A DFT architecture for an intentional agent

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Doctoral dissertation of Jan Tekülve

[Tekülve, Schöner, IEEE Trans Cog Dev Sys 2022;
Tekülve, Schöner *Cog Science*, in press (2024)]

Do the concepts of DFT potentially reach all processes of the mind?

- so that DFT would provide a neural foundation for understanding the mind?
- … hinges on what we mean by the "mind"

Do the concepts of DFT potentially reach all processes of the mind?

- borrowing terms from the philosophy of mind to explore this question
- "intentionality" in two "directions of fit" to sample qualitatively different form of mental and motor acts
- "psychological modes" to sample the mind from the sensory-motor to goal-achievement and knowledge

Intentionality

- *Intentionality* = the capacity of organisms and their nervous systems to generate mental states that are *about things in the world*
  - *things* may include an organism's own body
  - *things* may ultimately also includes the nervous system's own states

Two *directions of fit* of intentional states (Searle)

- *world-to-mind*: the world must match the intentional state to fulfill that state's *condition-of-satisfaction* (CoS) => the "motor" flavor of intentionality
- *mind-to-world*: the intentional state must match the state of the world to fulfill the CoS => "perceptual" flavor of intentionality

Six *psychological modes* of intentional states (Searle)

- *mind-to-world*
  - *perception*
  - *memory*
  - *belief*
- *world-to-mind*
  - *intention-in-action*
  - *prior intention*
  - *desire*

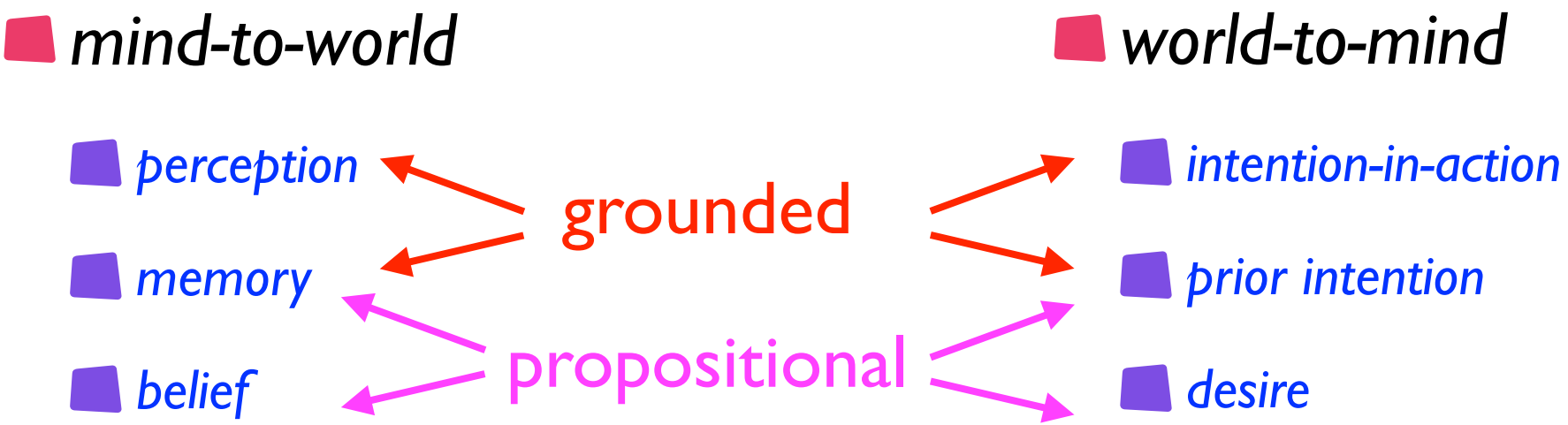
The six modes reflect the sensory-motor grounding of cognition

- *world-to-mind*
  - *motor control*
  - *action plans, decisions, sequences*
  - *goals, motivations, emotions*
- *mind-to-world*
  - *attention, active perception, working memory*
  - *scene and event memory*
  - *back-ground knowledge, learning from experience, communication*

Six *psychological modes* of intentional states (Searle)

- *mind-to-world*
  - *perception*
  - *memory*
  - *belief ~ knowledge*
- *world-to-mind*
  - *intention-in-action ~ action*
  - *prior intention ~ plans*
  - *desire ~ goals*

Six *psychological modes* of intentional states (Searle)

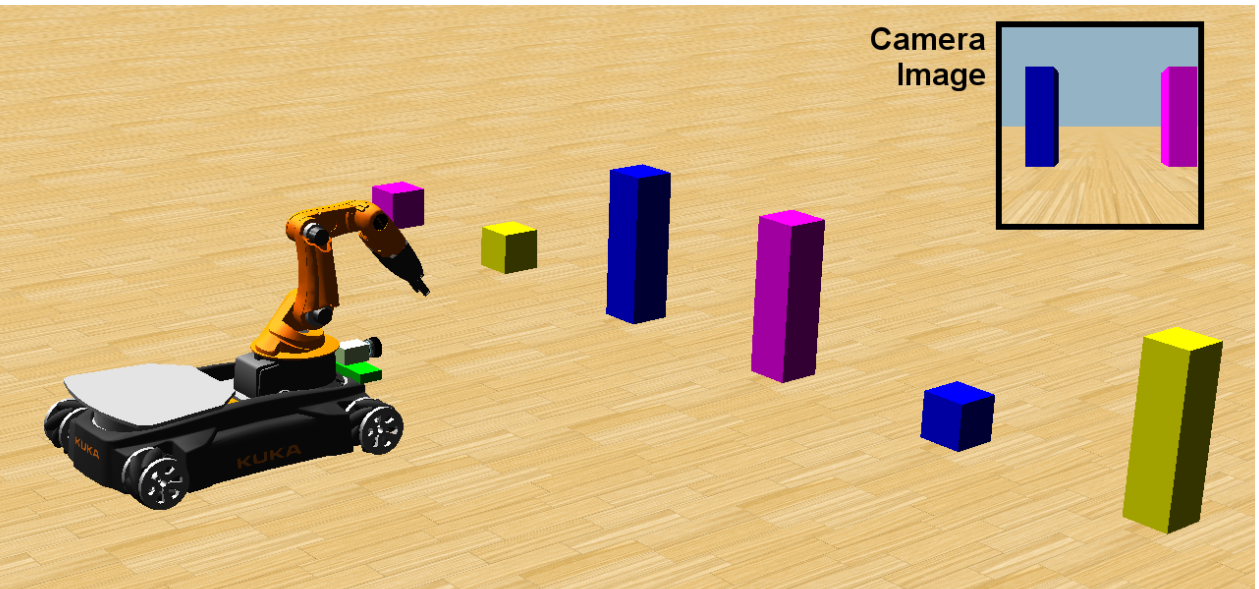


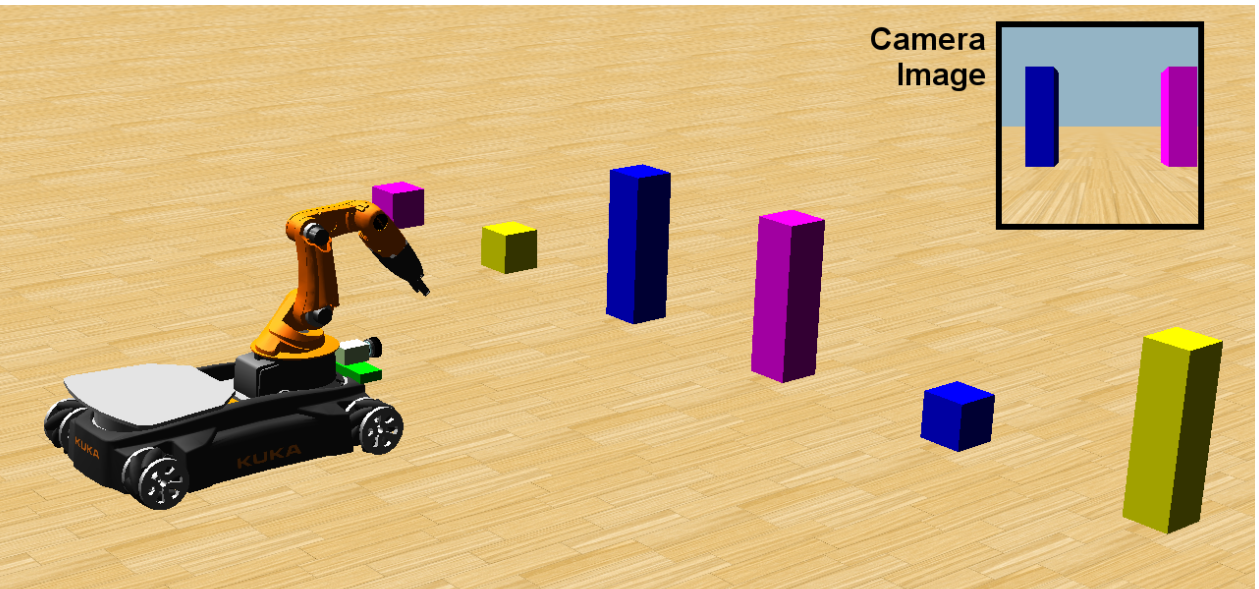
Six *psychological modes*

- Hypothesis: these psychological mode reach all of the mind

- *mind-to-world*
  - *perception*
  - *memory*
  - *belief*
- *world-to-mind*
  - *intention-in-action*
  - *prior intention*
  - *desire*

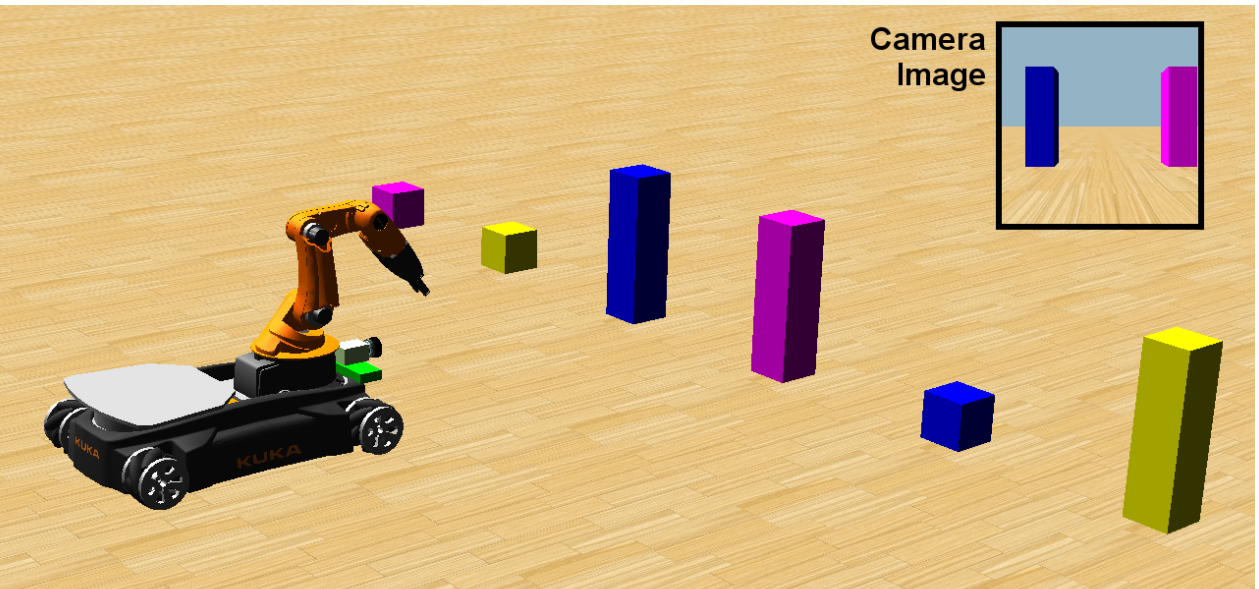
A first toy example of an intentional agent

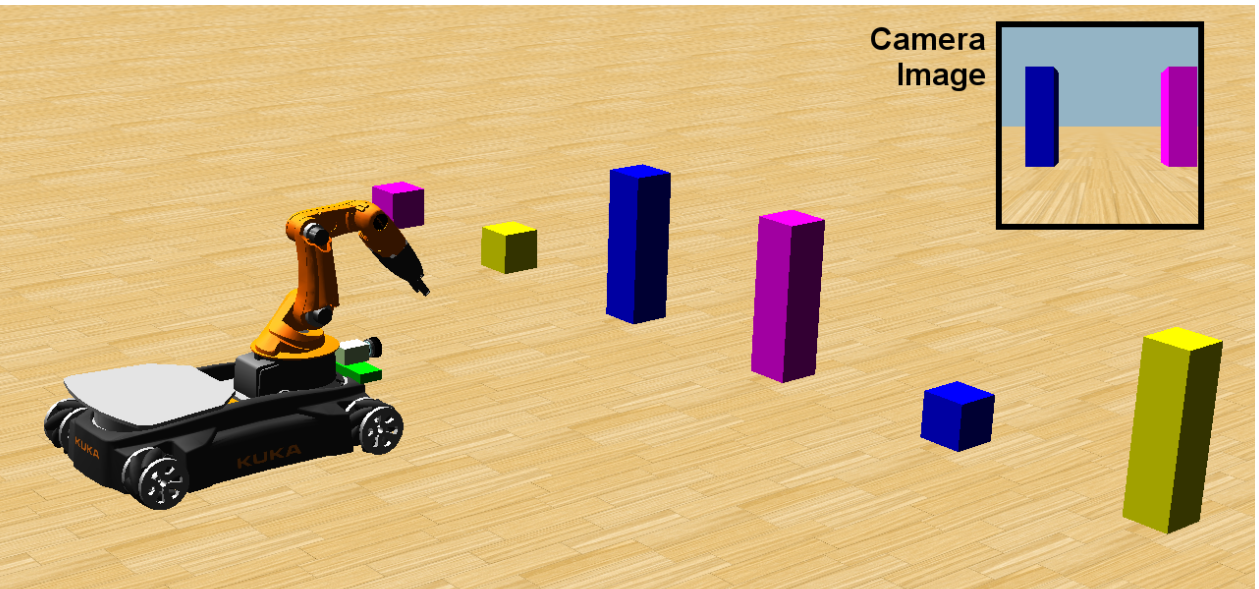




- environment
  - colored objects (small)
  - paint buckets (tall)
  - vehicle with arm
- perception
  - see color/feature
  - sense position, arm, paint in gripper
- intention in action
  - move in 1D
  - reach to take up paint
  - reach to apply a coat of paint

