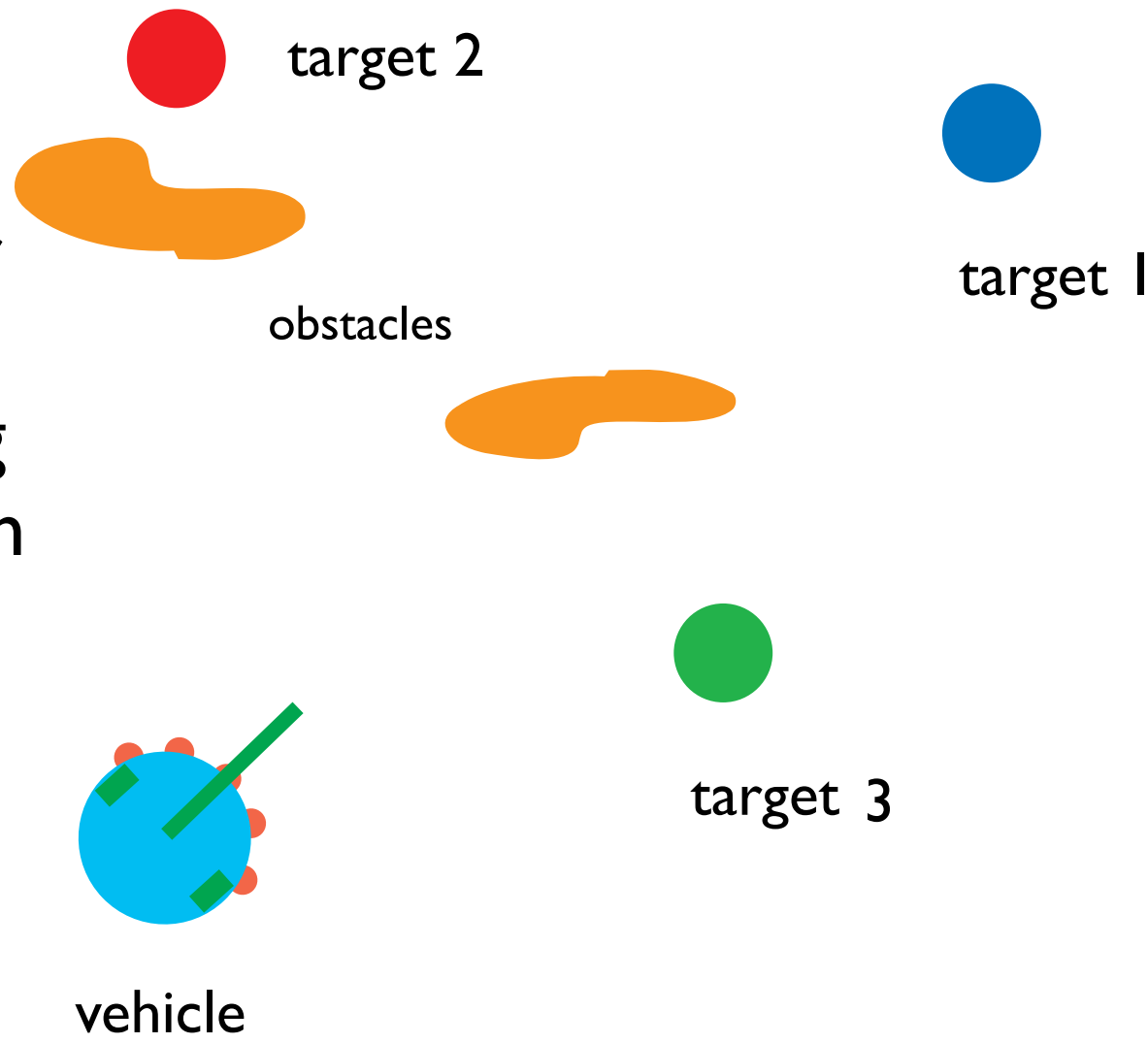
red a target



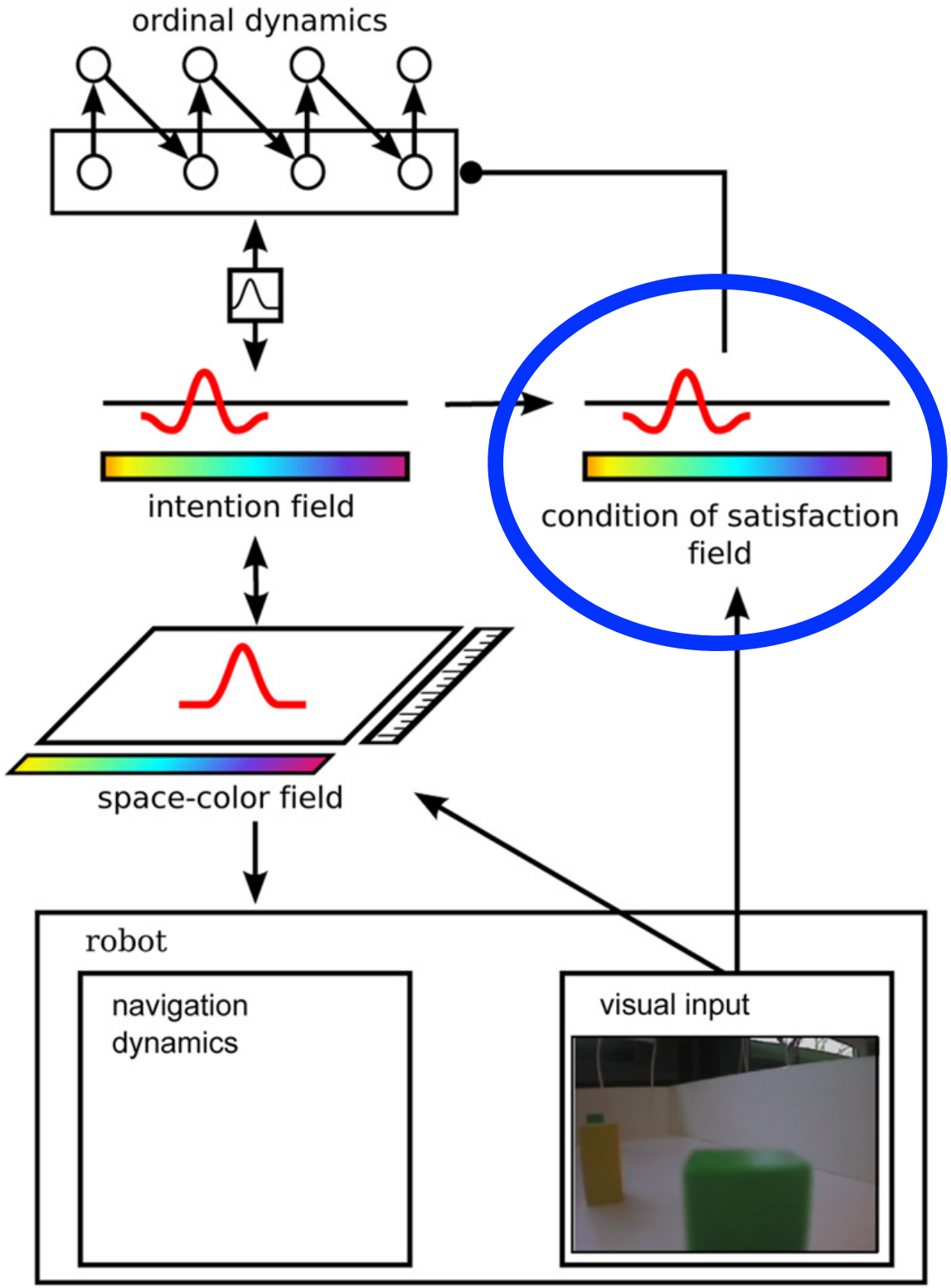
[Sandamirskaya, Schöner: Neural Networks 23:1163 (2010)]

Neural dynamics of sequence generation

- when the sought color is found, switch to the next color by releasing the previous state from stability…through an instability

