

DFT Foundations 3: Learning

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Patterns of connectivity give meaning to neural fields

- how do these patterns arise?

- morphogenesis... modeled by fixed connectivity

- learning...

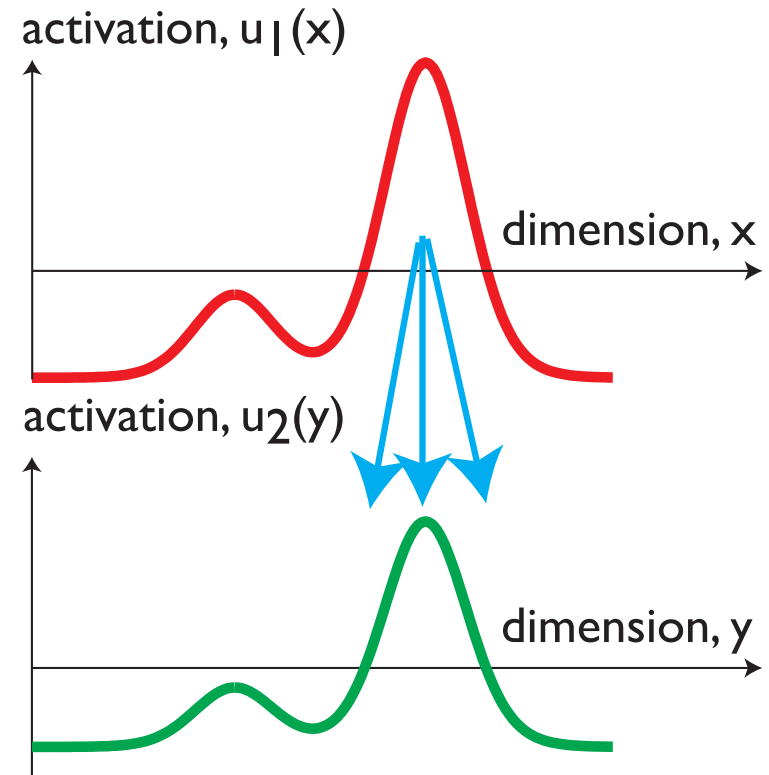
Hebbian learning

■ Hebbian learning of projections

■ among fields

■ forward from sensory input to fields

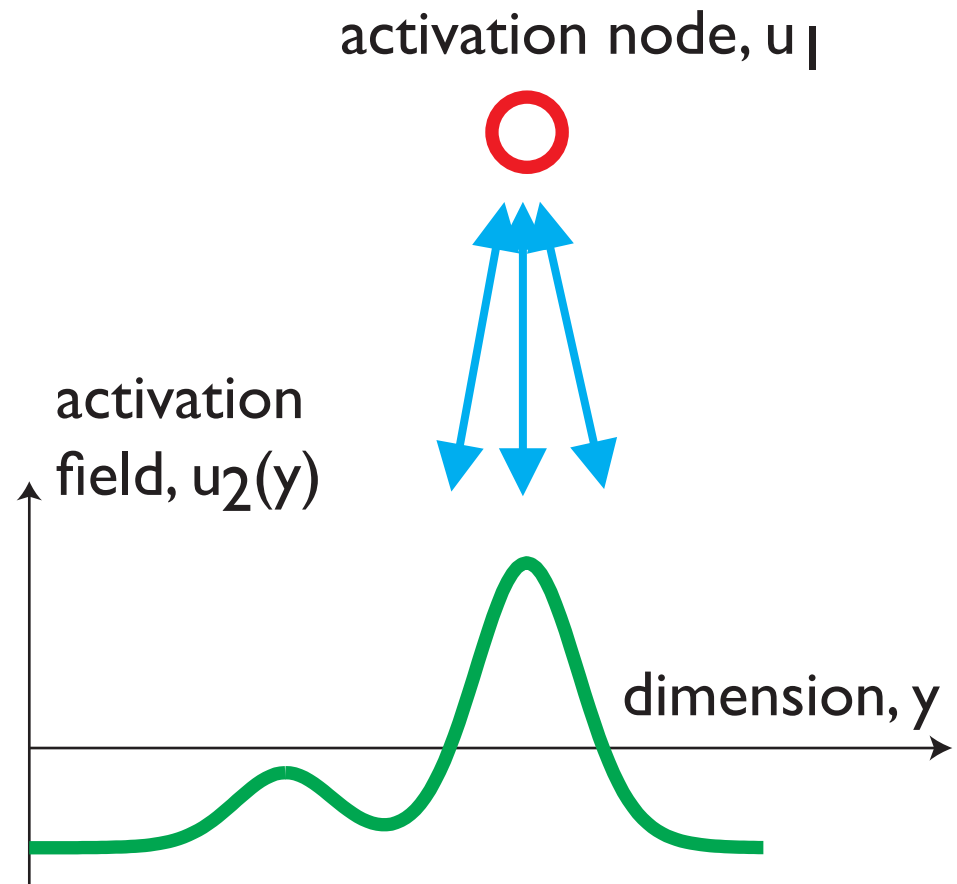
■ interaction leads to localized rather than distributed representations (SOM)



$$\tau \dot{W}(x, y, t) = \epsilon(t) \left(-W(x, y, t) + f(u_1(x, t)) \times f(u_2(y, t)) \right)$$

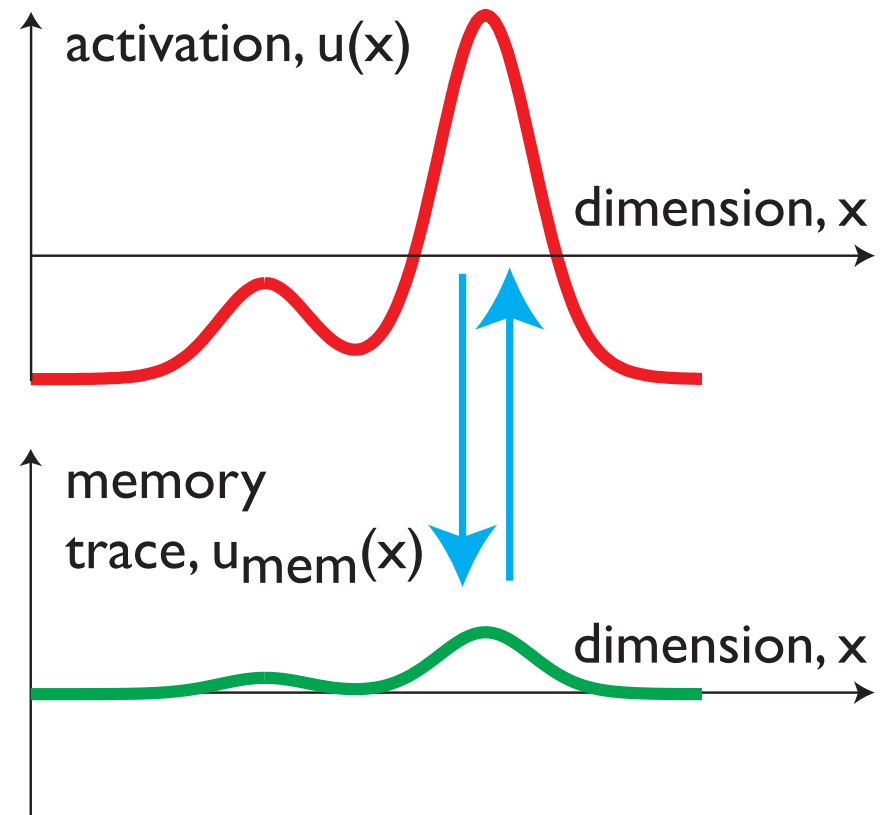
Hebbian learning

- learning reciprocal connections between zero-dimensional nodes and fields
- \Rightarrow grounded concepts
- analogous to the output layer of DNN
- \Rightarrow ensembles of such nodes coupled inhibitorily form the basis for conceptual thinking...