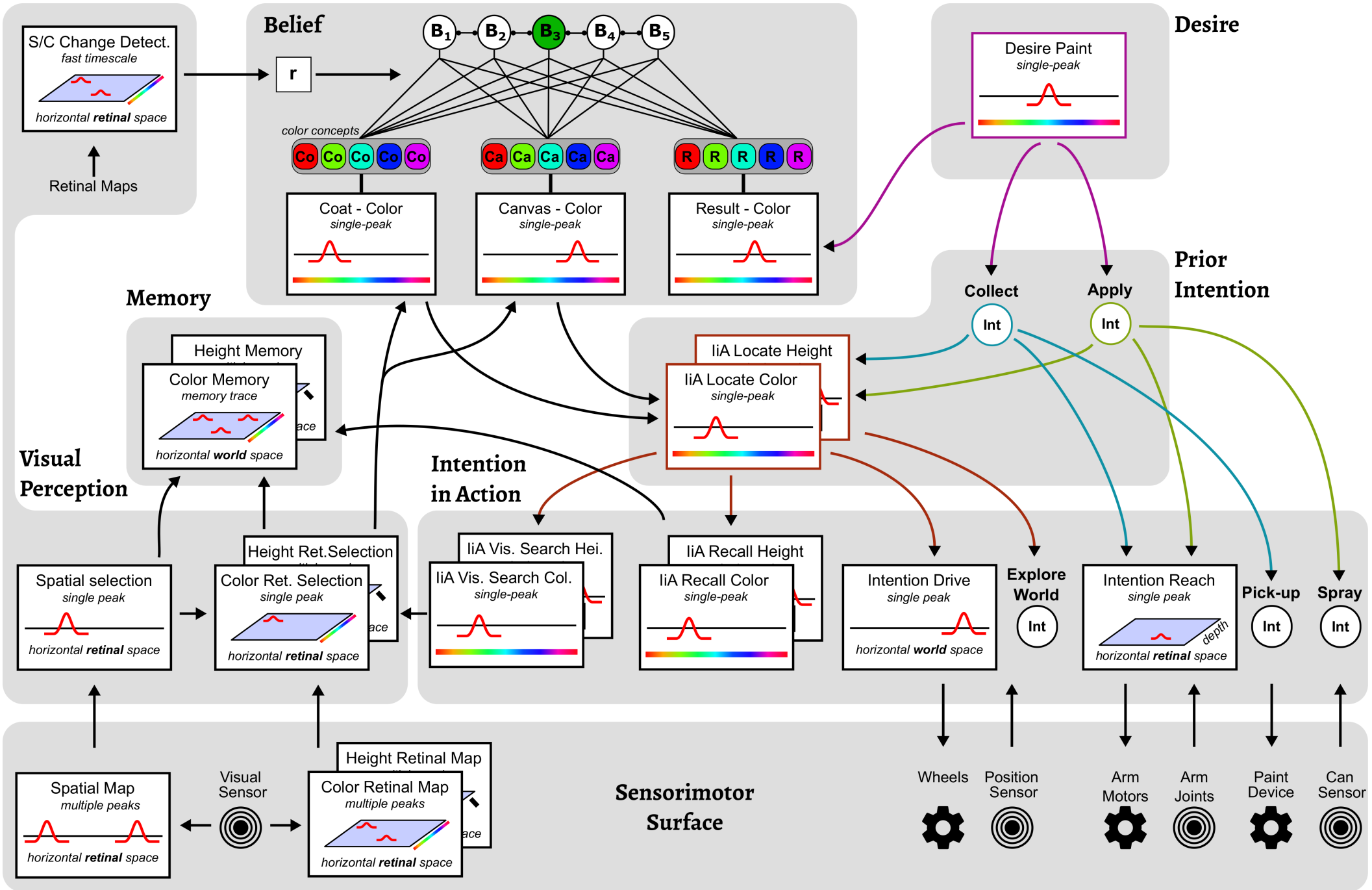
- memory
  - of visual scene
- prior intentions
  - search to paint
  - search to load paint
  - reach to apply paint
  - move to a recalled location …

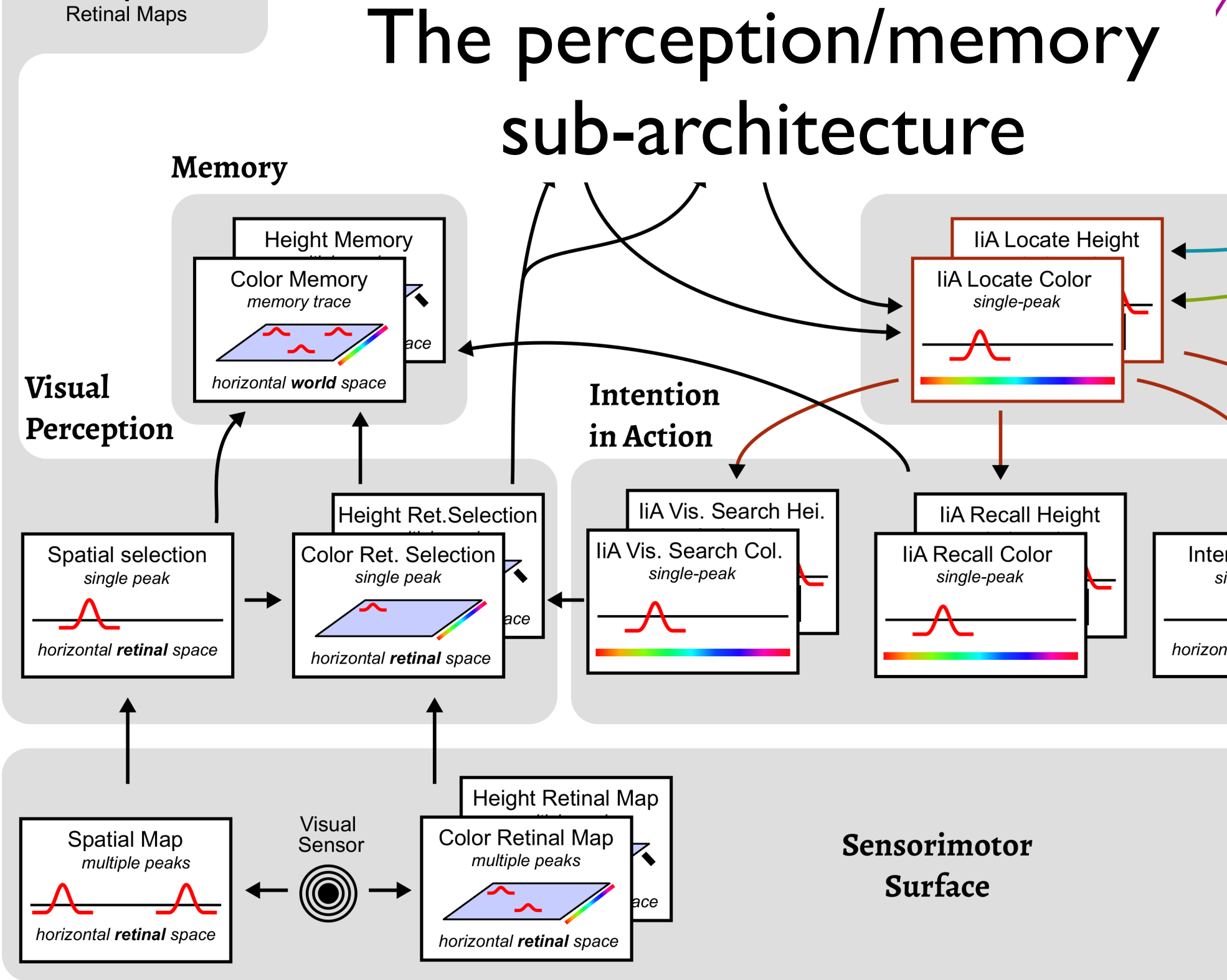


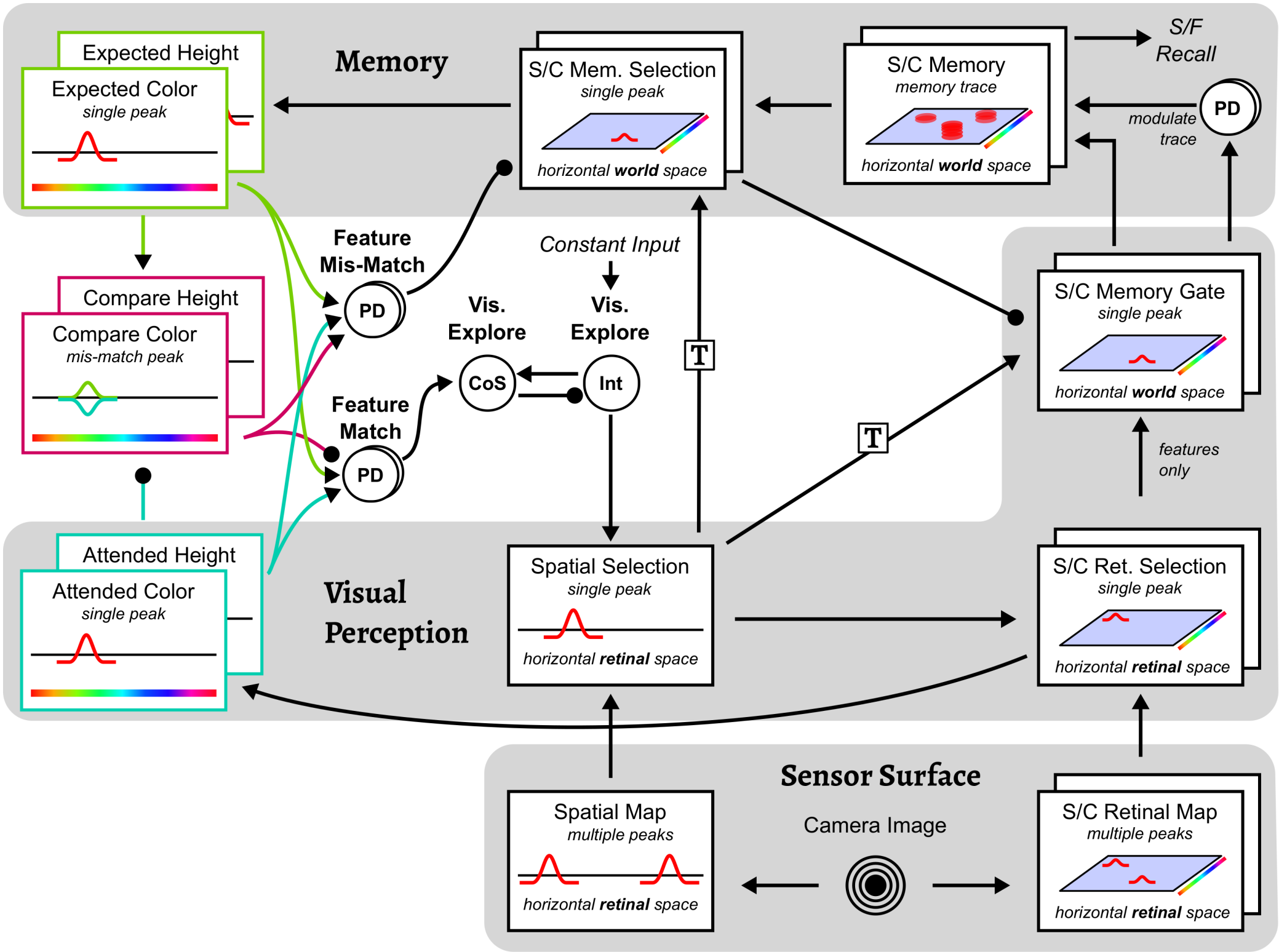


- beliefs
  - (propositional)
  - rules linking color concepts: which paint on which canvas generates which new color
  - learn these beliefs
- desires
  - to point cubes in a particular color

Neural dynamic architecture

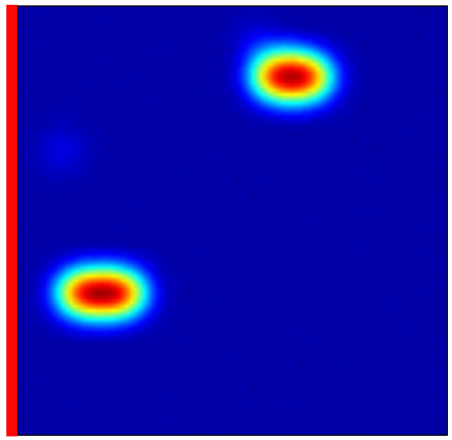



Retinal Maps
The perception/memory sub-architecture
Memory
Height Memory
Color Memory
memory trace
horizontal world space
IiA Locate Height
IiA Locate Color
single-peak
Visual Perception
Intention in Action
Height Ret.Selection
Spatial selection
single peak
horizontal retinal space
Color Ret. Selection
single peak
horizontal retinal space
IiA Vis. Search Hei.
IiA Vis. Search Col.
single-peak
IiA Recall Height
IiA Recall Color
single-peak
Spatial Map
multiple peaks
horizontal retinal space
Visual Sensor
Height Retinal Map
Color Retinal Map
multiple peaks
horizontal retinal space
Sensorimotor Surface


Memory
Expected Height
Expected Color
single peak
S/C Mem. Selection
single peak
horizontal world space
S/C Memory
memory trace
horizontal world space
S/F
Recall
PD
modulate
trace
Feature
Mis-Match
Constant Input
Compare Height
Compare Color
mis-match peak
PD
Vis.
Explore
Vis.
Explore
CoS
Int
T
Feature
Match
PD
T
S/C Memory Gate
single peak
horizontal world space
features
only
Attended Height
Attended Color
single peak
Visual
Perception
Spatial Selection
single peak
horizontal retinal space
S/C Ret. Selection
single peak
horizontal retinal space
Sensor Surface
Spatial Map
multiple peaks
horizontal retinal space
Camera Image
S/C Retinal Map
multiple peaks
horizontal retinal space