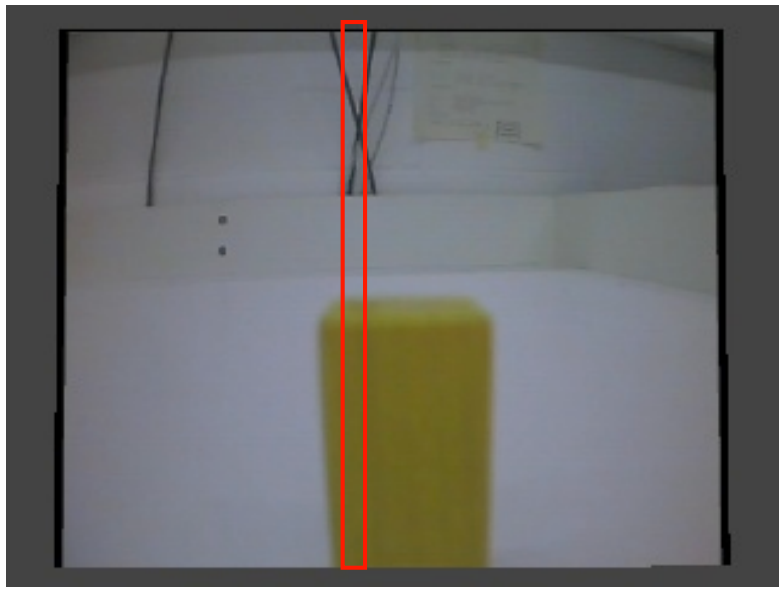


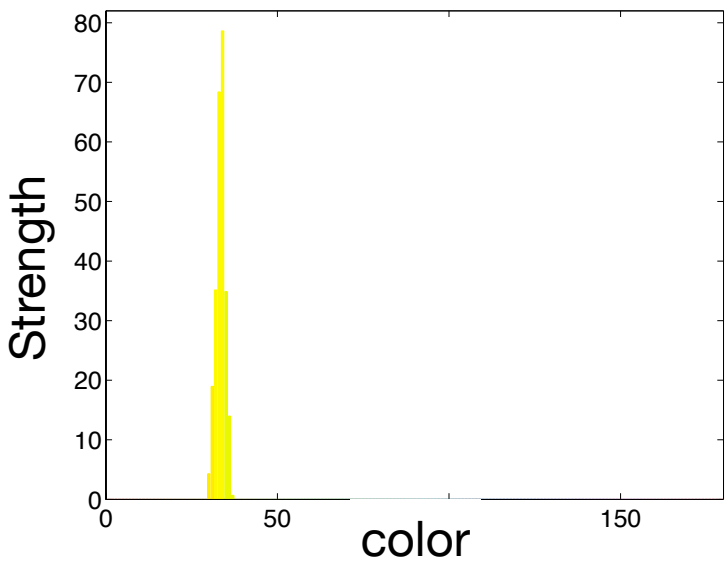
“Condition of Satisfaction” (CoS)



[Sandamirskaya, Schöner, 2010]

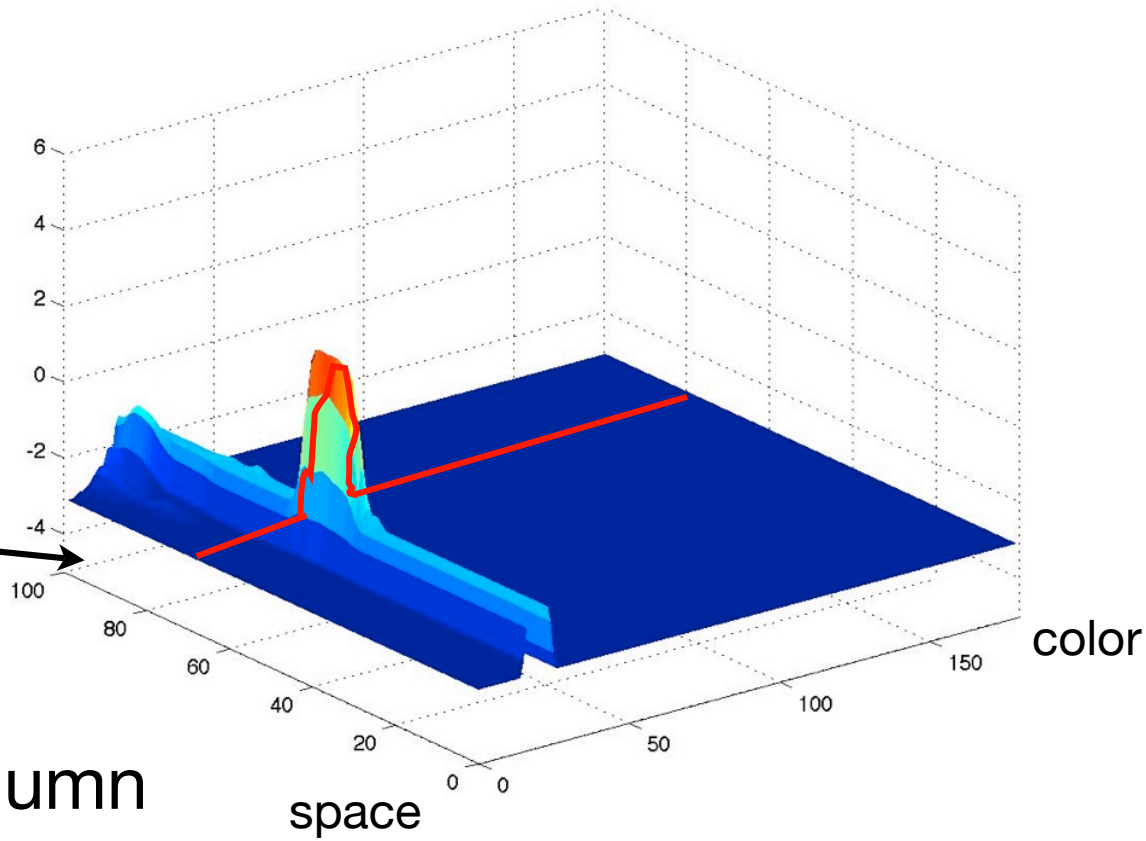
Camera image





Color histogram of the column

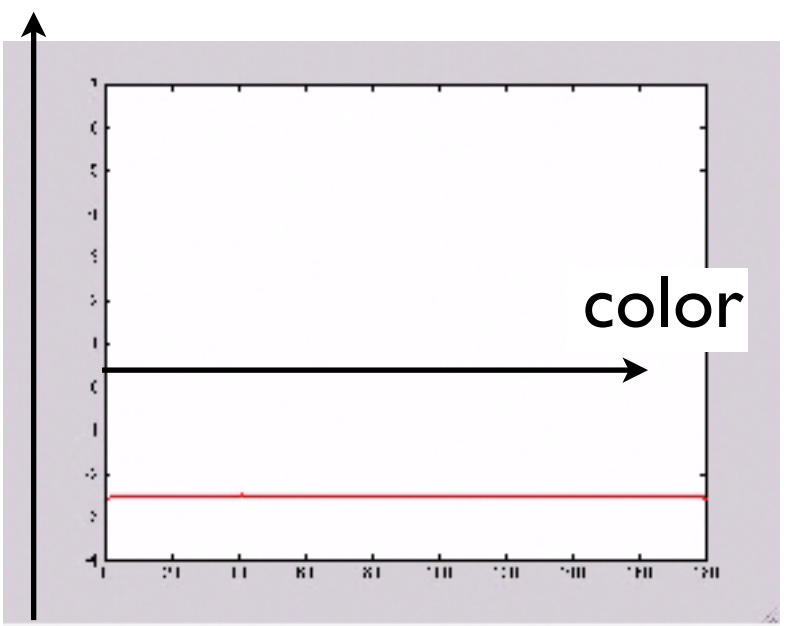
Color-space DF



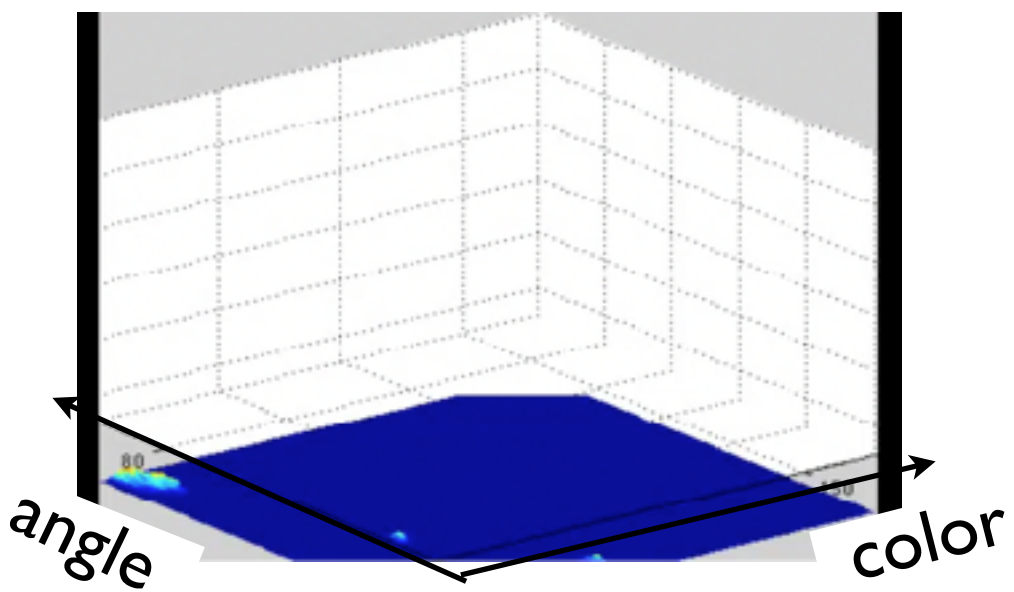
ordinal stack

condition of satisfaction (CoS)