The memory trace

- facilitatory trace of patterns of activation
- in excitatory field: leads to sensitization
- in inhibitory field: leads to habituation

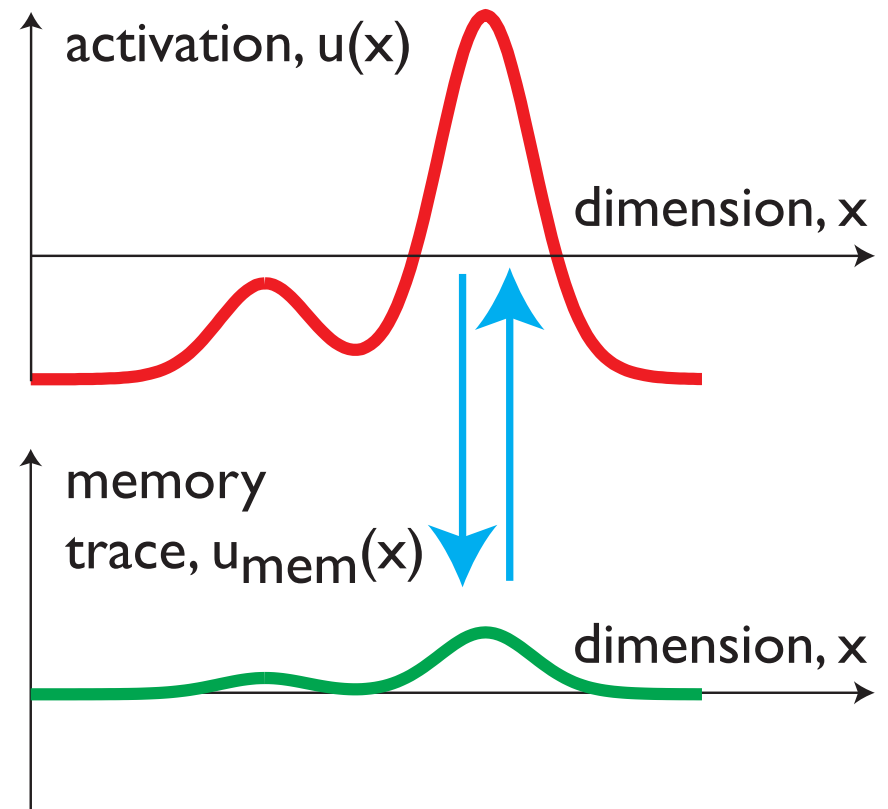


The memory trace

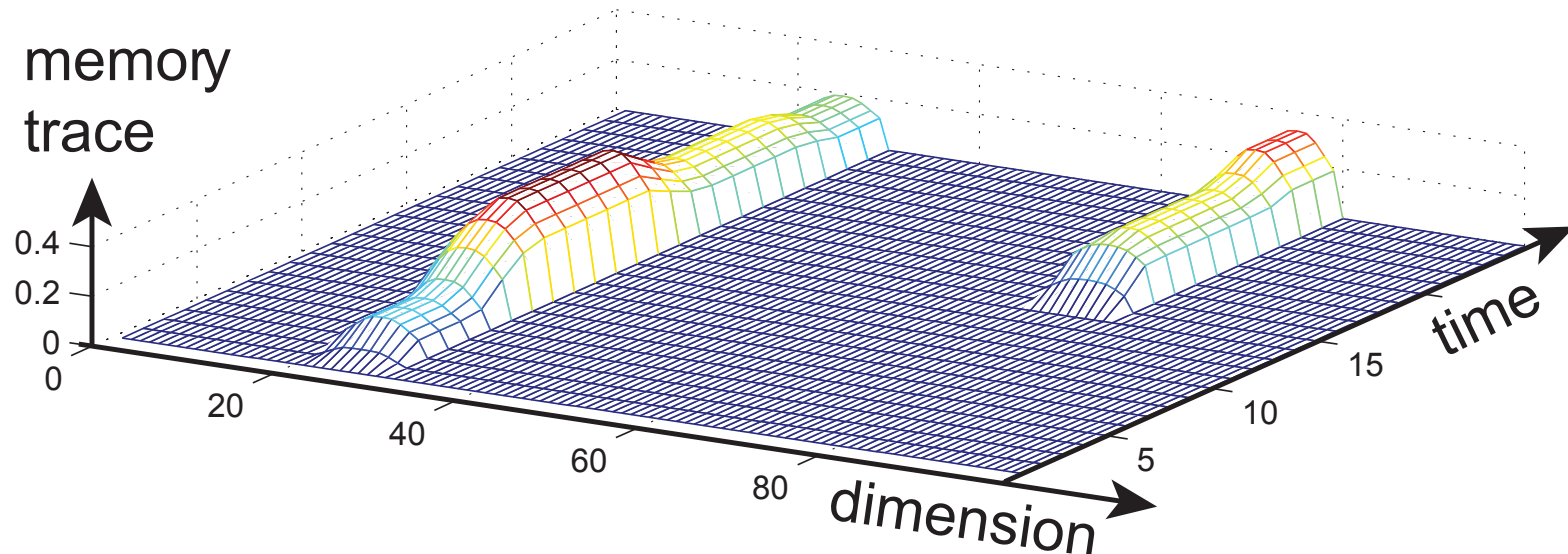
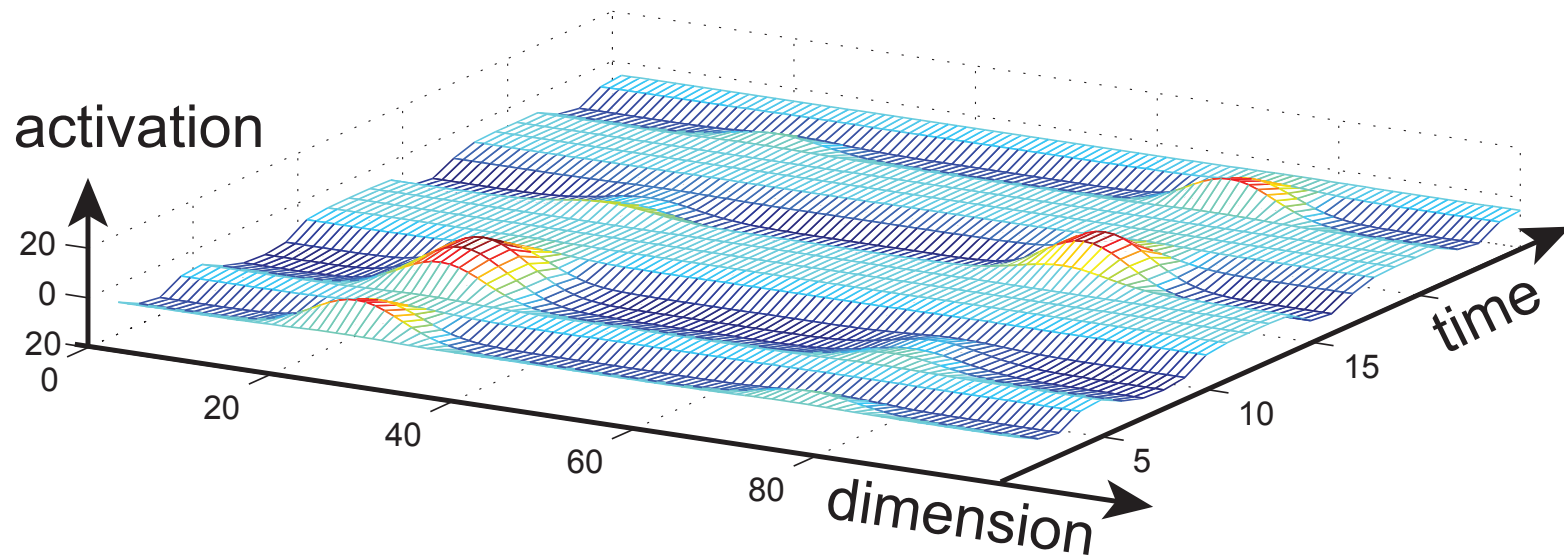
$$\tau \dot{u}(x, t) = -u(x, t) + h + s(x, t) + \int dx' w(x - x') \sigma(u(x', t)) + u_{\text{mem}}$$