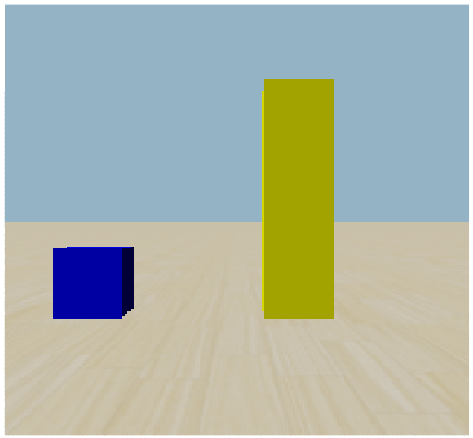
The sensory surface

Retinal Color Map



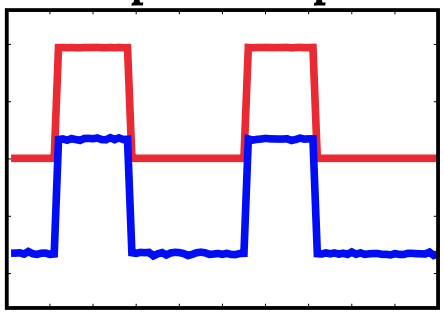
retinal space

Camera Image



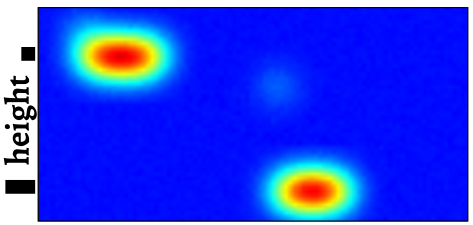
retinal space

Spatial Map



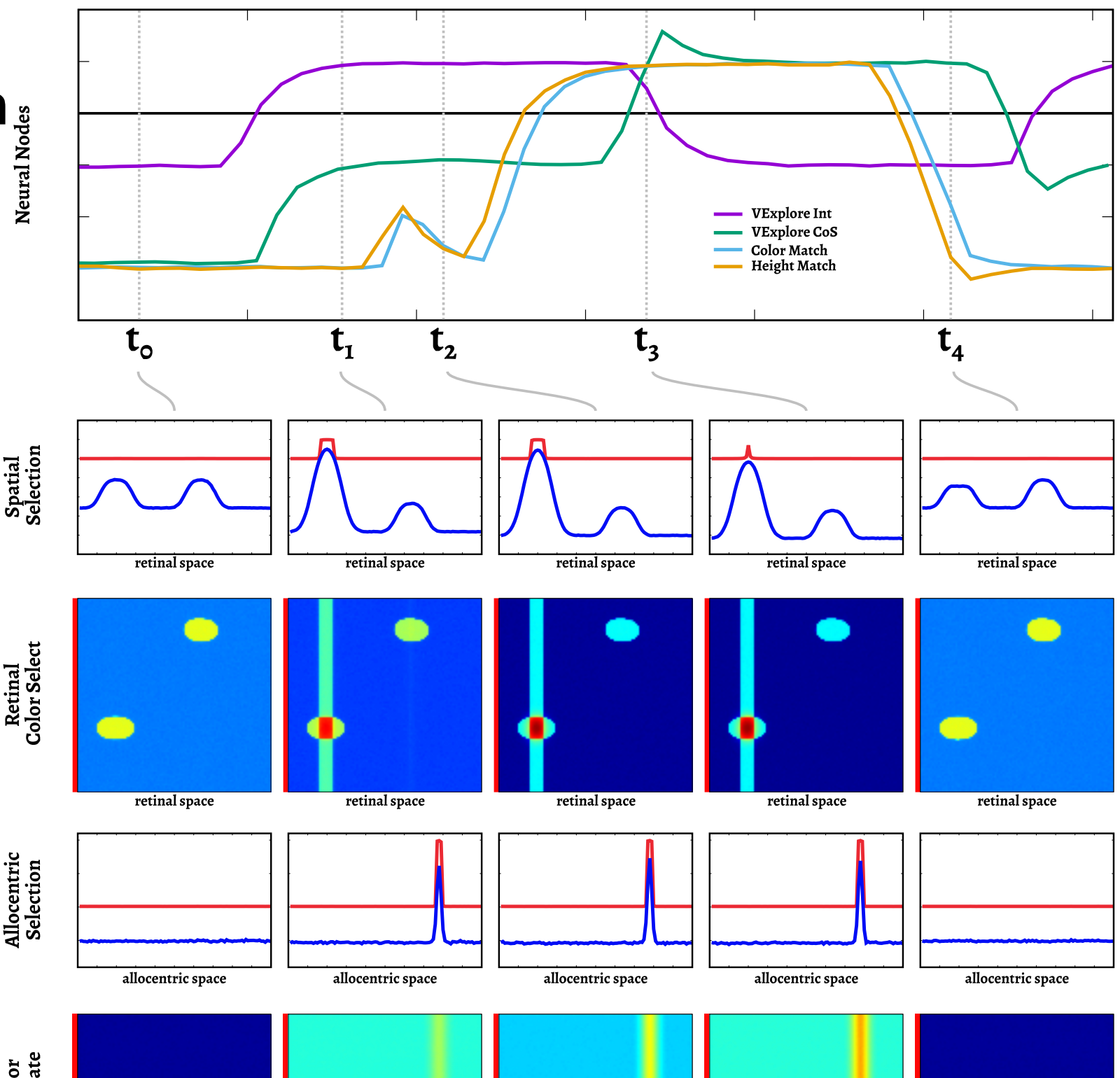
retinal space

Retinal Height Map

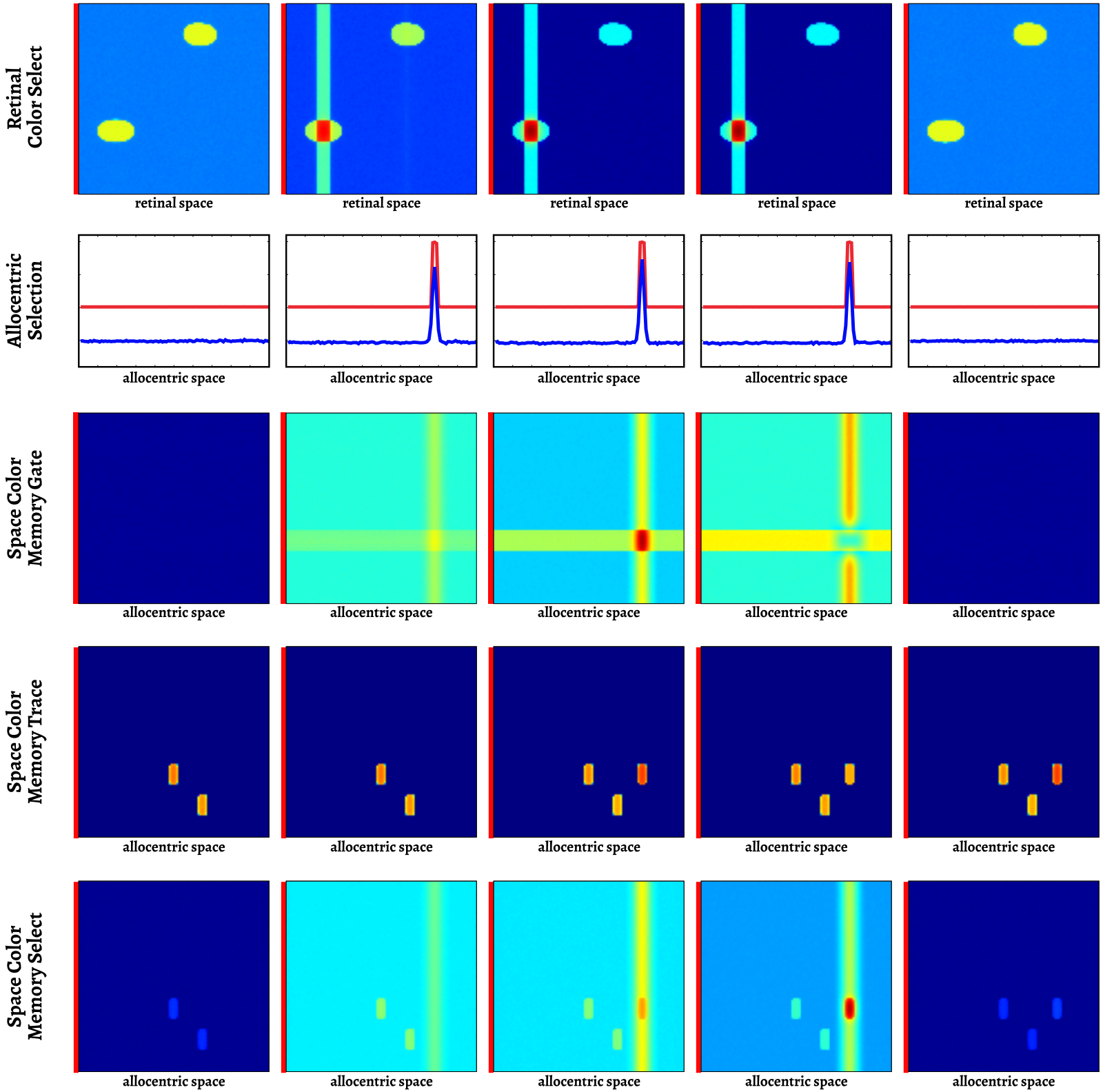


retinal space

Visual exploration



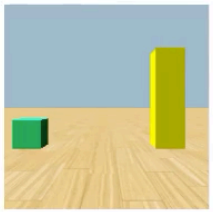
Visual exploration



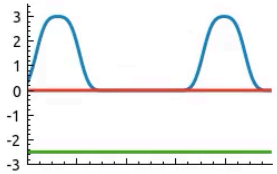
From perception to scene memory

[memory initially empty, then sequentially built]