intentional state



2D feature-space field



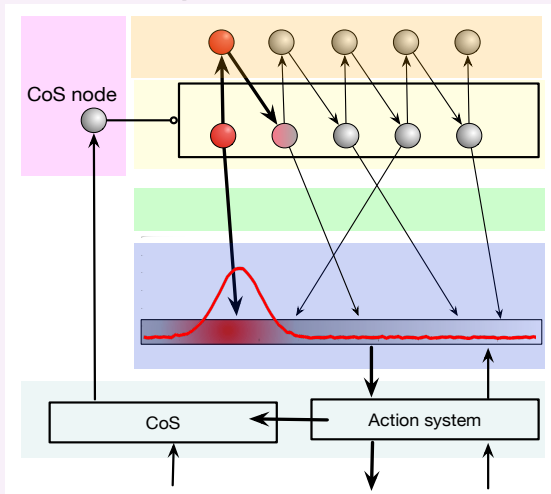
Neuromorphic implementation

- by Yulia Sandamirskaya's group at INI Zürich.
- (see also http://sandamirskaya.eu)
- this is unpublished work to date…

Sequence learning and generation in neuromorphics

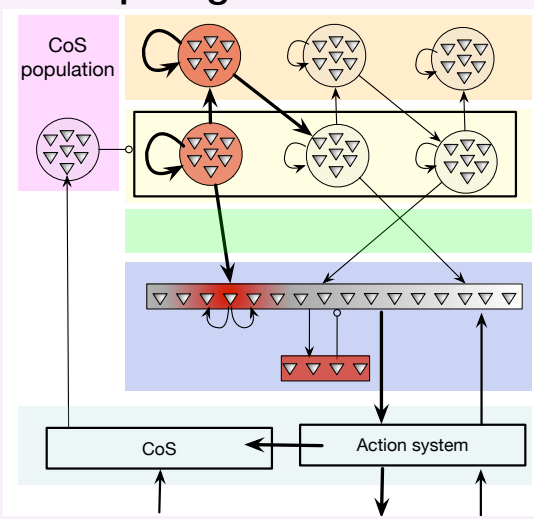
System development

Neural-Dynamic Architecture



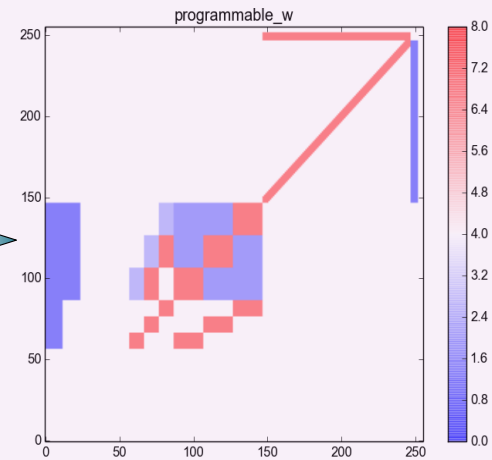
Sandamirskaya, Schöner, 2010

Spiking NN architecture



Sandamirskaya et al, in press

Connectivity matrix

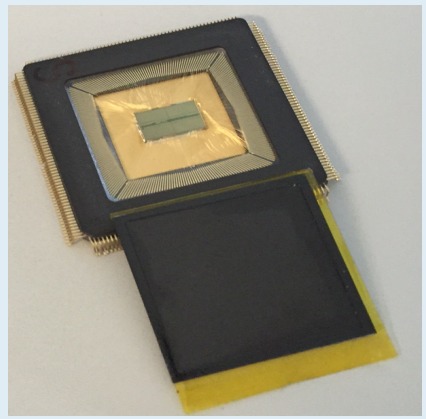


Validation and model improvement

Robotic system

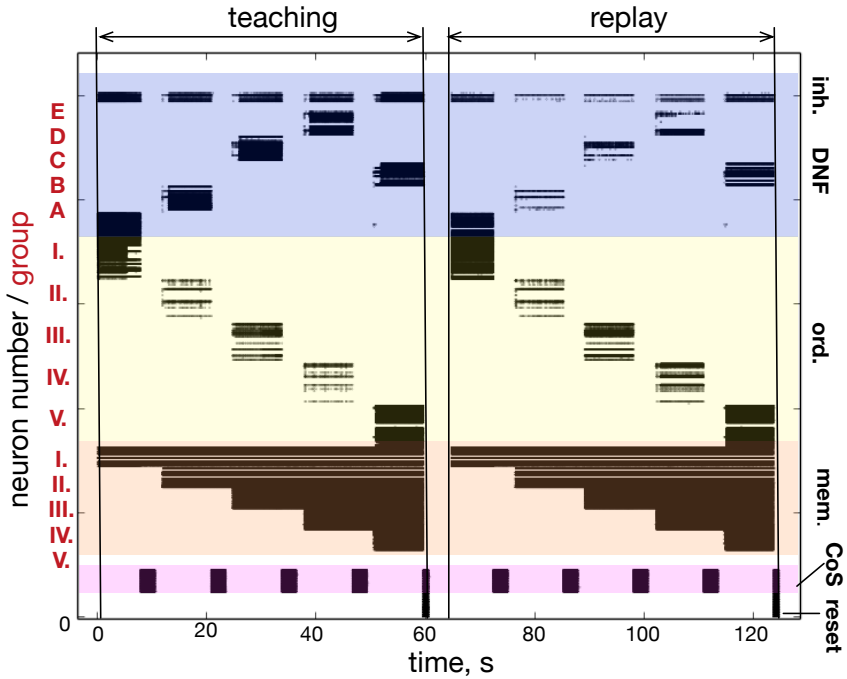
Robot

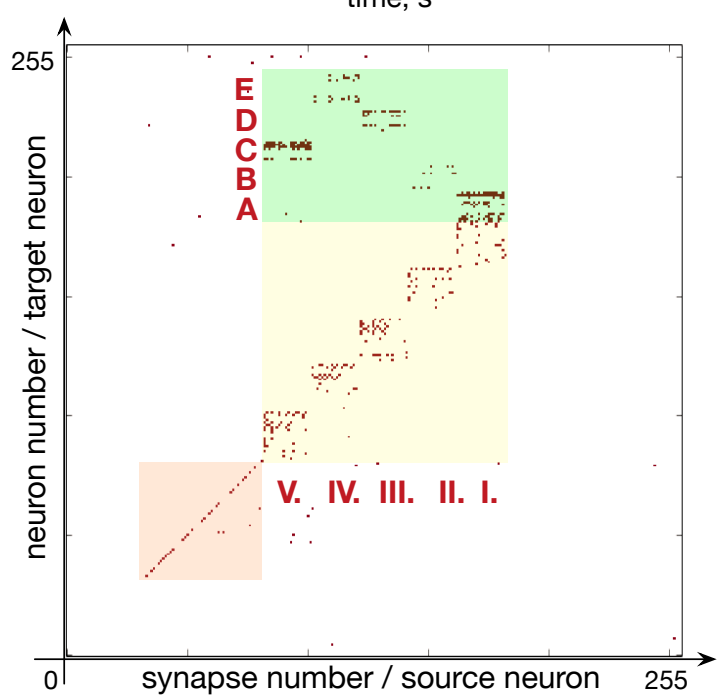
Neuromorphic chip



Sequence learning on chip

“ABDEC”