$$\tau_{\text{mem}} \dot{u}_{\text{mem}}(x, t) = -u_{\text{mem}}(x, t) + \sigma(u(x, t))$$

$$\tau_{\text{mem}} \dot{u}_{\text{mem}}(x, t) = 0 \quad \text{if} \quad \int dx' \sigma(u(x', t)) \approx 0$$

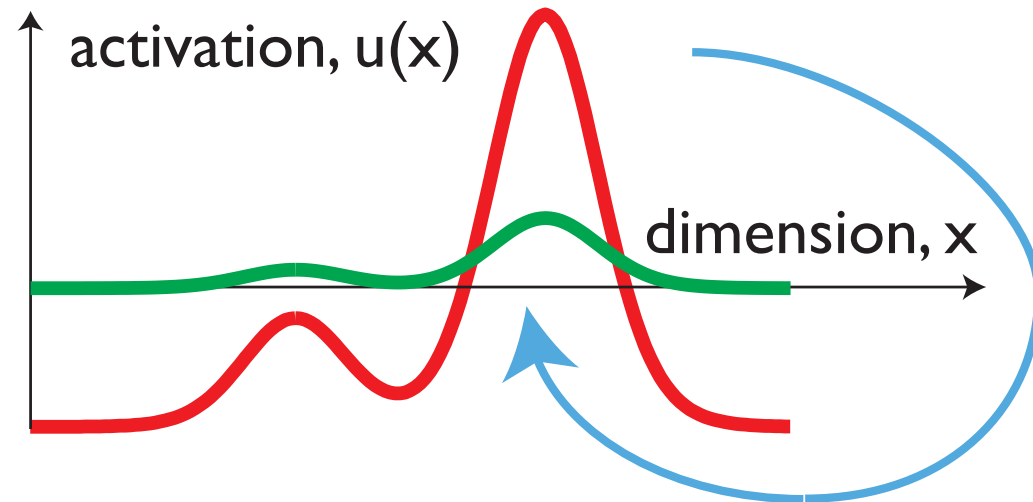


=> the memory trace reflects the history of detection decisions



Memory trace ~ first-order Hebbian learning

- increases local resting level at activated locations
- ~ the bias input in NN
- boost-driven detection instability amplifies small bias => important role in DFT



The memory trace is functionally different from conventional Hebbian learning

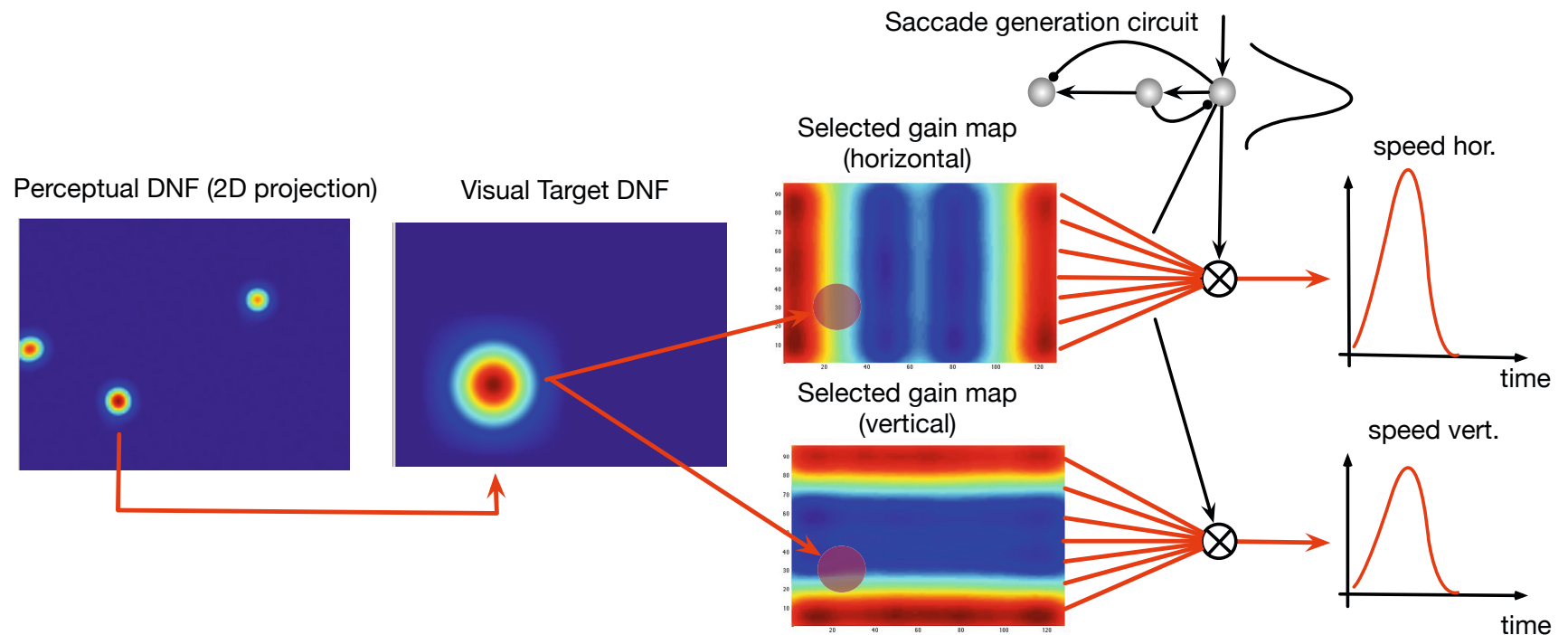
- the memory trace enables the re-activation of a past pattern of activation even when the input that caused the past pattern of activation is absent
- this is the basis for cued recall in DFT

Autonomous learning

- Learning from experience..
- .. which requires first.. experience!
- Hypothesis; this is what learning in humans and other animals entails!