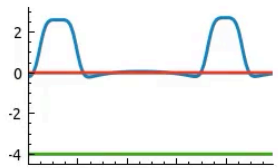
Camera



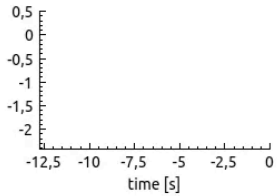
Saliency



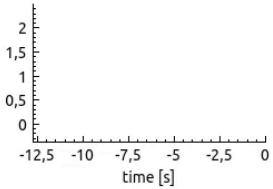
Saliency Selection



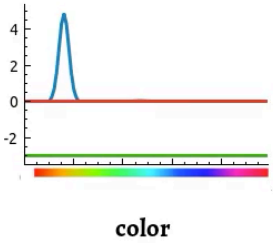
Intention Vis. Explore



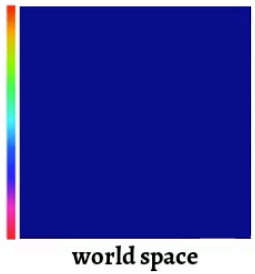
CoS Vis. Explore



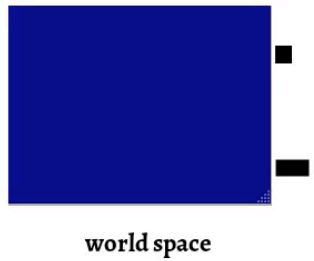
Attended Color



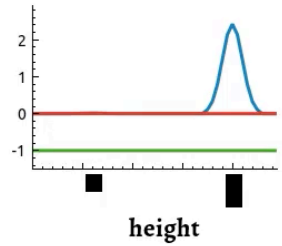
S/C Memory



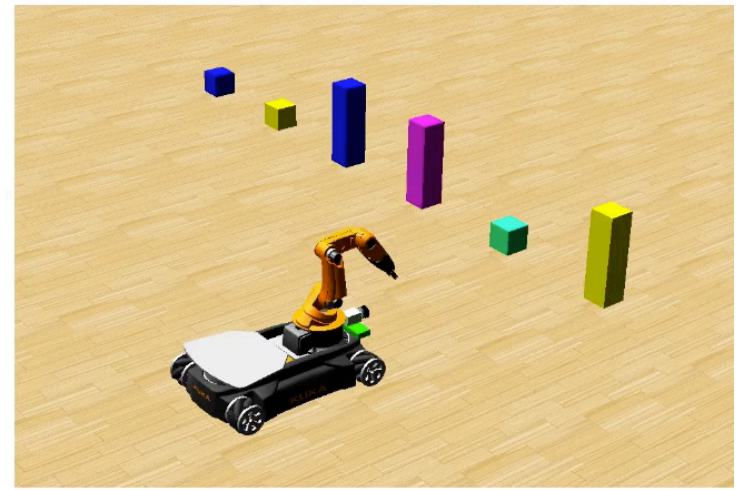
S/H Memory



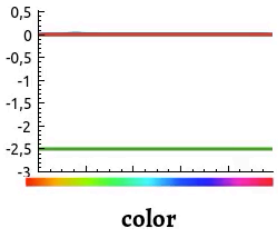
Attended Height



Scene

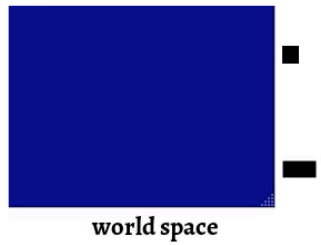


Expected Color

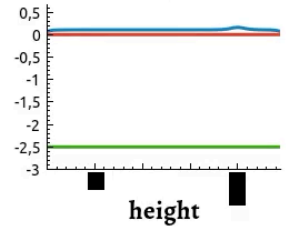


S/C Mem. Selection

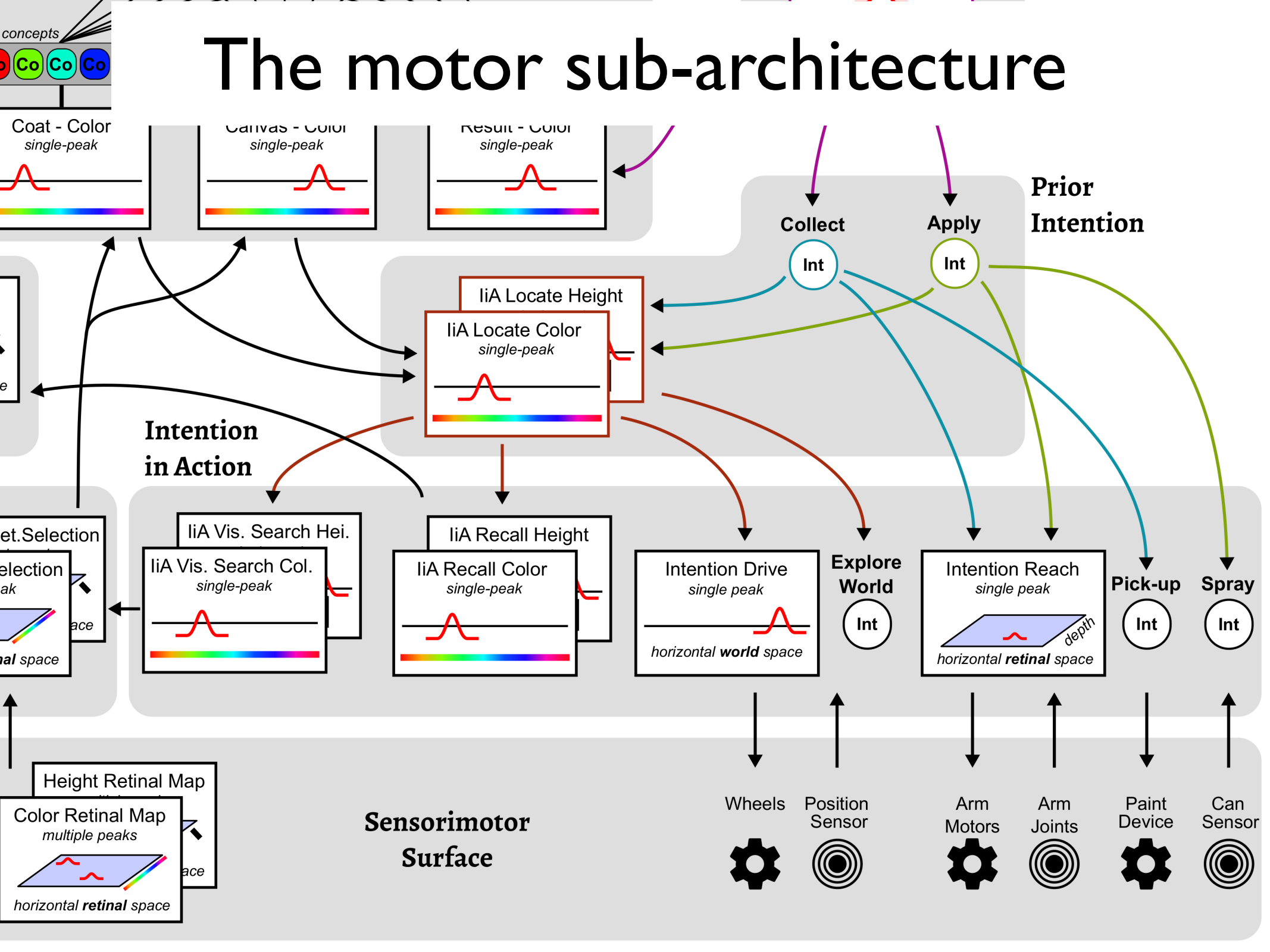
S/H Mem. Selection



Expected Height



The motor sub-architecture



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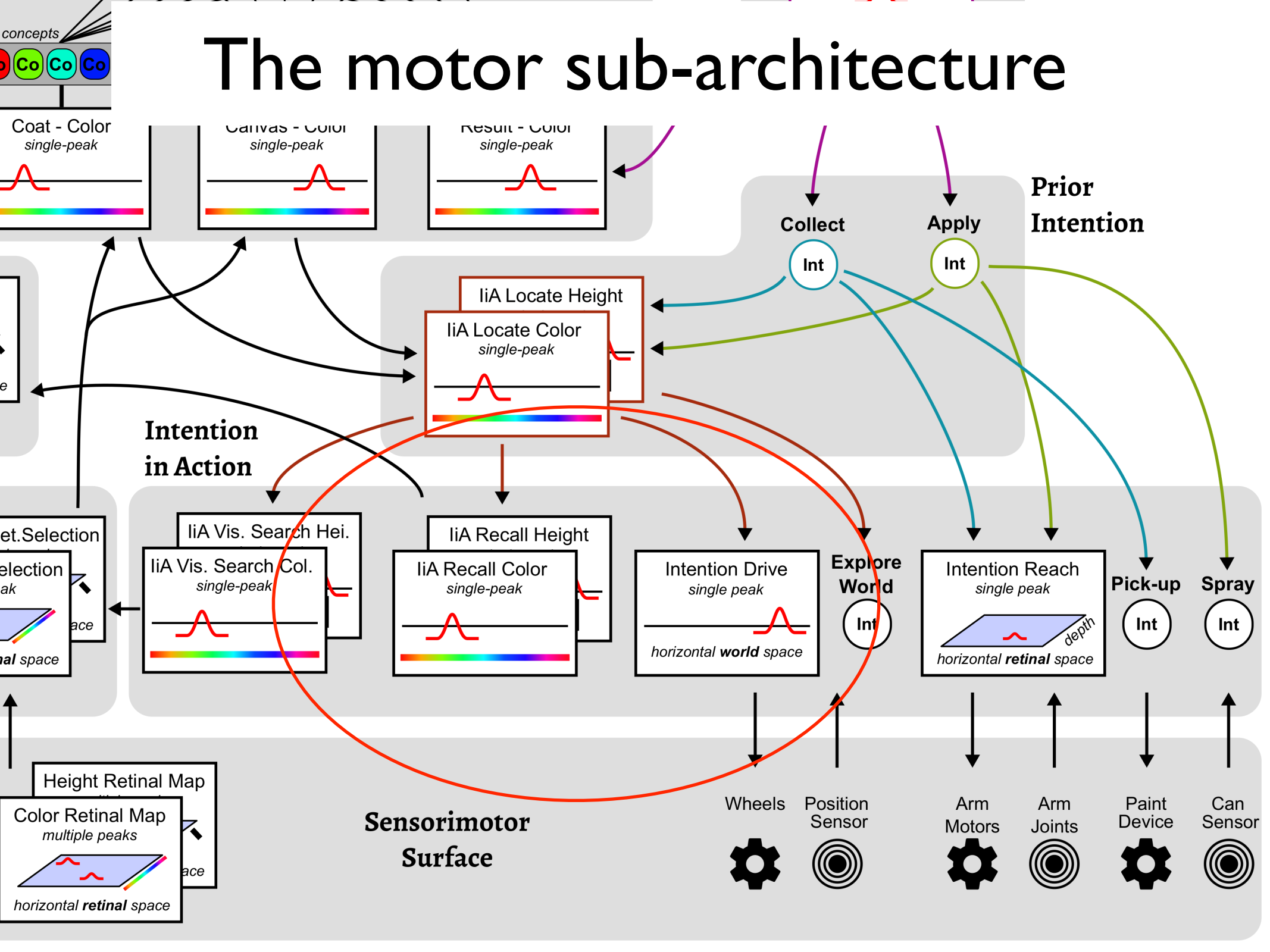
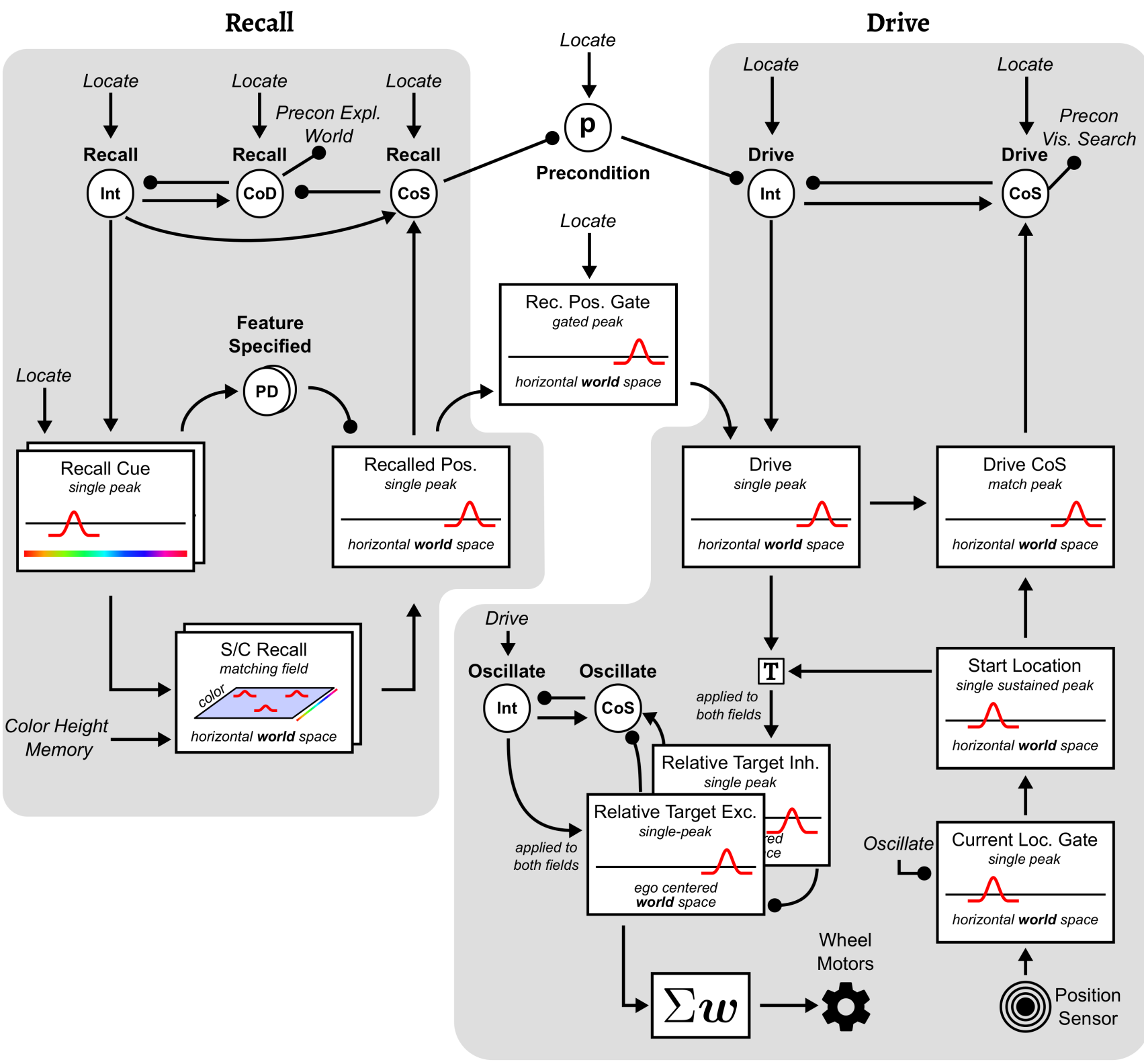
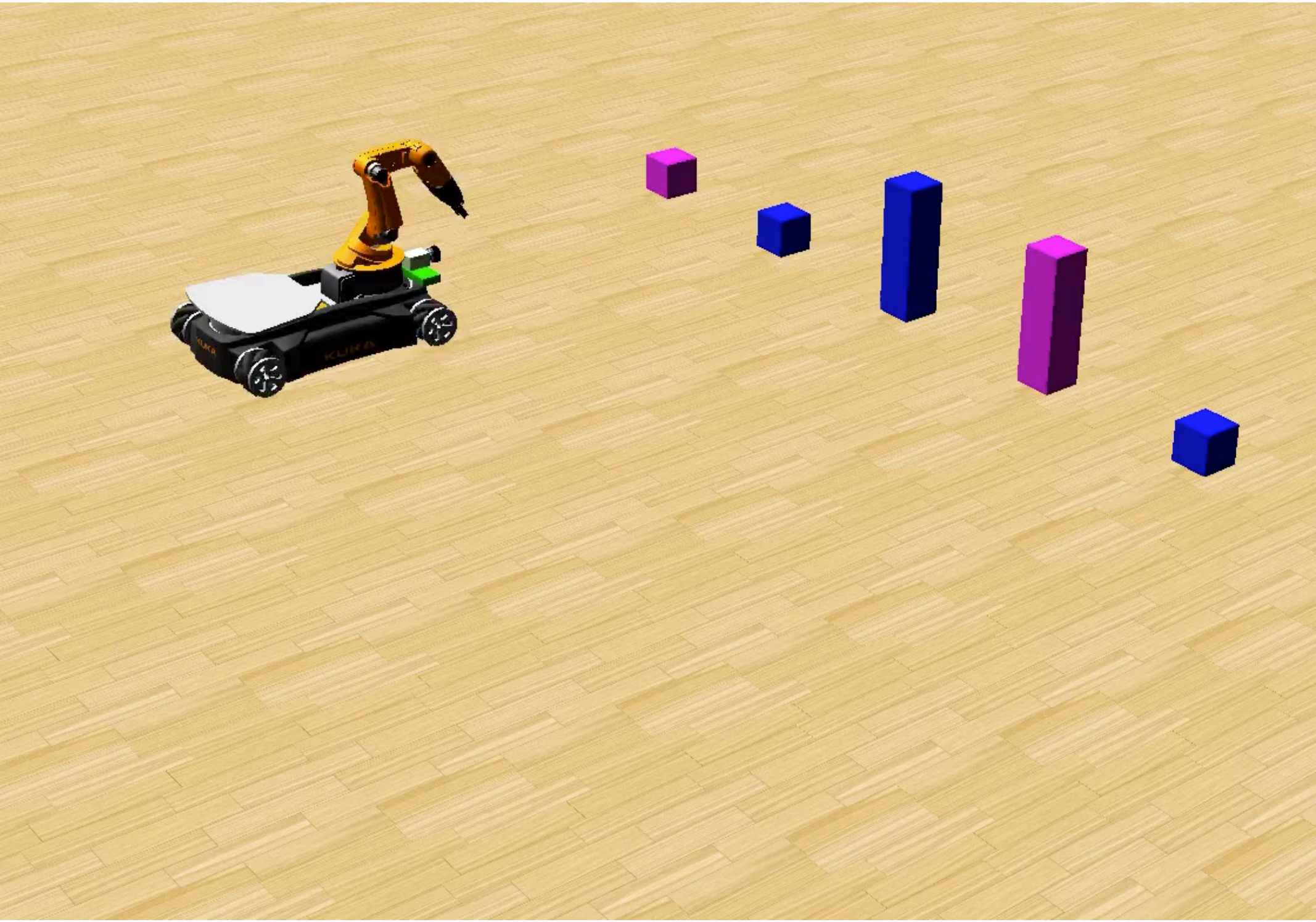
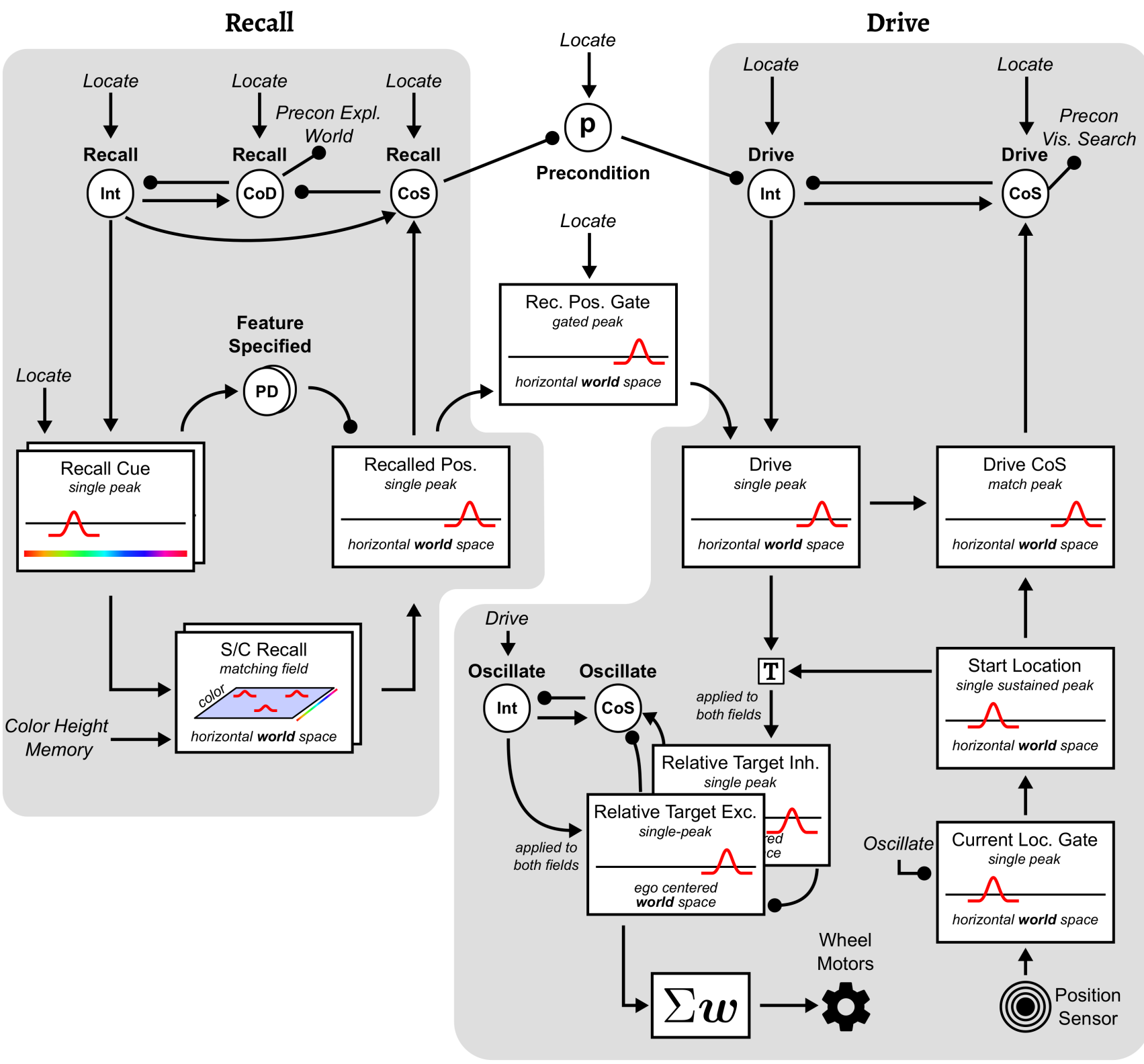