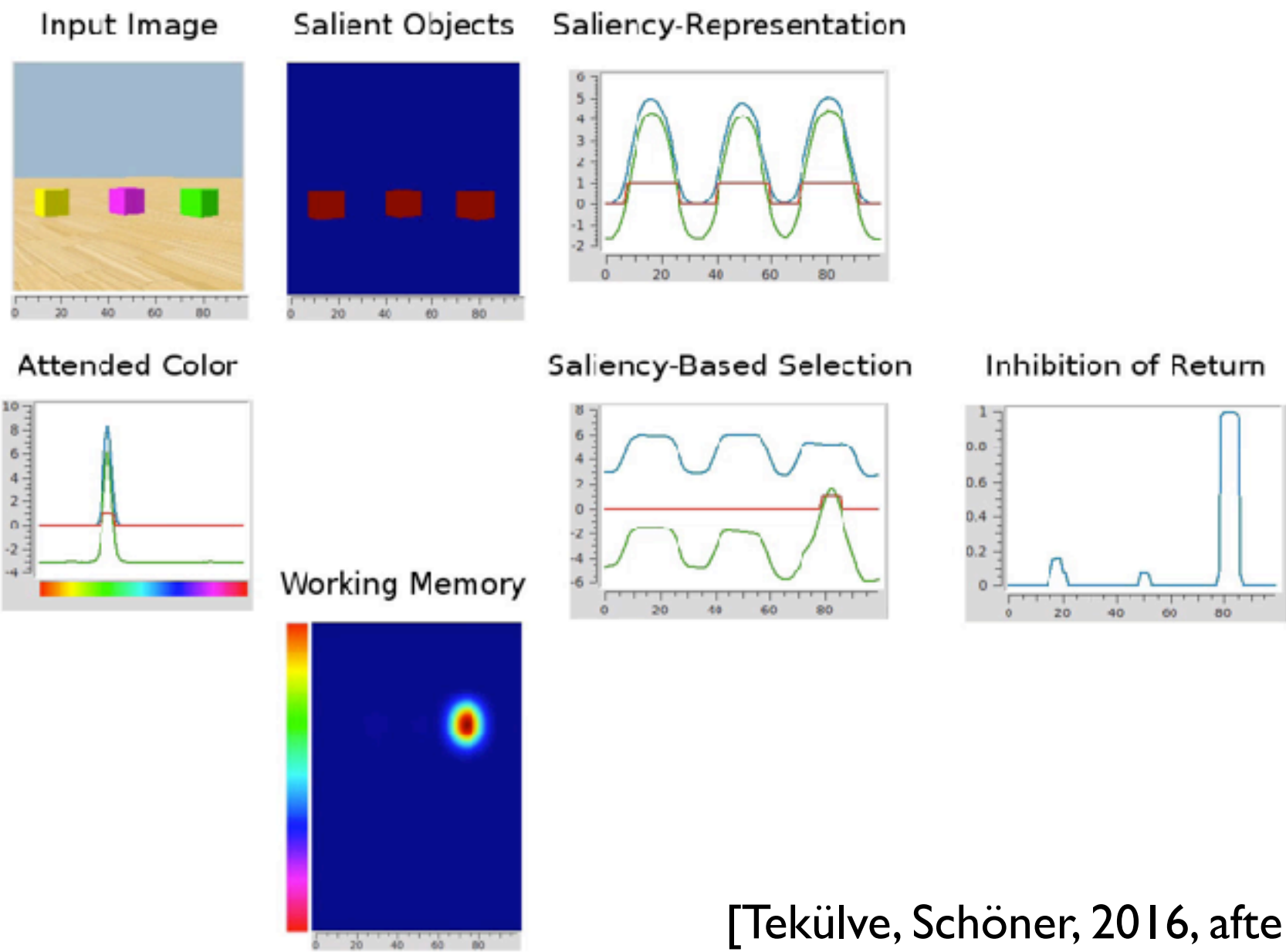




Sandamirskaya, unpublished

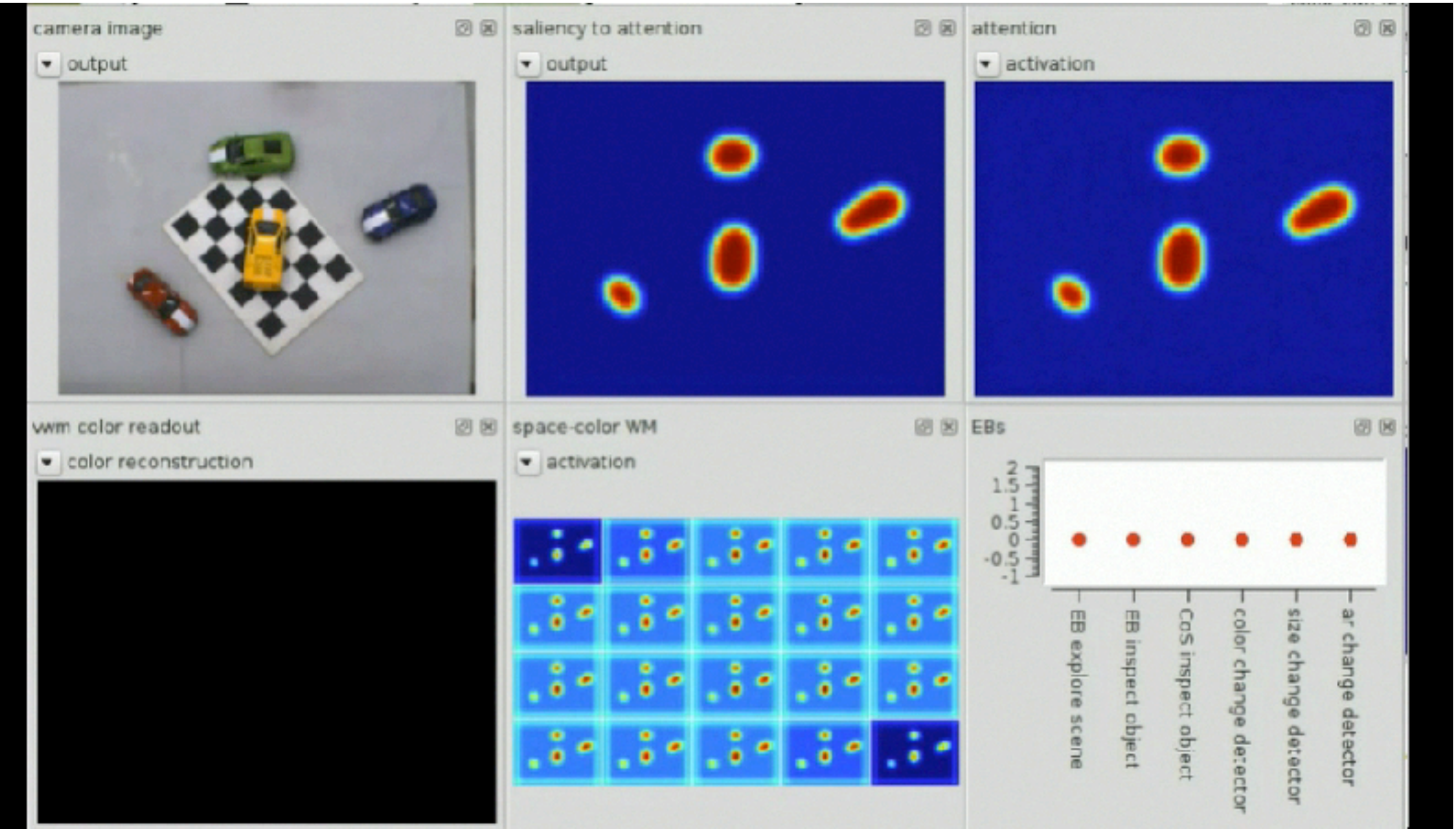
Architectures

Sequence of shifts of attention