Variants of autonomous learning: Adaptation

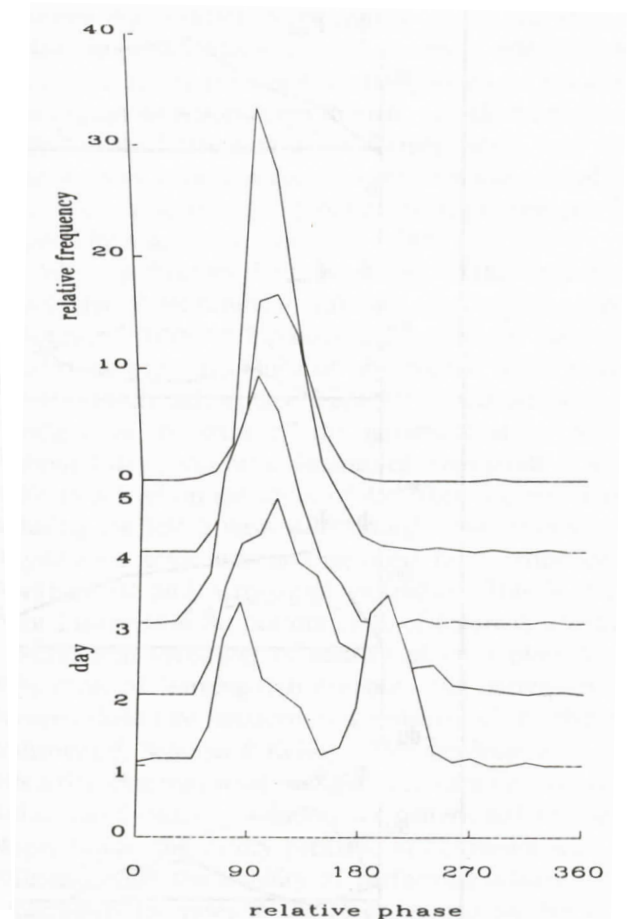
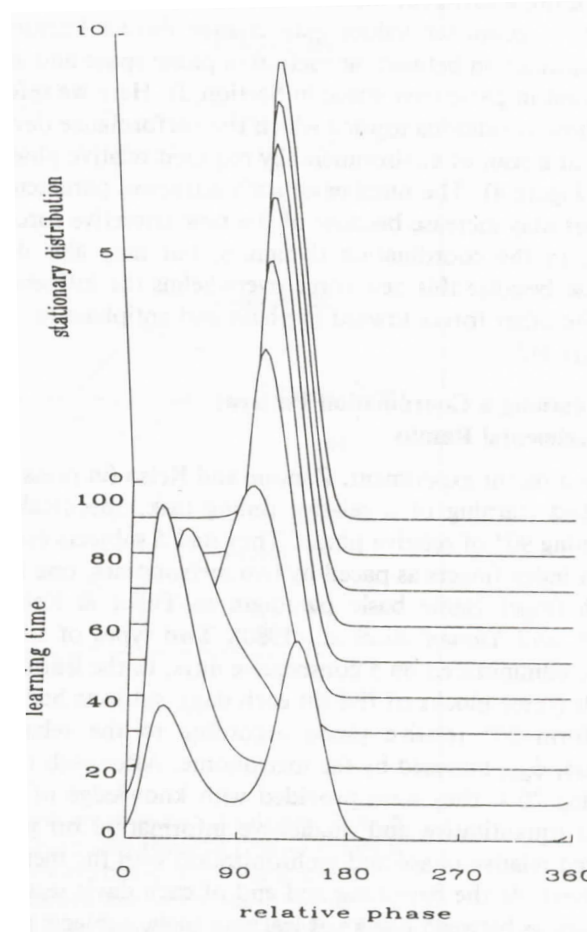
- Example: adjusting gain of saccadic eye movements... Sandamirskaya et al
- even this “simple” form of adaptation requires extensive processing infrastructure



[Storck, Sandamirskaya, *LNCS* 2014]

Variants of autonomous learning: Skill

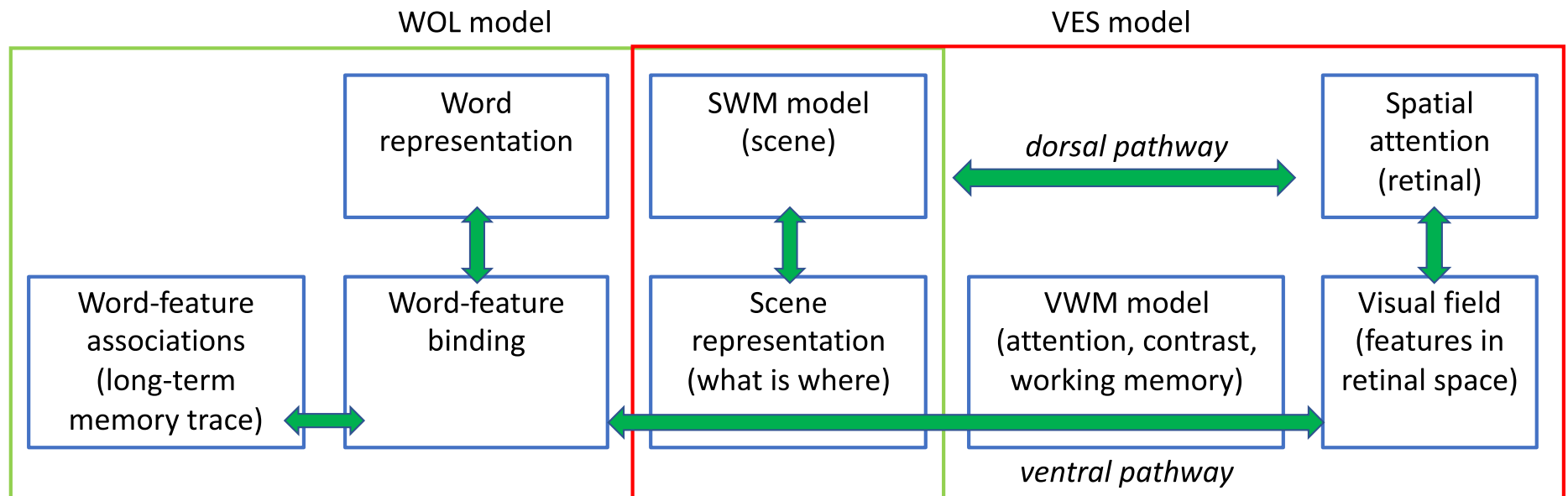
- Old work in movement coordination... suggests that learning is change of dynamics... stabilization of new patterns
- related work in multi-joint movement