Recall
Drive
Locate
Locate
Locate
Precon Expl. World
Recall
Recall
Recall
Int
CoD
CoS
p
Precondition
Locate
Rec. Pos. Gate
gated peak
horizontal world space
Locate
Locate
Precon Vis. Search
Drive
Drive
Int
CoS
Feature Specified
Locate
PD
Recall Cue
single peak
Recalled Pos.
single peak
horizontal world space
Drive
single peak
horizontal world space
Drive CoS
match peak
horizontal world space
S/C Recall
matching field
color
horizontal world space
Color Height Memory
Drive
Oscillate
Oscillate
Int
CoS
T
applied to both fields
Start Location
single sustained peak
horizontal world space
Relative Target Inh.
single peak
Relative Target Exc.
single-peak
ego centered world space
applied to both fields
Oscillate
Current Loc. Gate
single peak
horizontal world space
Wheel Motors
Σw
Position Sensor


KUKA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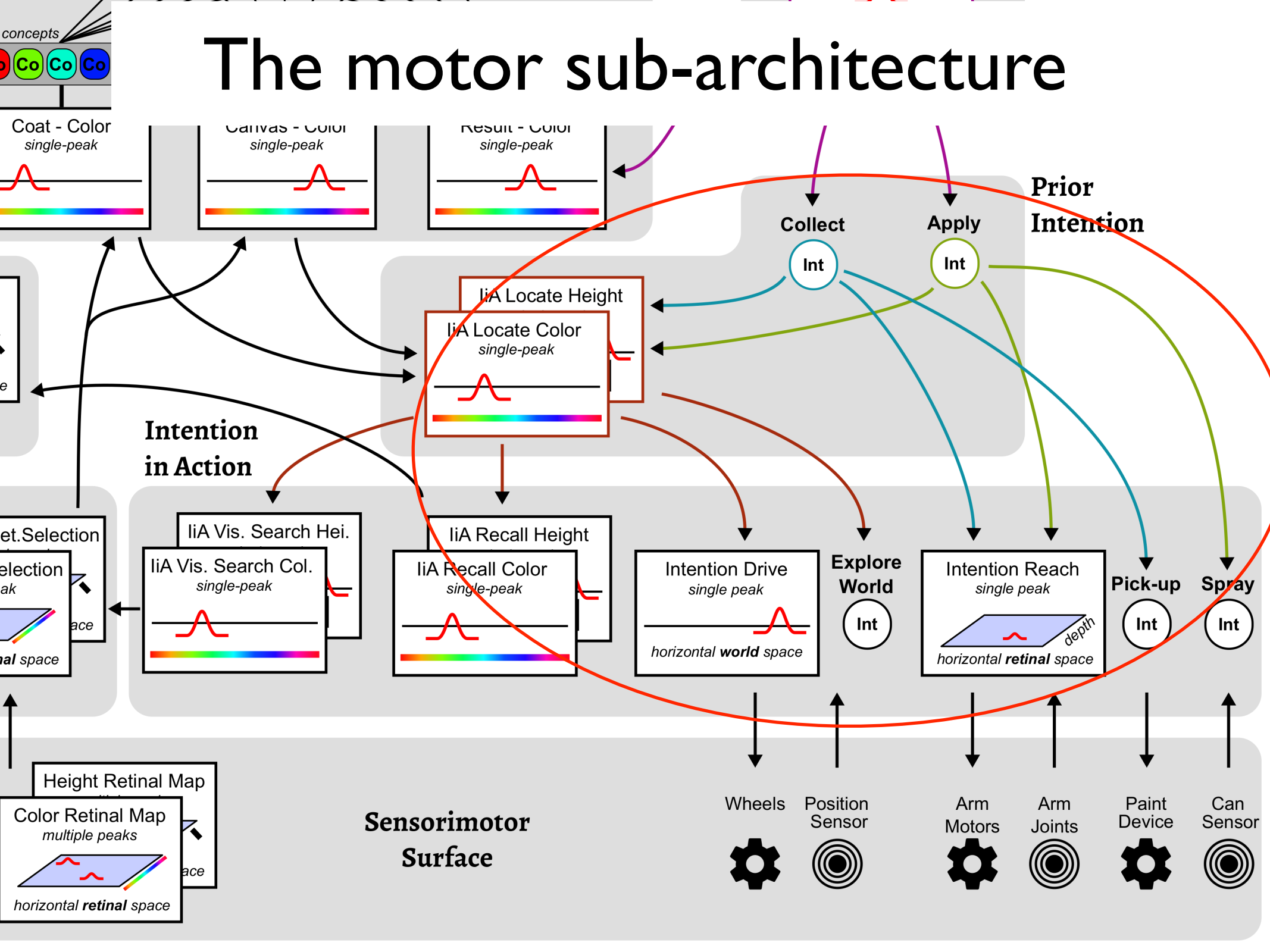
single peak
horizontal world space
Wheel Motors
Σw
Position Sensor

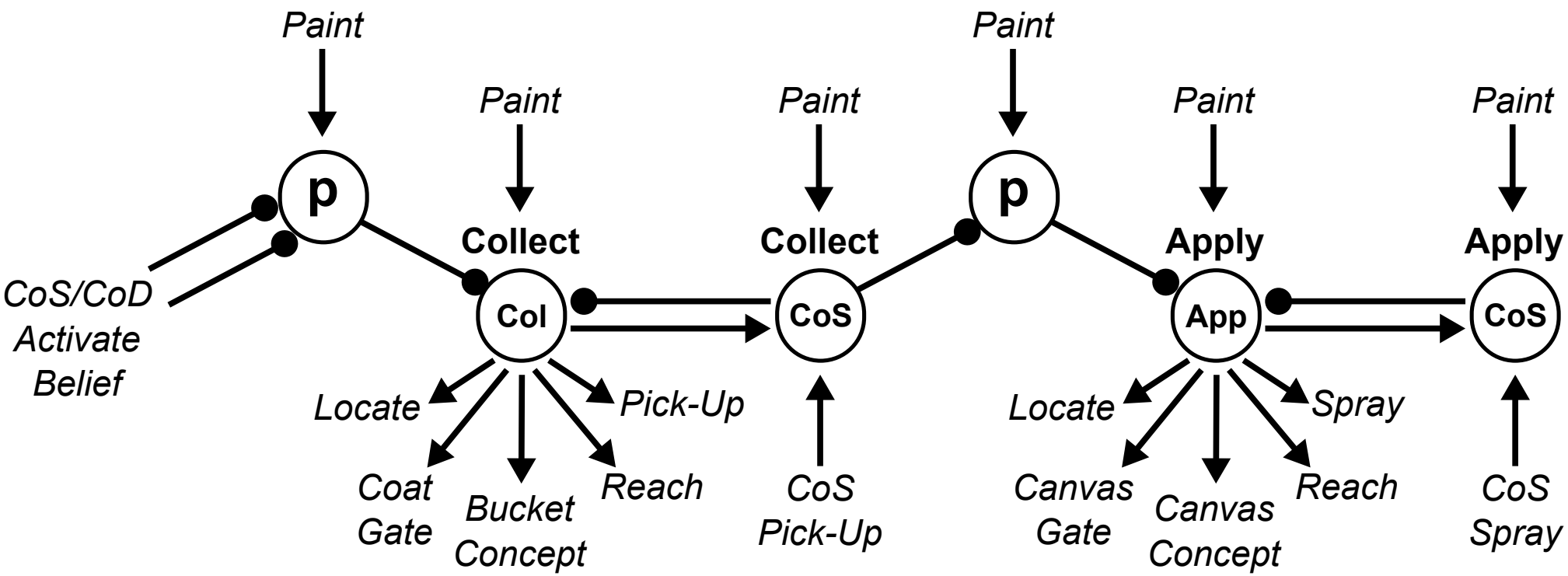
Recall from memory

- is a "motor" intention… (a world-to-mind intention)
- as it is aimed at achieving a particular state of the mind (which is part of the world)