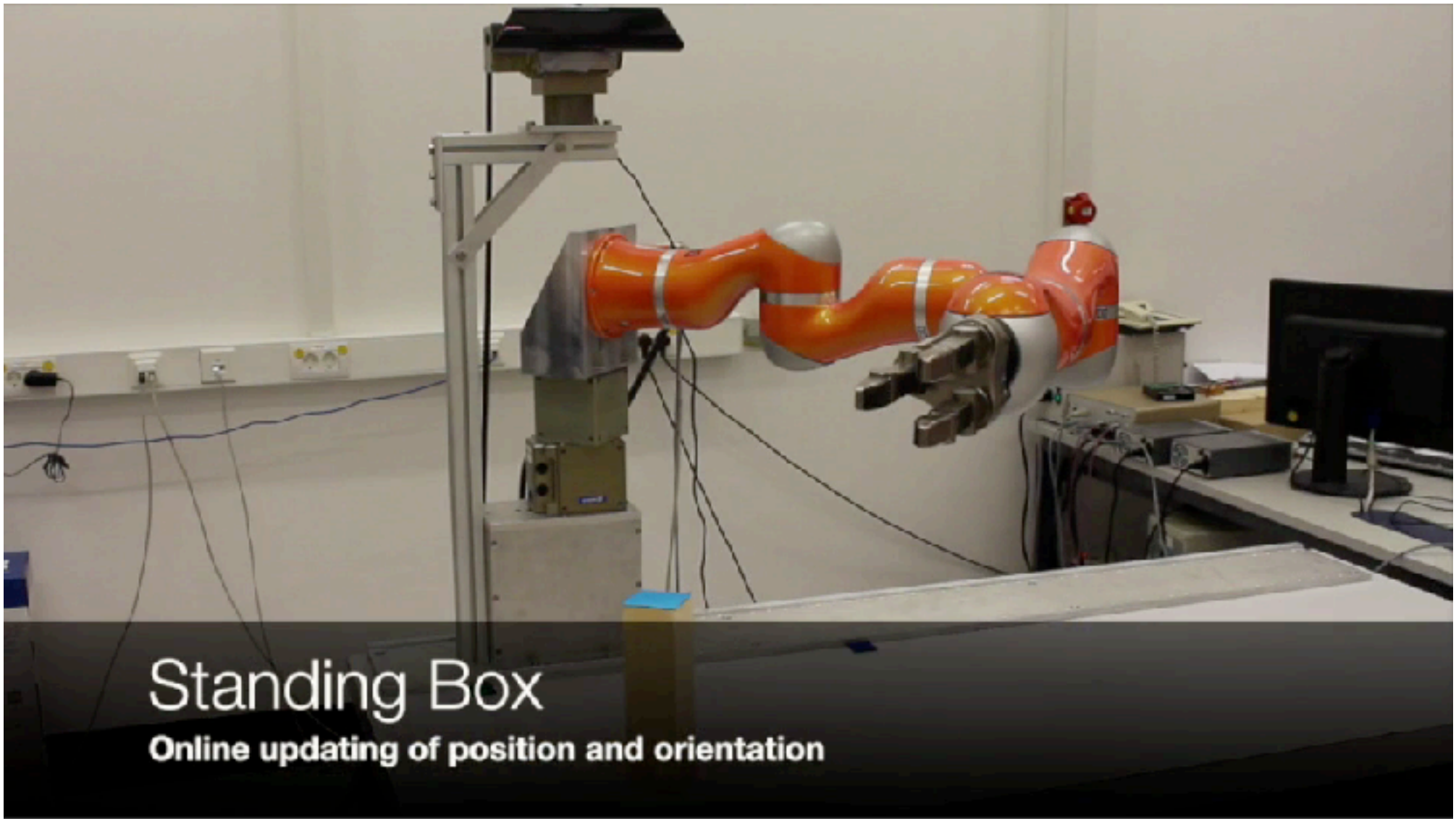
[Tekülve, Schöner, 2016, after Zibner]

Building a scene memory



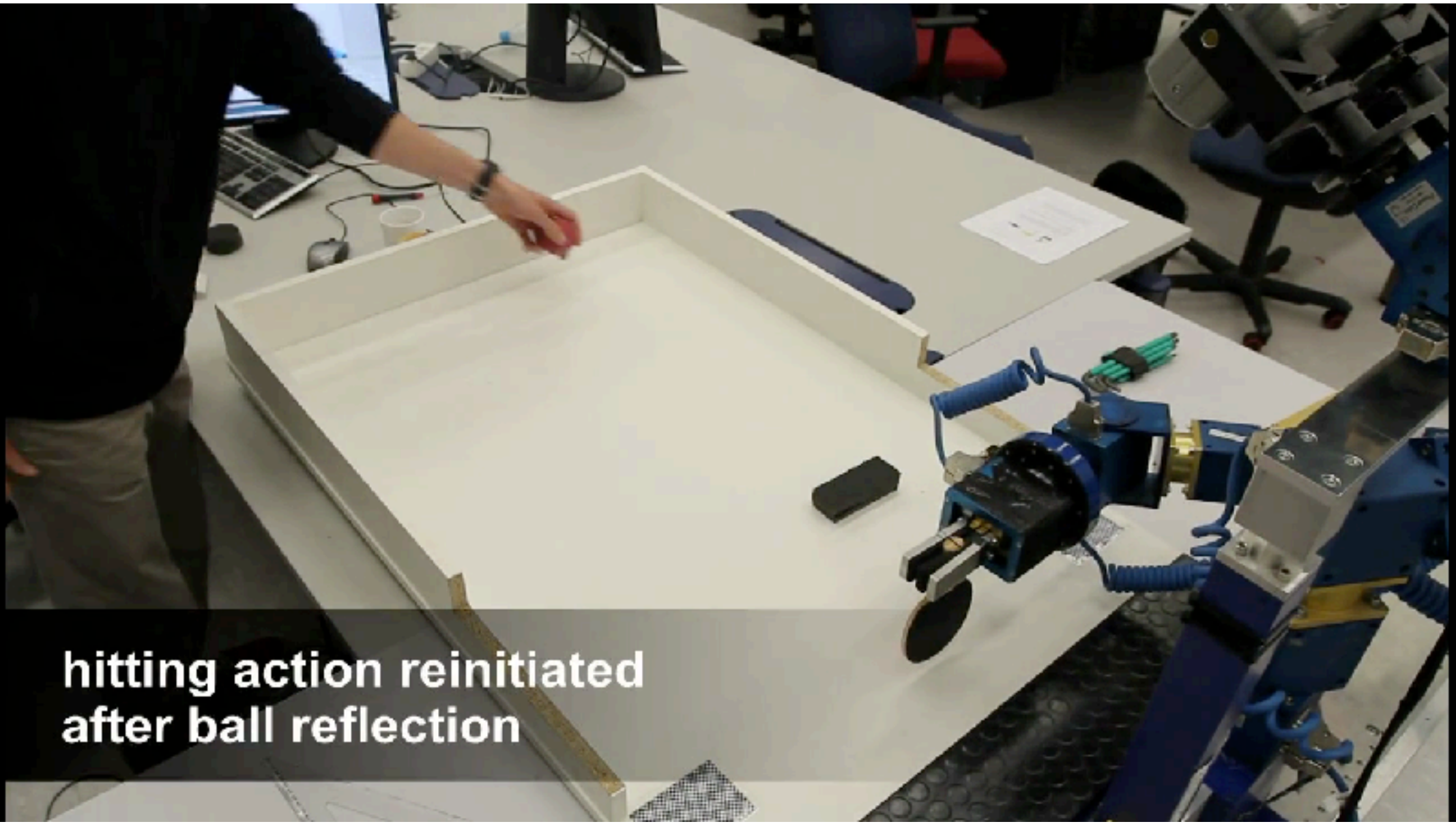
[Zibner 2015]