[Schöner, Zanone,
Kelso, *JMB*, 1992\

Variants of autonomous learning: Words

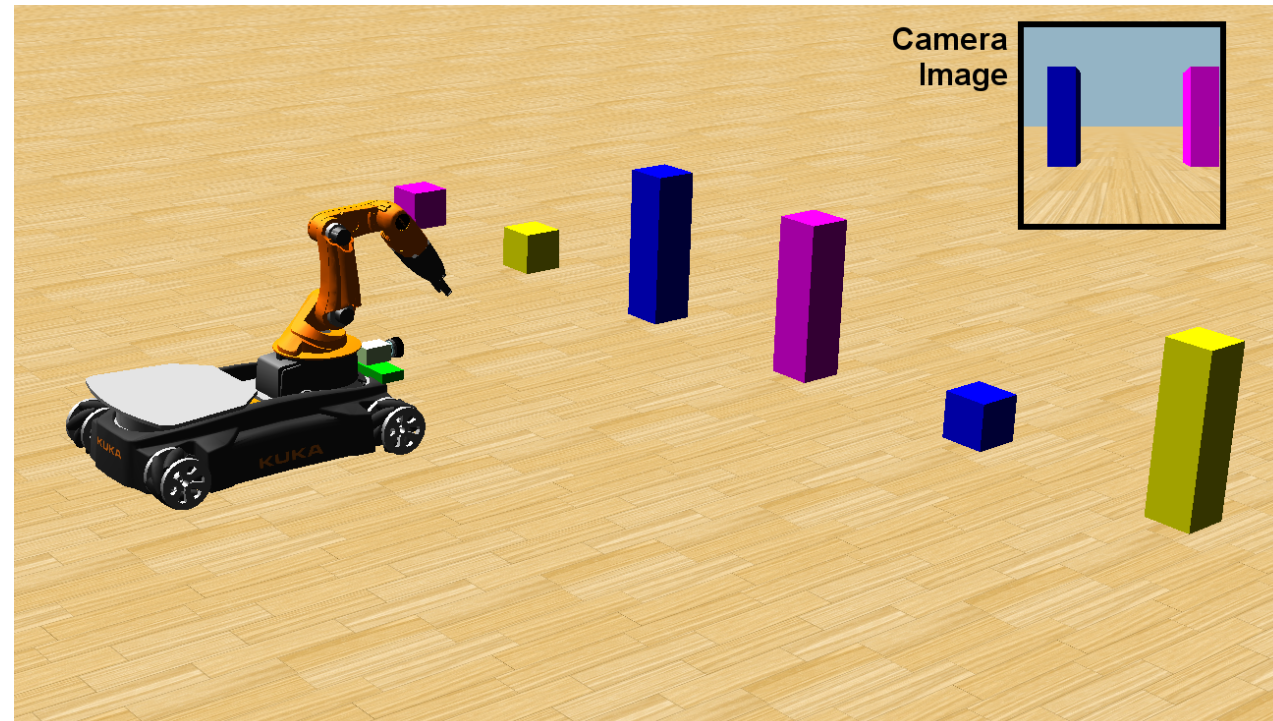
- linking word representations (nodes) to features of objects
- tracking word-feature binding across episodes of experiencing the word (cross-situational word learning)



Variants of autonomous learning: Contingencies

- learning regularities in the world (contingencies, rules) by acting on the world
- an important part of development

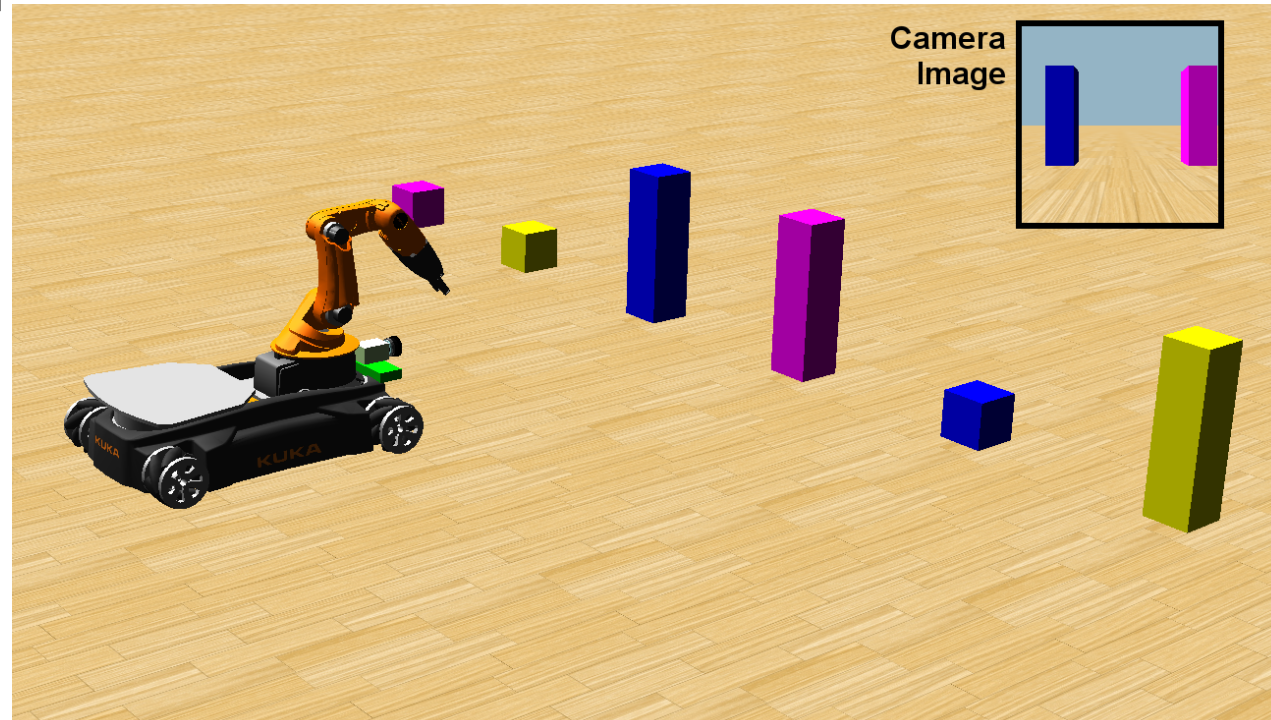
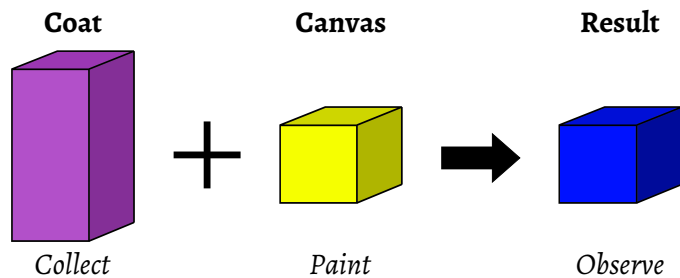
■ DFT: an intentional agent acts on the world and gathers experience: later lecture