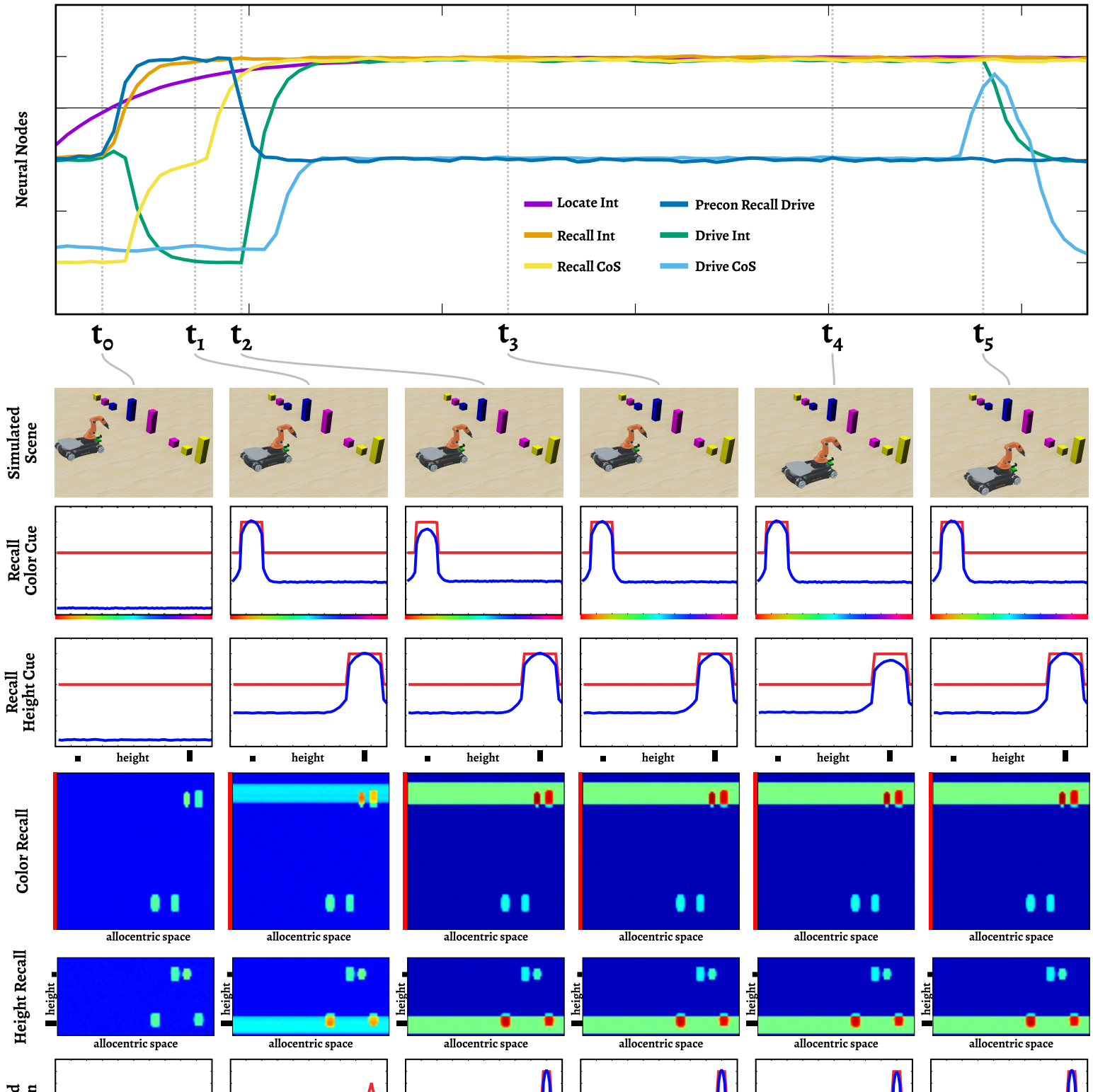
The motor sub-architecture



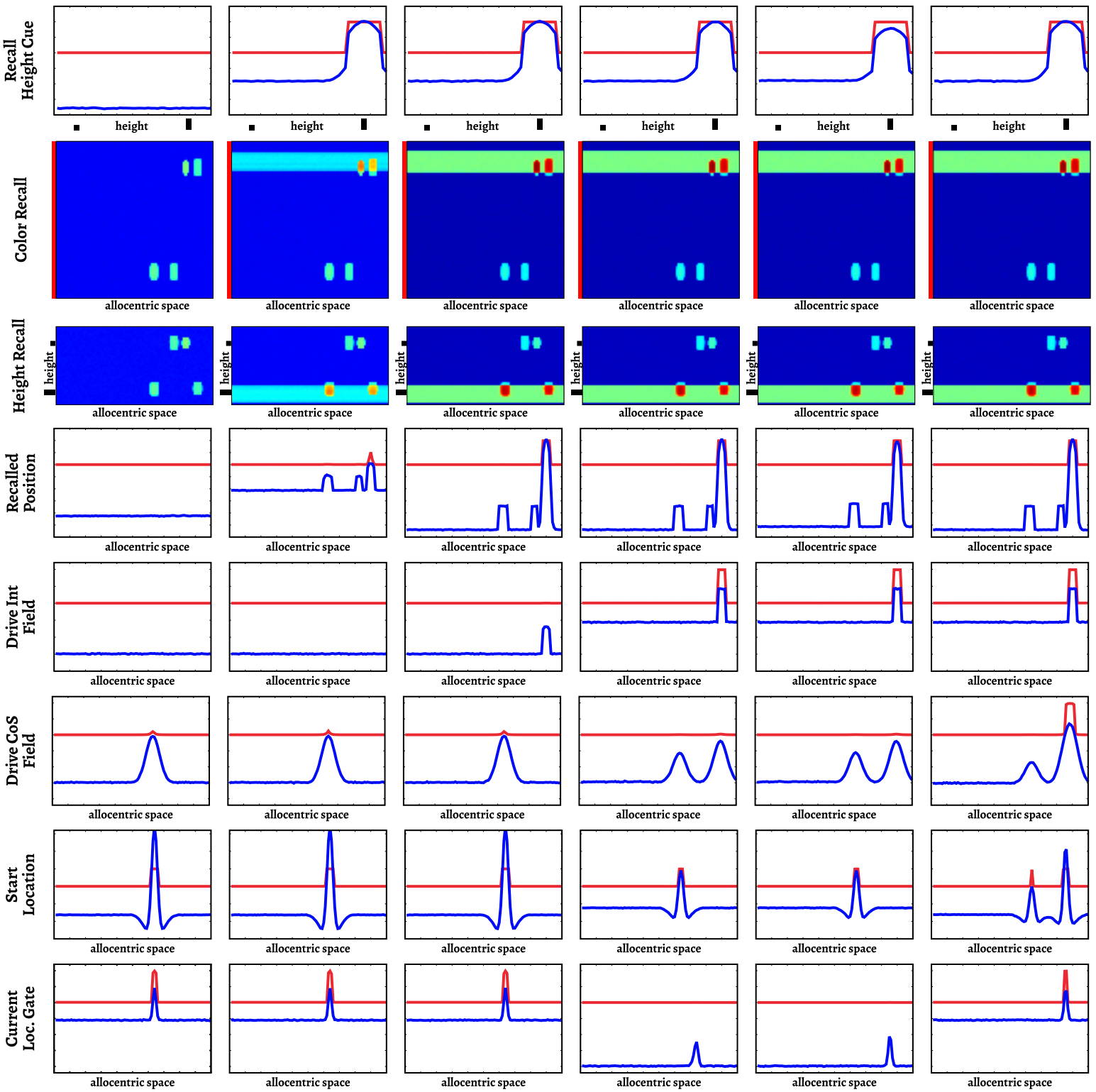
- chaining to organize the paint behavior