Reaching and grasping with online updating

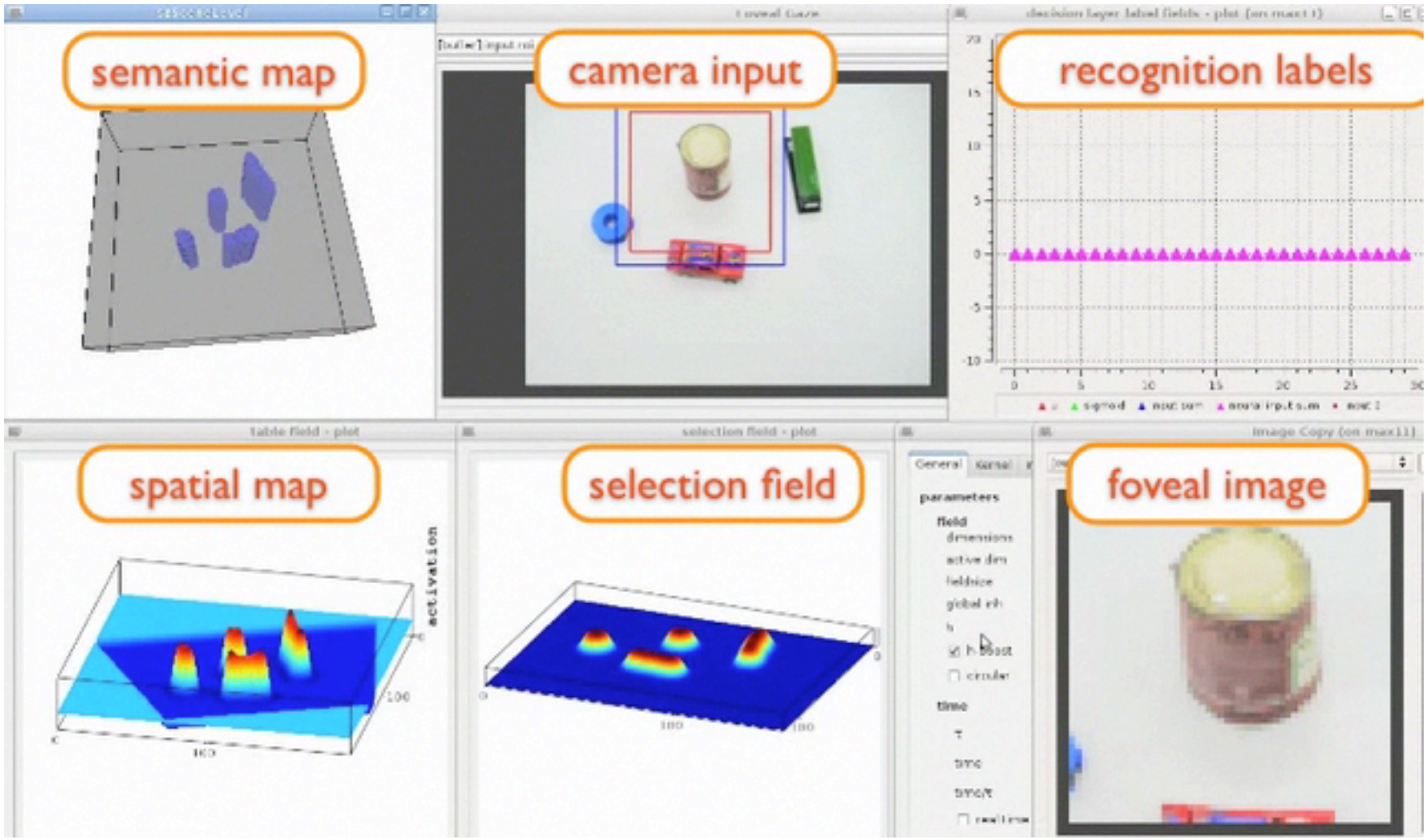


[Knips et al., ICRA 2014]

Online reorganization of sequence



object recognition in a scene representation



[Zibner, Faubel, IROS 2011]

Higher cognition

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A Neural Dynamic Model Generates Descriptions of Object-Oriented Actions

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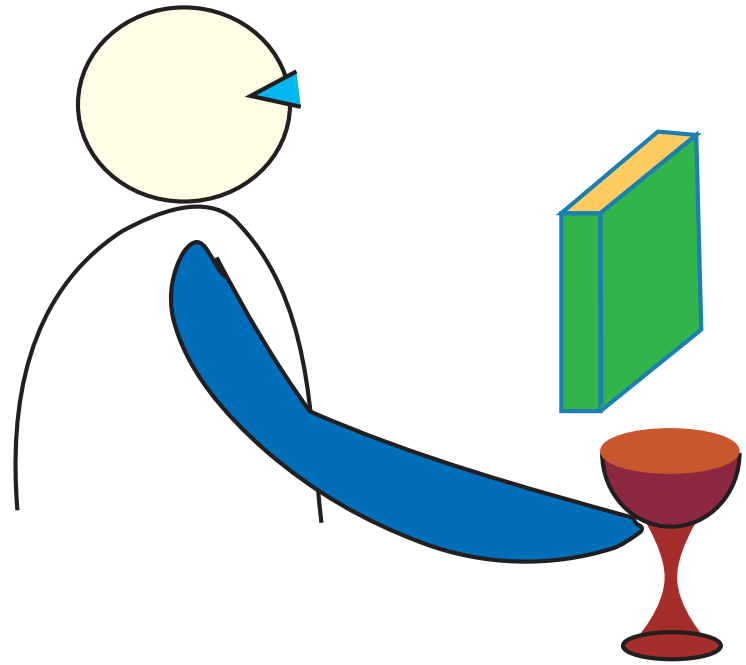
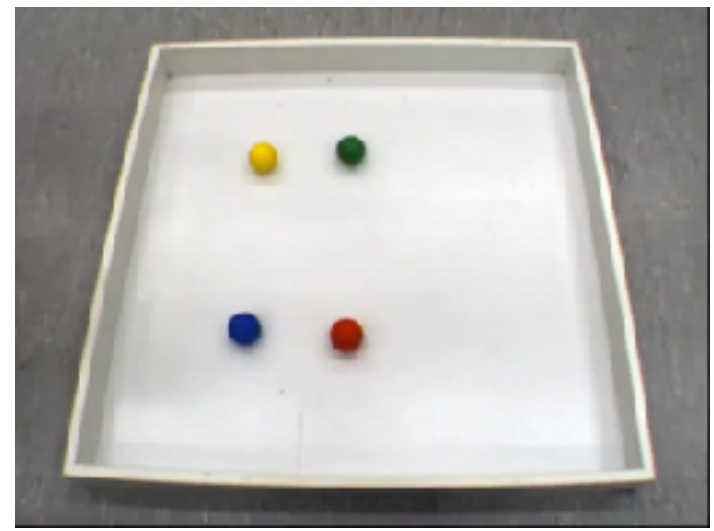
Perceptually grounding language

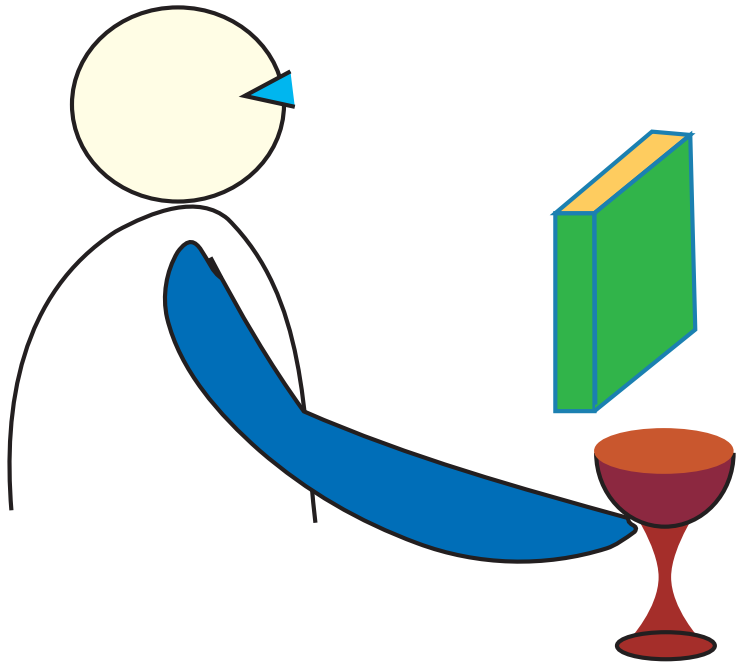
- human language/thought in its simplest form is about "things" that are our there in our environment, perceivable, reachable by action
- perceptually grounding language:
  - "this cup is brown"
  - "the cup to the right of the book" (spatial language)
  - "the green ball moves away from the yellow ball" (verb)