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

Variants of autonomous learning: Contingencies

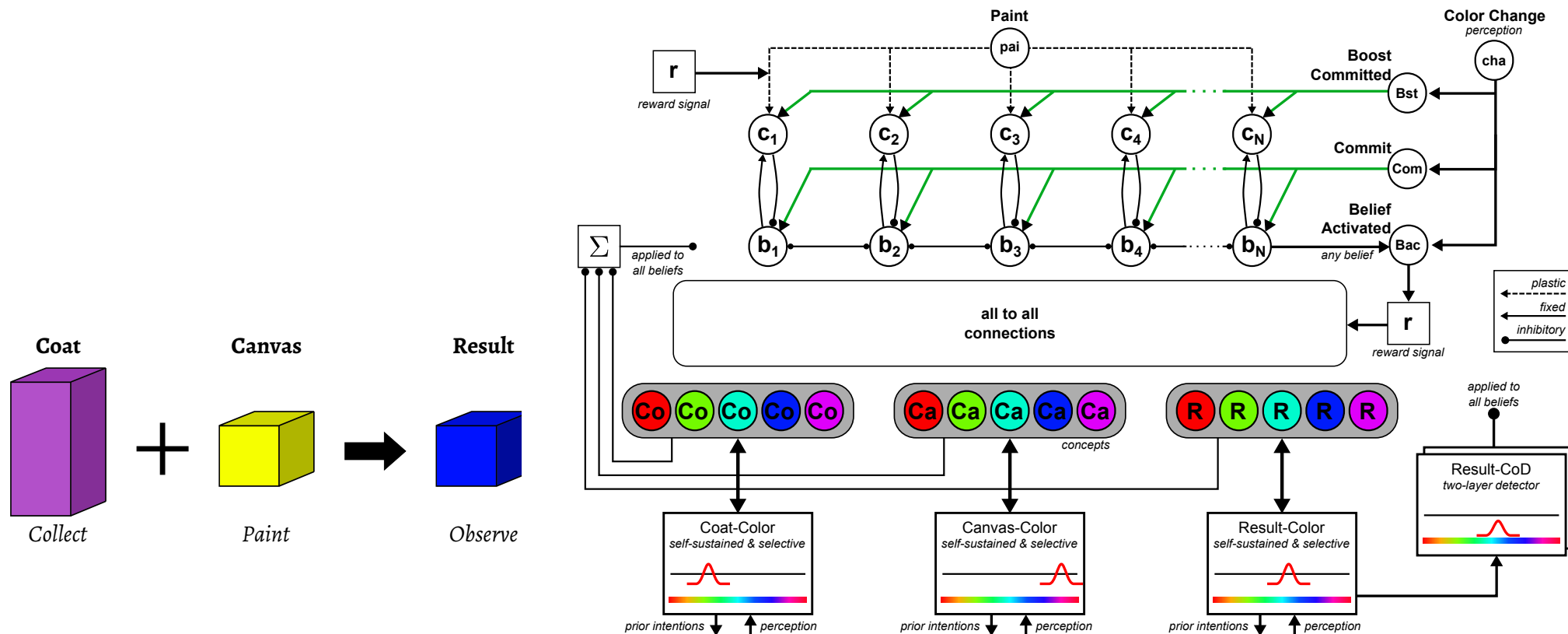
- learns color rules of painting from a single episode of this sequences of events:
- collects paint of a given color from a container (coat)
- paints a canvas container
- observes result color



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

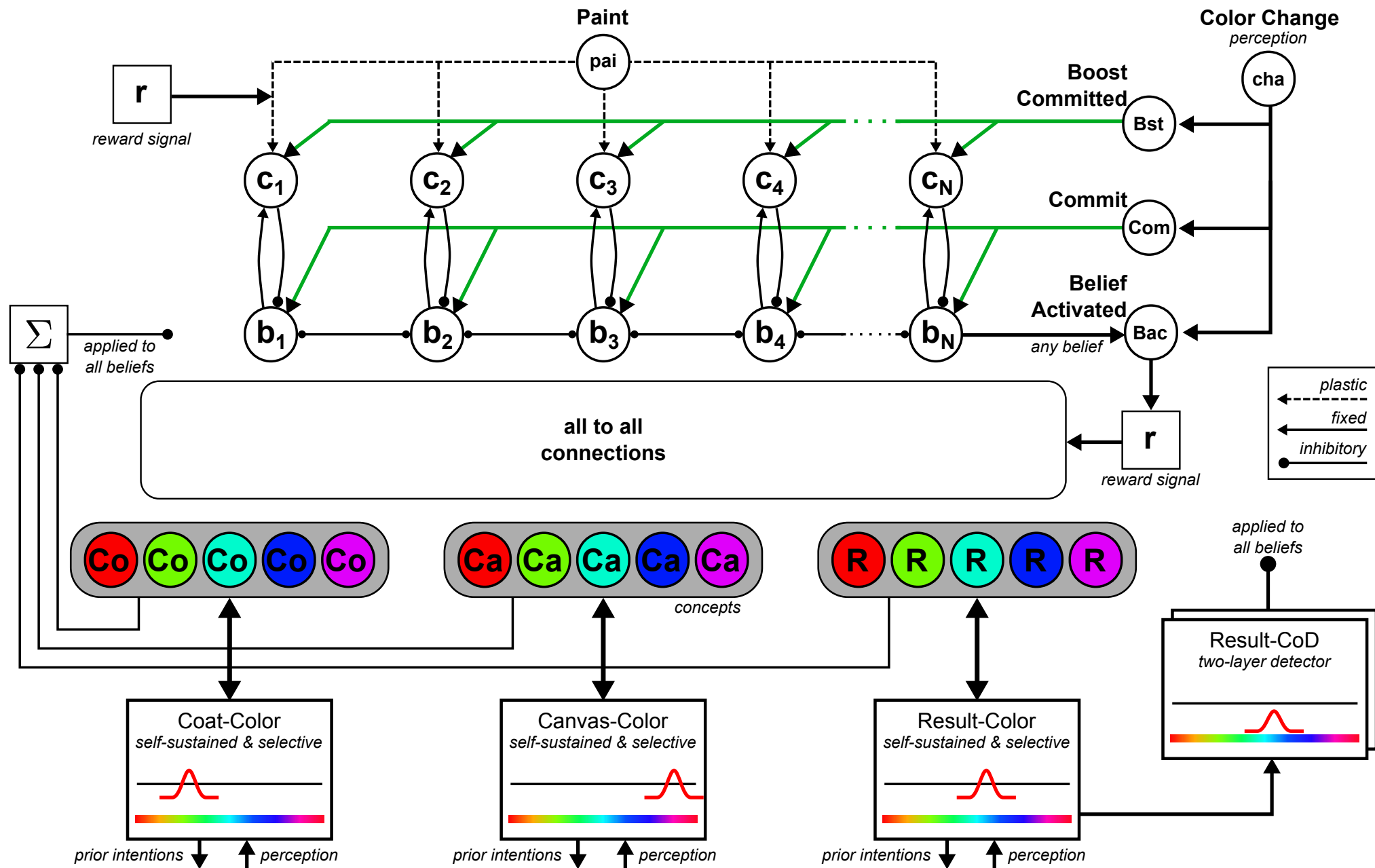
Variants of autonomous learning: Contingencies