Recall and drive

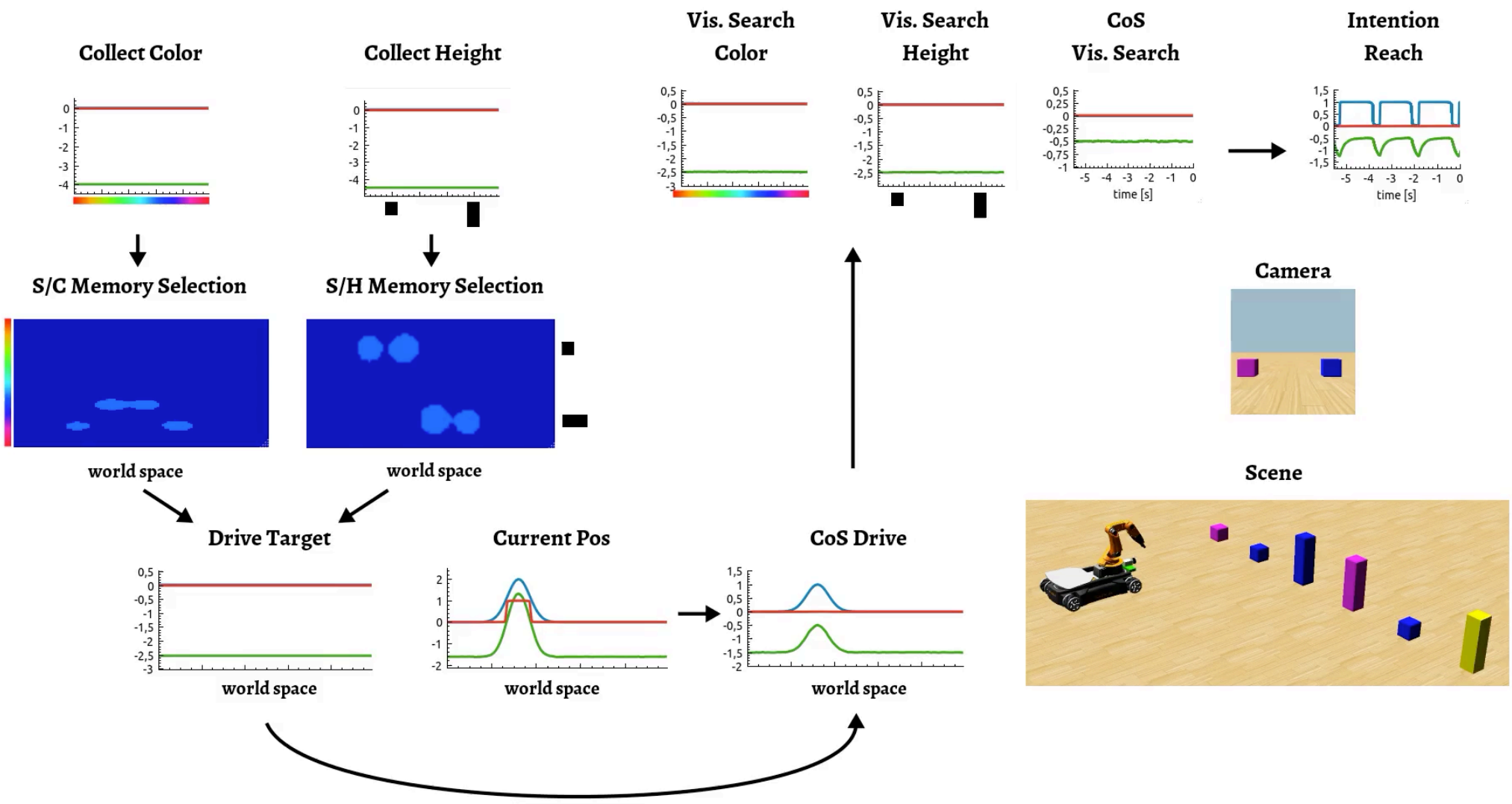


Recall and drive

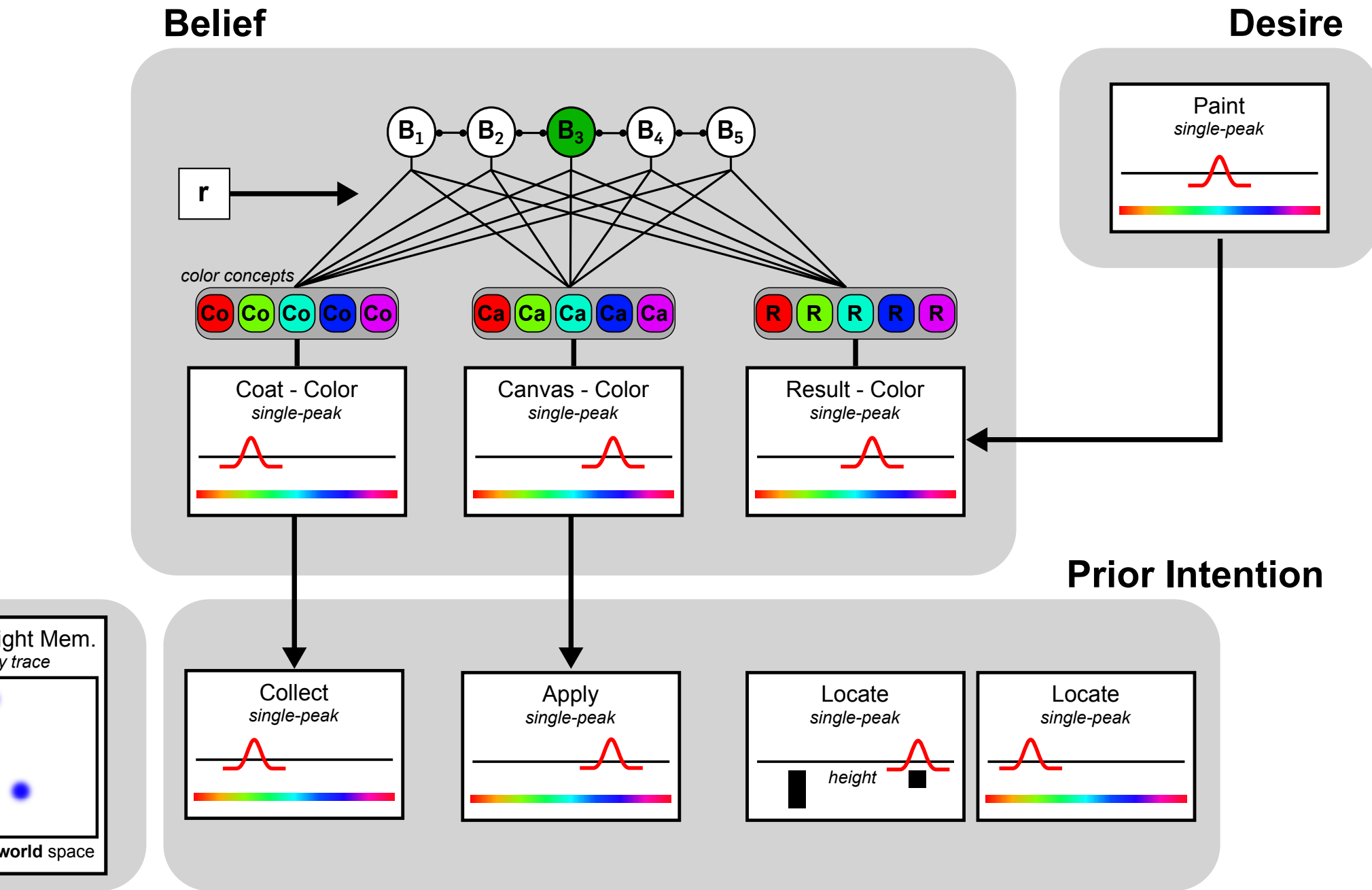


Recall-drive-search

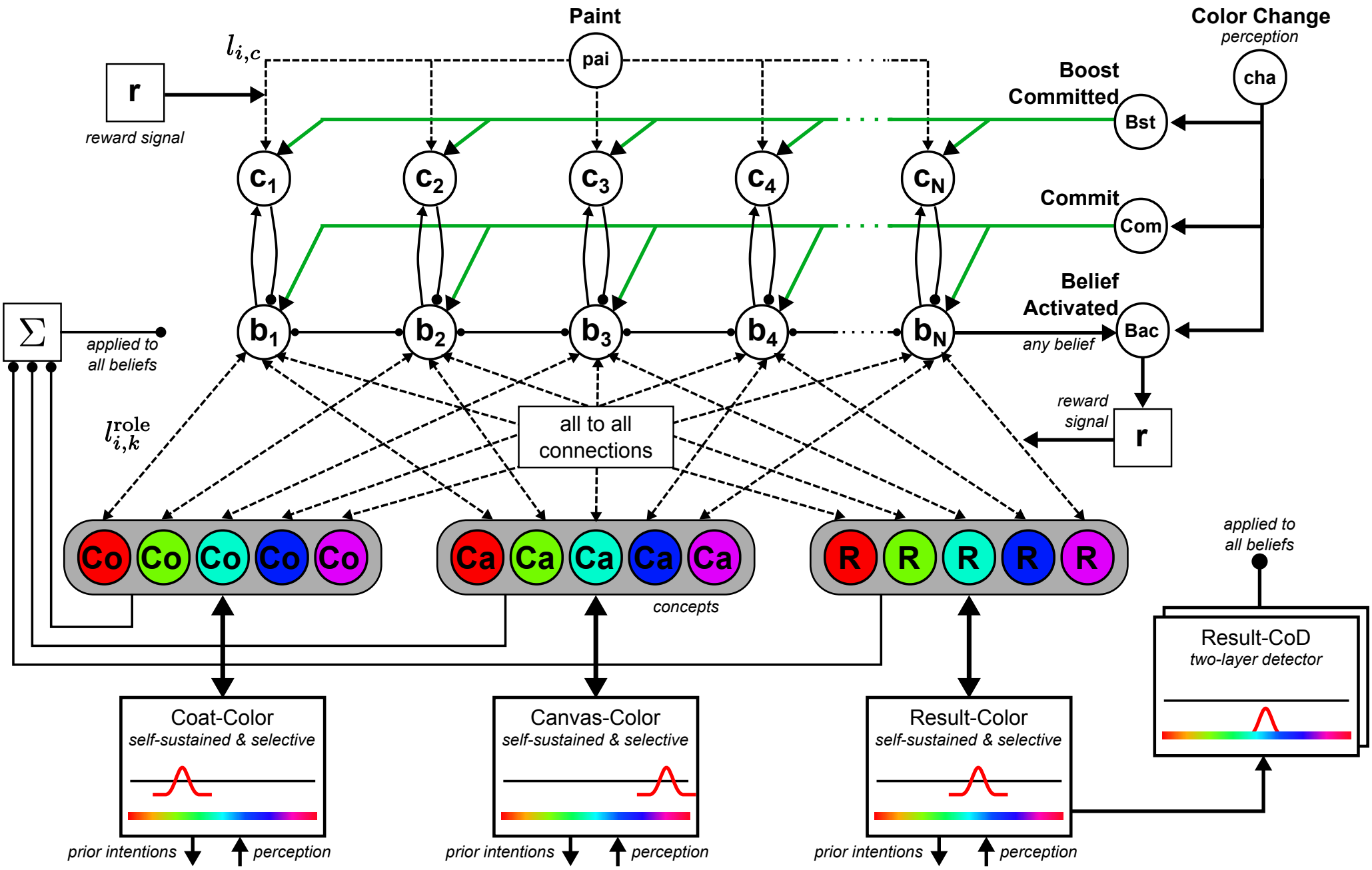
[based on a desire and an activated belief, looking for a tall pink object, which is in memory]



The belief sub-architecture

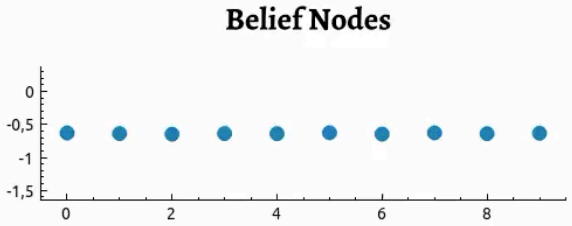


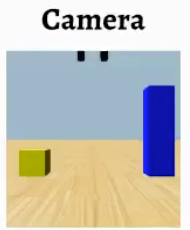
Learning a new belief

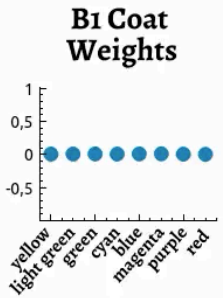


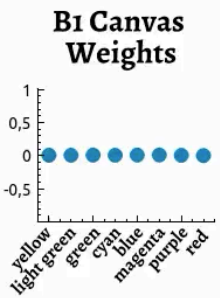
Learn a new belief

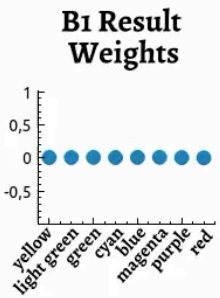
[while exploring: applying blue paint to yellow cube]