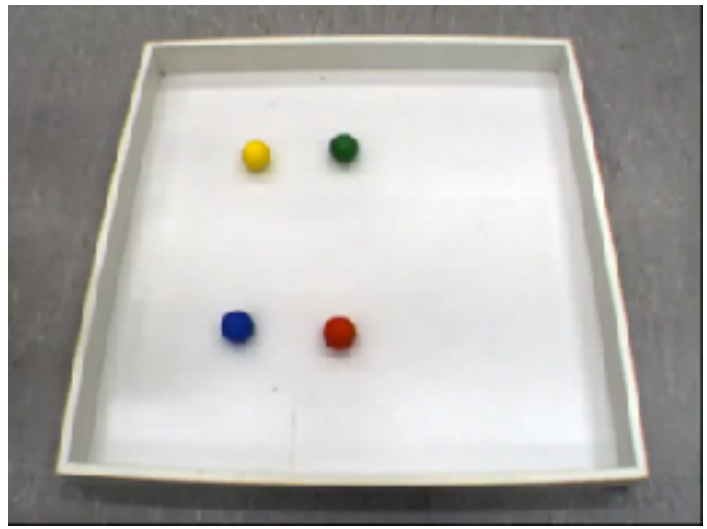


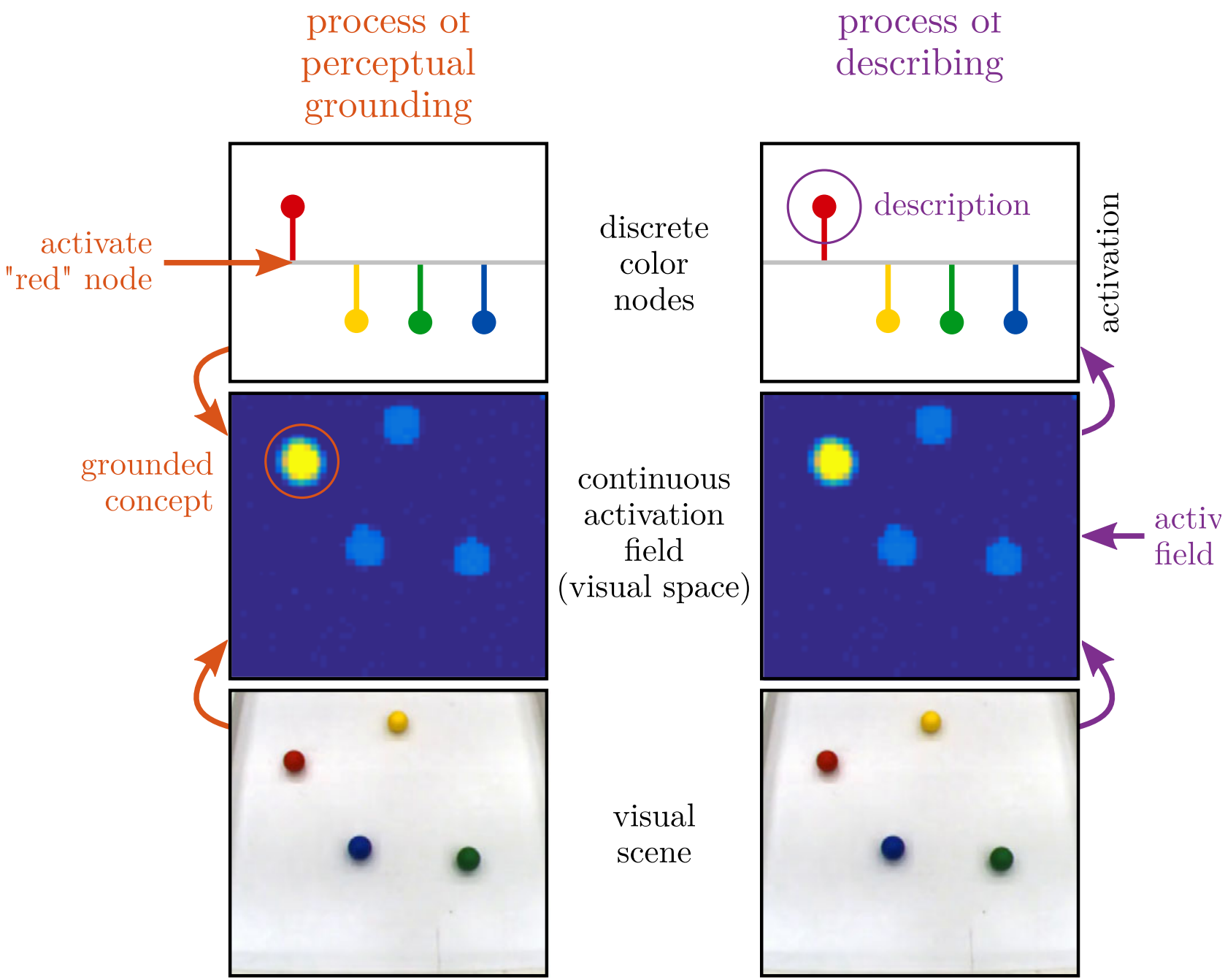


Generating language

- human language/thought in its simplest form is about "things" that are our there in our environment, perceivable, reachable by action
- generating language
  - "this cup is brown"
  - "the cup to the right of the book" (spatial language)
  - "the green ball moves away from the yellow ball" (verb)