- that learned contingency is represented as a “belief” in a network

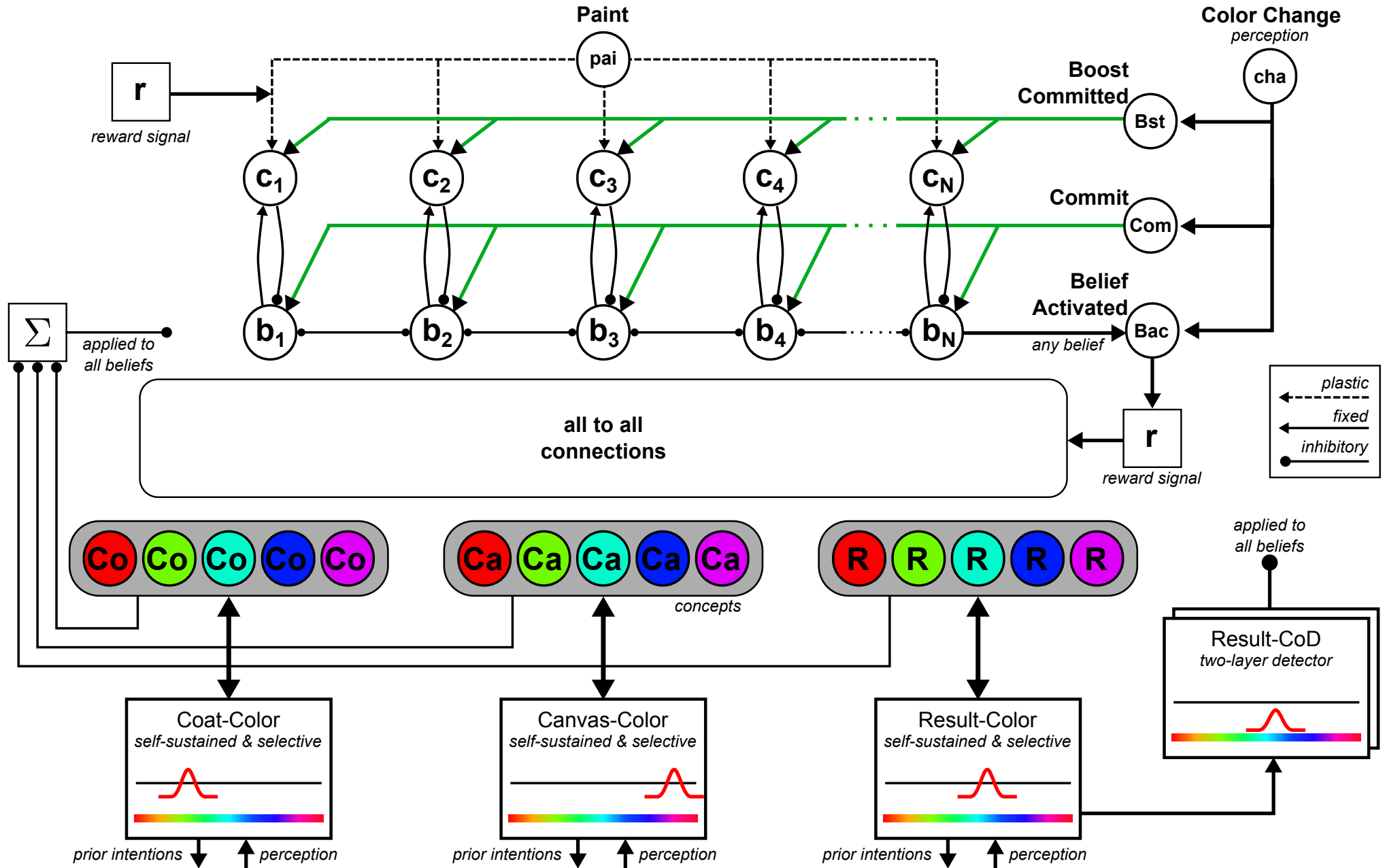


[Tekülve, Schöner, IEEE Trans Cog Dev Sys 2022;
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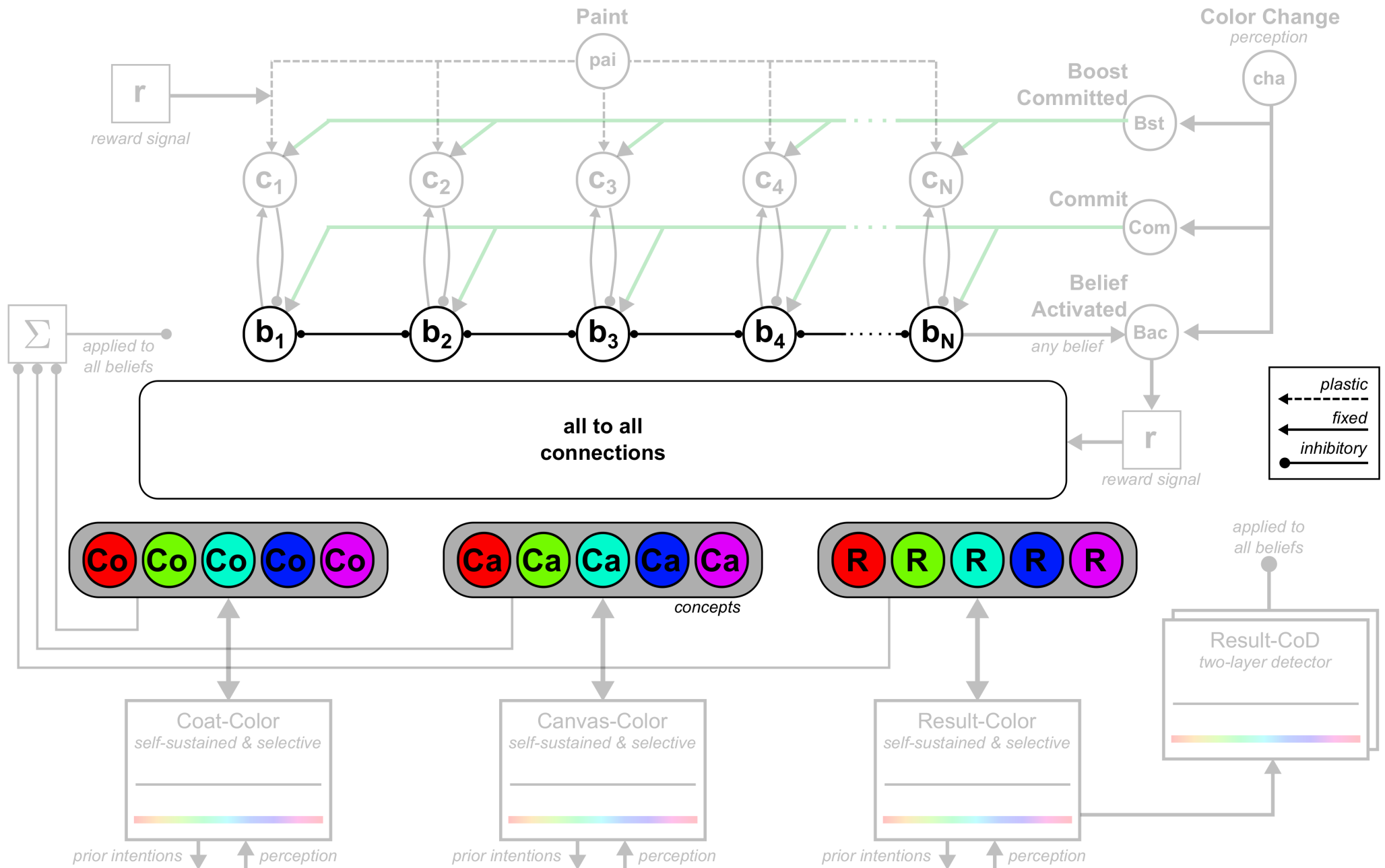
Belief network