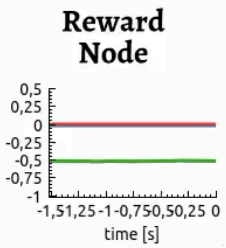


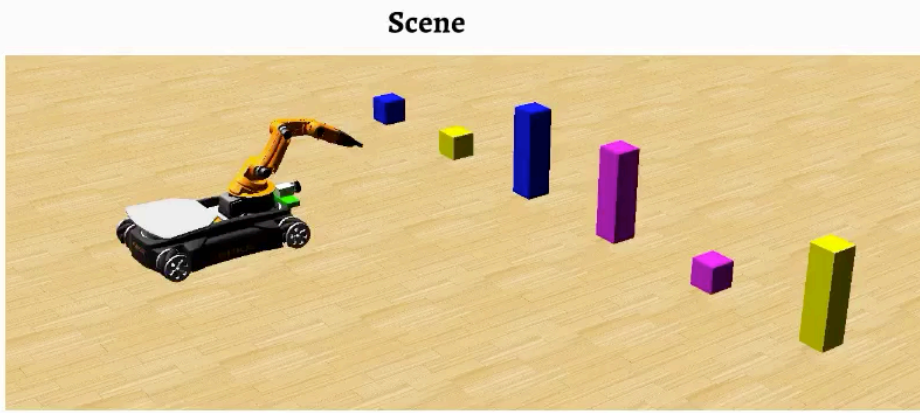


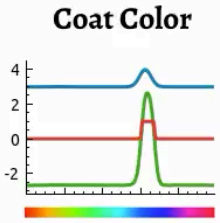


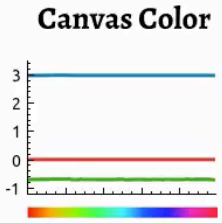


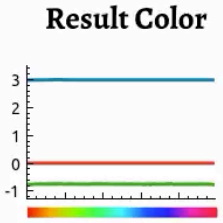


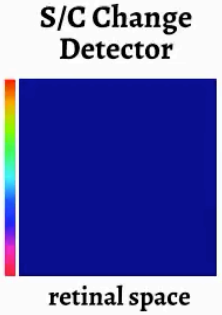






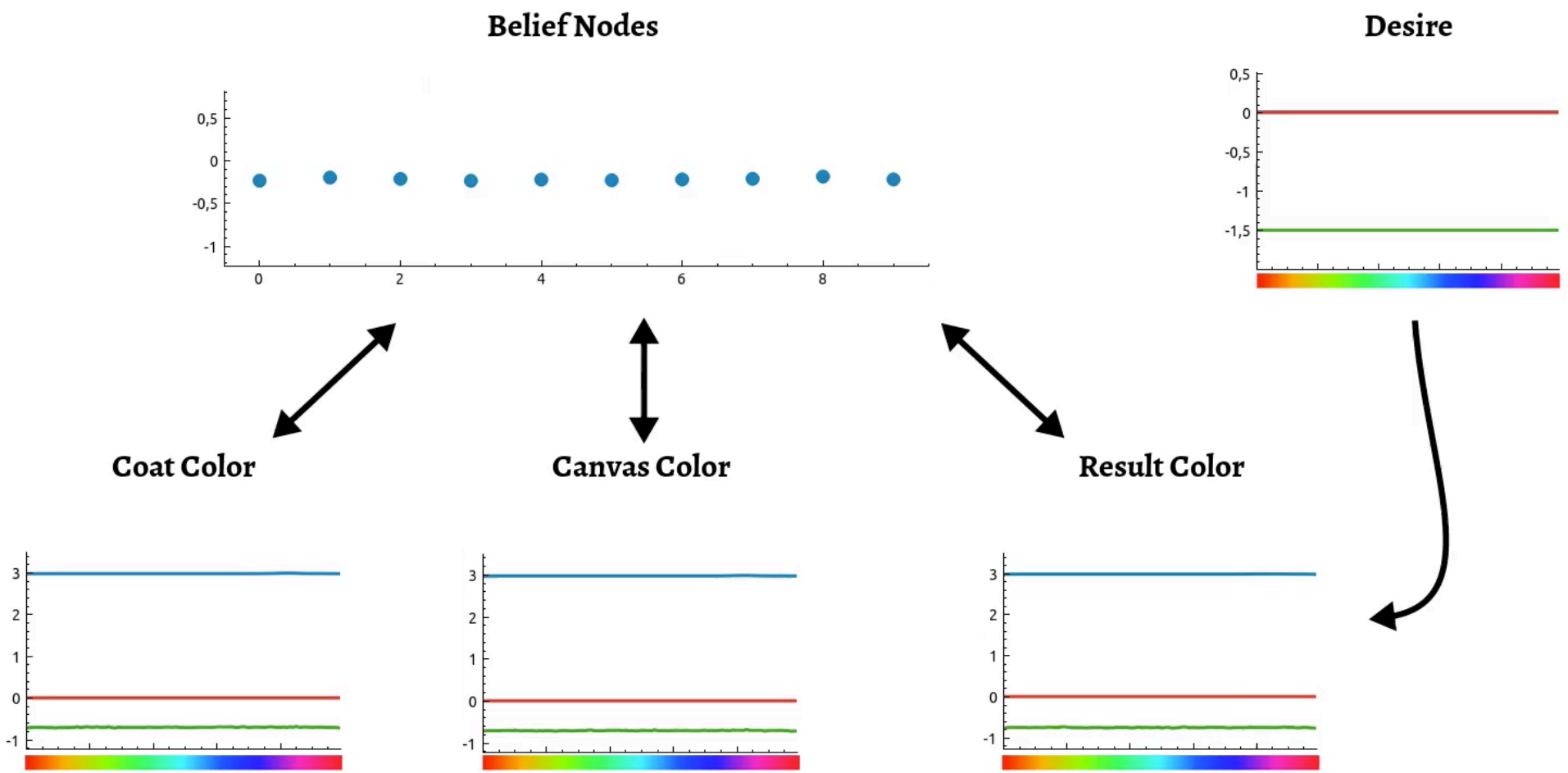




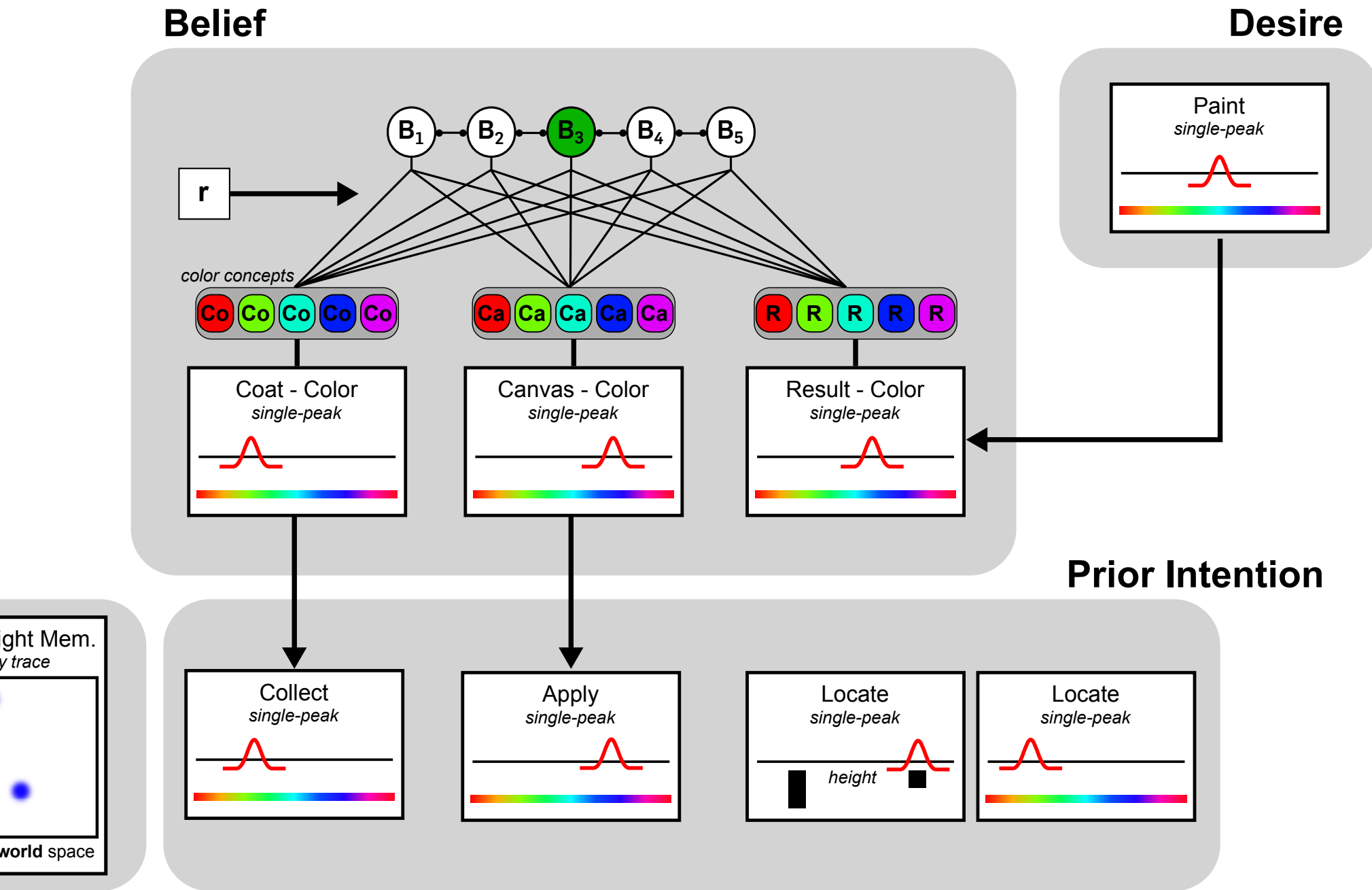


Recall a belief

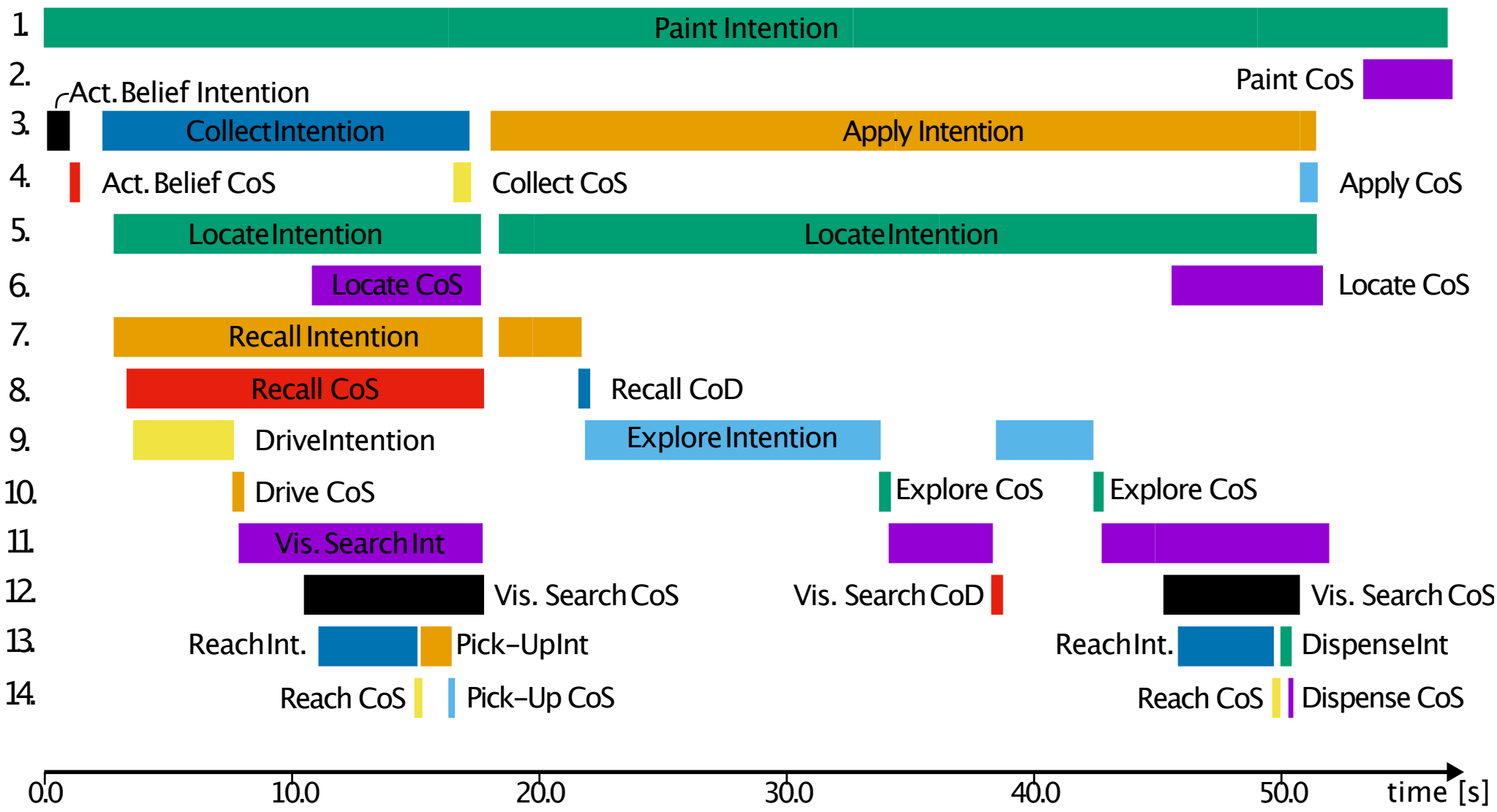
[triggered by a desire and objects in scene memory]



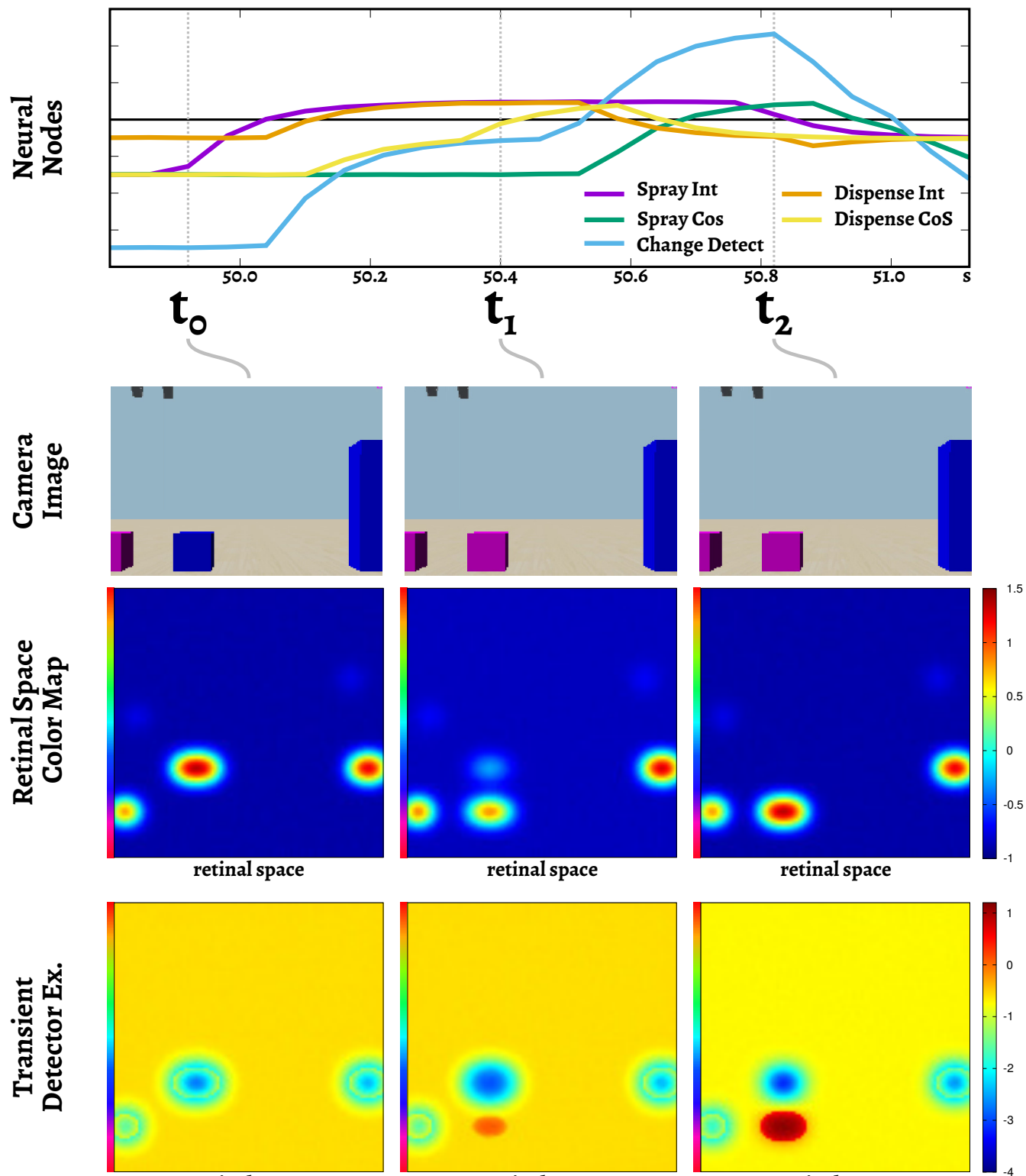
The desire sub-architecture



Achieving a desire

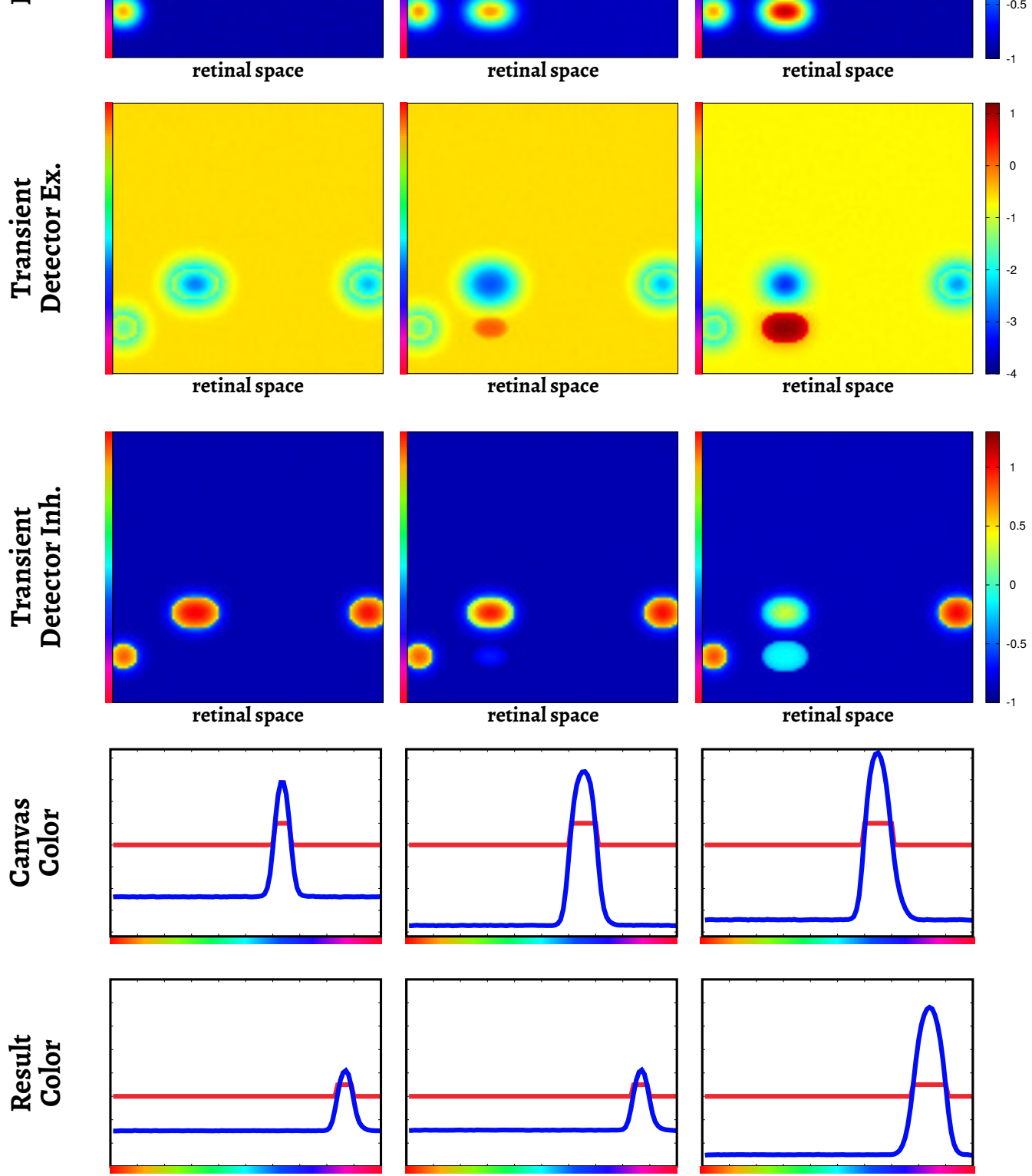


Spray


Neural Nodes
Spray Int
Spray Cos
Change Detect
Dispense Int
Dispense CoS
50.0
50.2
50.4
50.6
50.8
51.0
s
t_0
t_1
t_2
Camera Image
Retinal Space Color Map
retinal space
retinal space
retinal space
1.5
1
0.5
0
-0.5
-1
Transient Detector Ex.
1
0
-1
-2
-3
-4

Spray

uses transient detection to detect the change of color



Conclusion: The two directions of fit

- processes in the two directions of fit differ in their temporal structure
  - W2M: intention on, CoS on, then both off
  - M2W: intention=CoS on as long as state is present
- insight that processes underlying visual cognition are W2M ("motor")
  - visual search
  - recall from memory
- expect "thinking" (inference, reasoning) to be similarly W2M

Conclusion: The six psychological modes

- are all reached by DFT
- (desire/goals poor here… goal switching etc are possible extensions)

Conclusion: Scaling

- the neural dynamics scales due to the robustness of attractor solutions