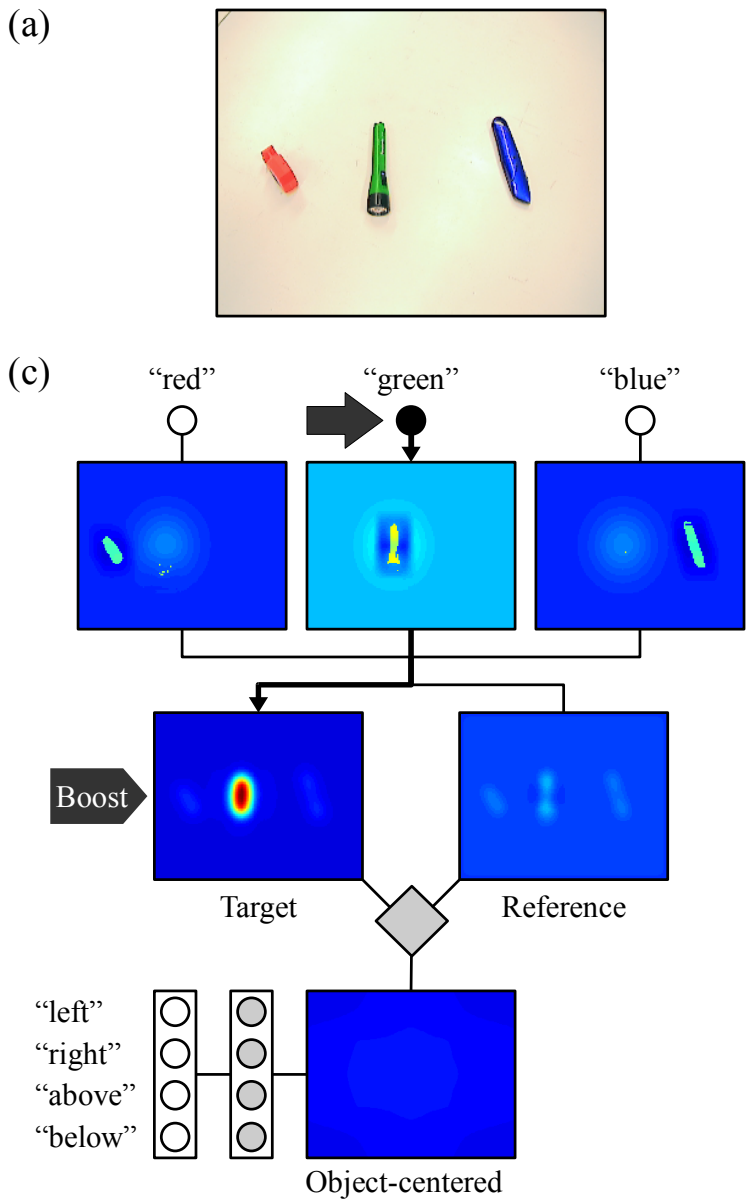




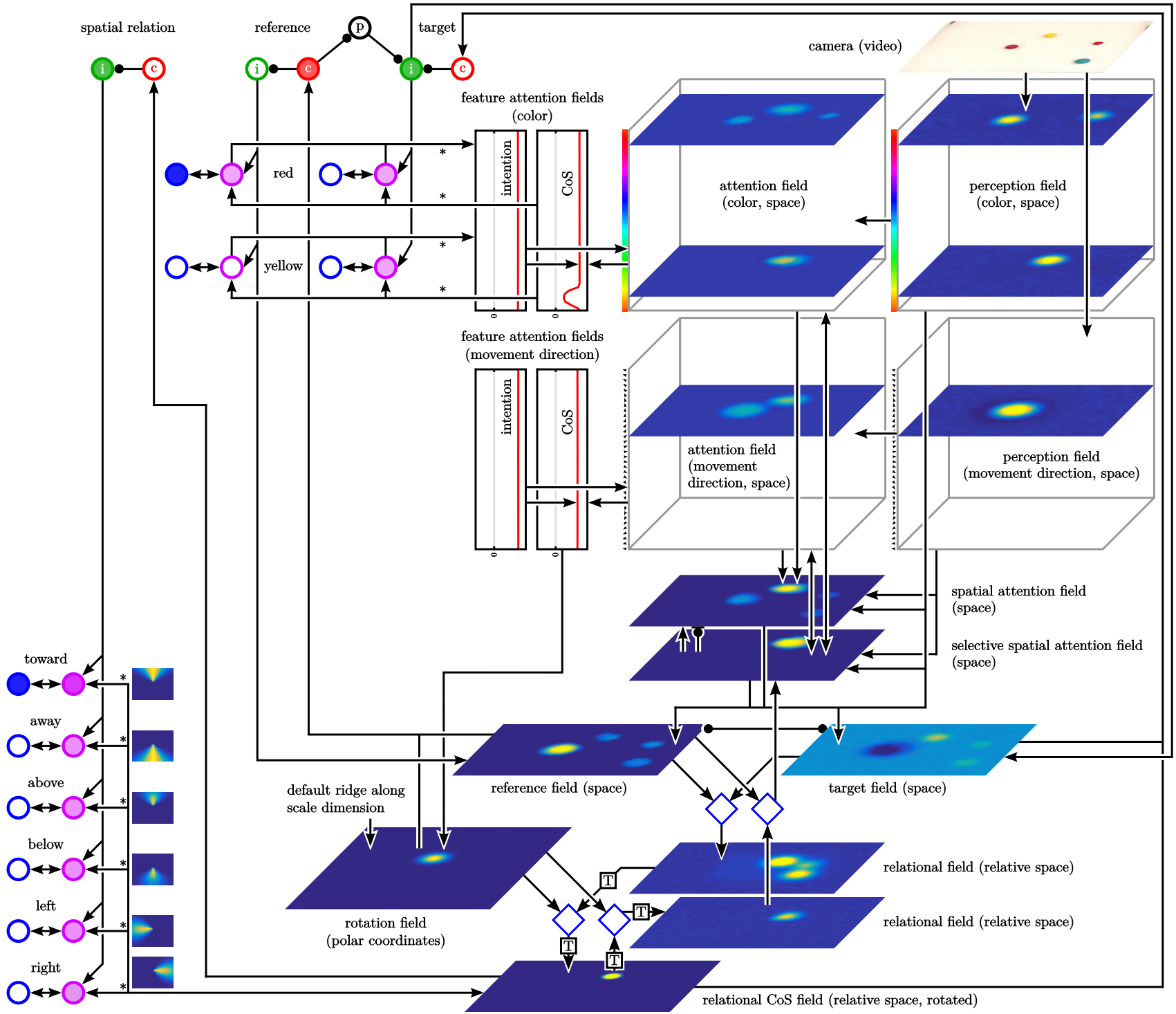

process of perceptual grounding
process of describing
activate "red" node
discrete color nodes
description
activation
grounded concept
continuous activation field (visual space)
activ field
visual scene

Processing steps entailed in grounding and generating language

- bringing objects into the perceptual/ attentional foreground
- transforming one object in a reference frame centered in the other object: coordinate transform => Sebastian Schneegans talk
- applying spatial/verb "operators"=neural coupling structures that enable detection of relationship



[Lipinski et al., JEP:LMC 2012]

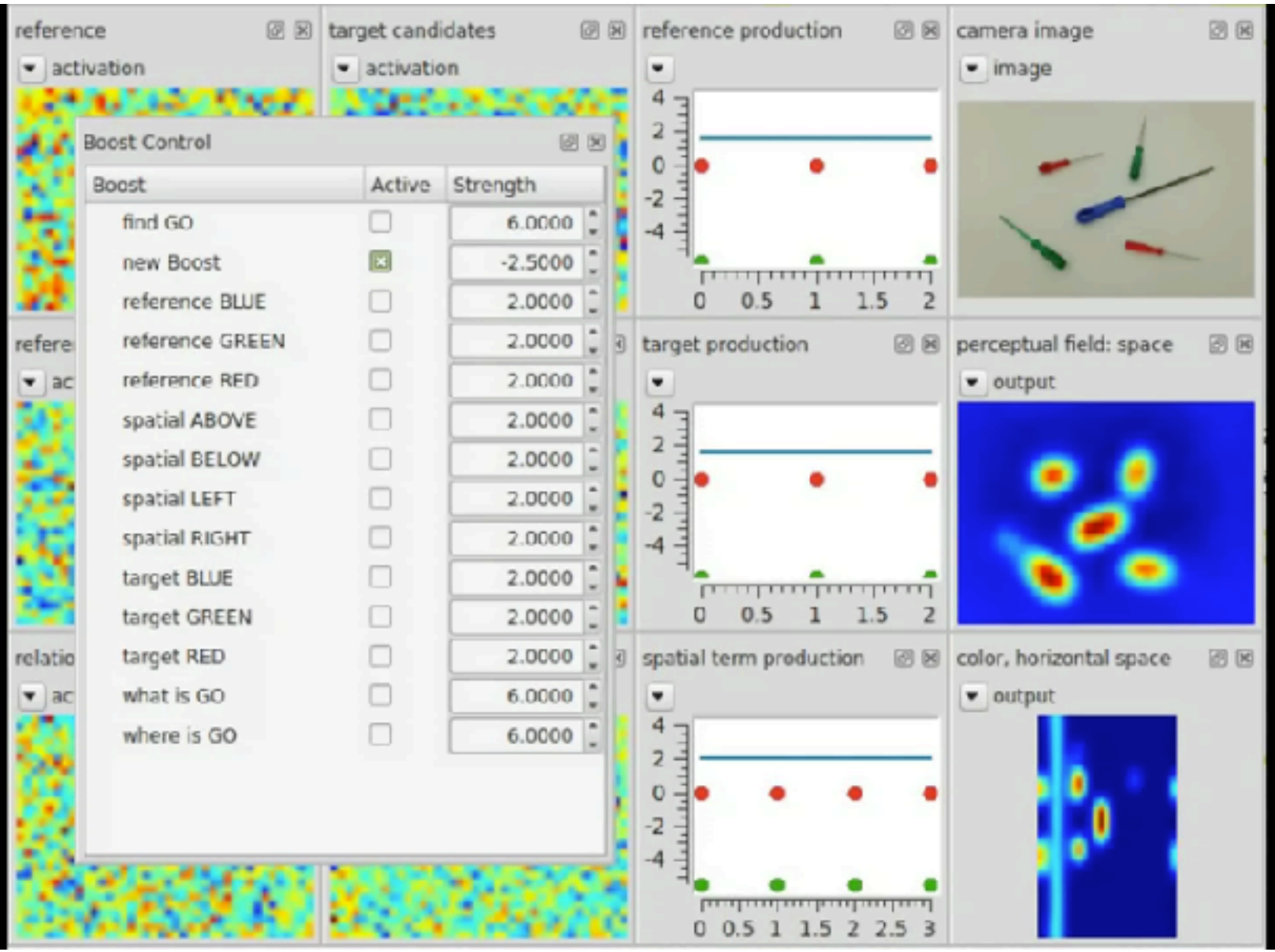

spatial relation
reference
target
camera (video)
feature attention fields (color)
red
yellow
intention
CoS
attention field (color, space)
perception field (color, space)
feature attention fields (movement direction)
attention field (movement direction, space)
perception field (movement direction, space)
spatial attention field (space)
selective spatial attention field (space)
toward
away
above
below
left
right
reference field (space)
target field (space)
default ridge along scale dimension
rotation field (polar coordinates)
relational field (relative space)
relational field (relative space)
relational CoS field (relative space, rotated)

autonomous processing

- some processing steps must occur sequentially in time… e.g. because they entail testing hypotheses one after another
- the switch from one to the other must occur autonomously: as one process is "satisfied", it deactivates and leaves room for the next…
- … or one processes may be "dissatisfied", also leading to a switch…

[Richter, Lins, Schneegans, Sandamirskaya, Schöner Proc. Cog Sci 2014]

“red to the left of green”



[Richter, Lins, Schöner TopiCS 2017]

Conclusion

- …. go a far way from the simple sensory motor cognition of Braitenberg vehicles
- … toward higher cognition
- … all neural dynamics, gathered into architectures
- … in which instabilities are key to the autonomous generation of sequences of thoughts or actions