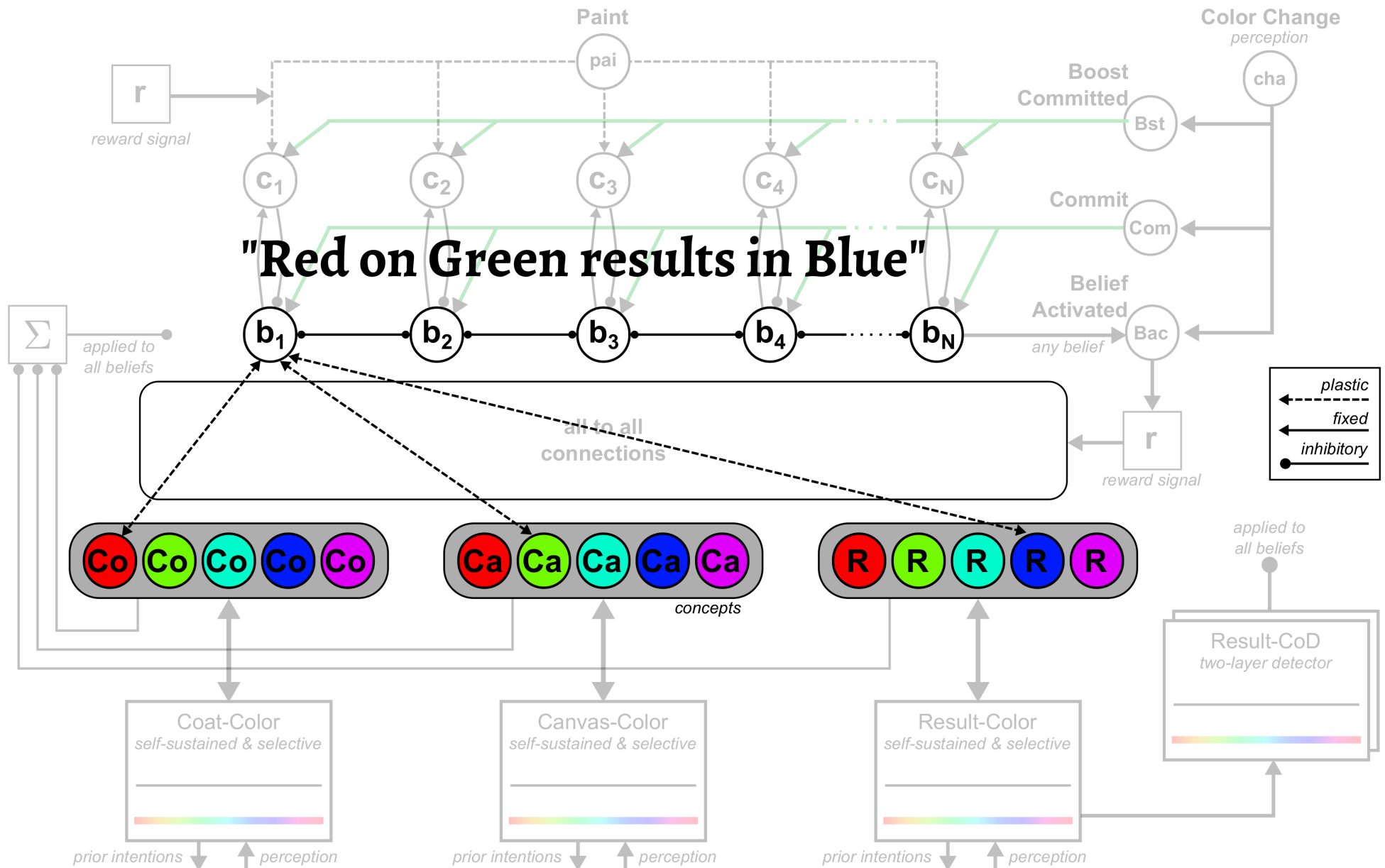
~Adaptive resonance ART Grossberg



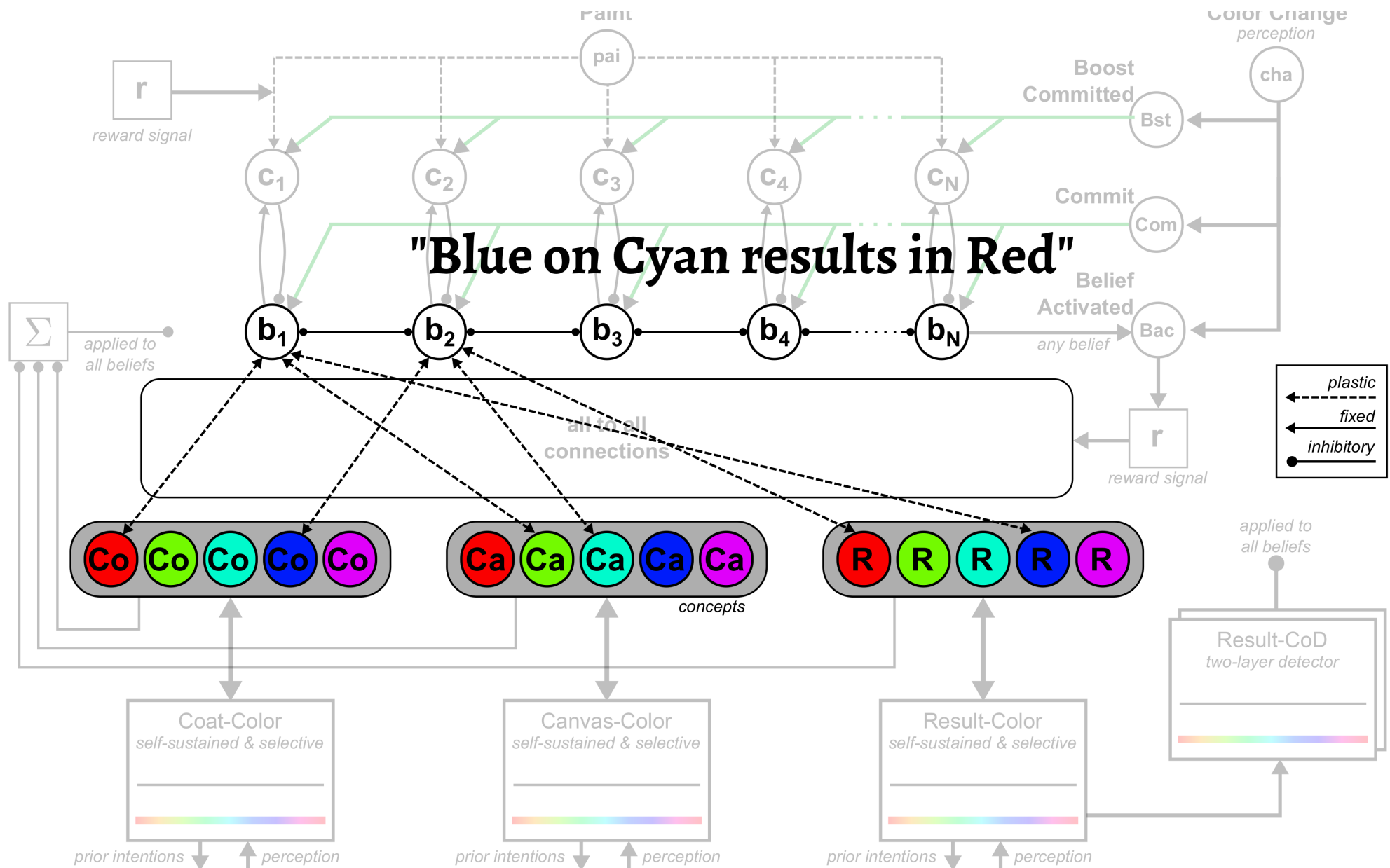
Belief and concept/role nodes



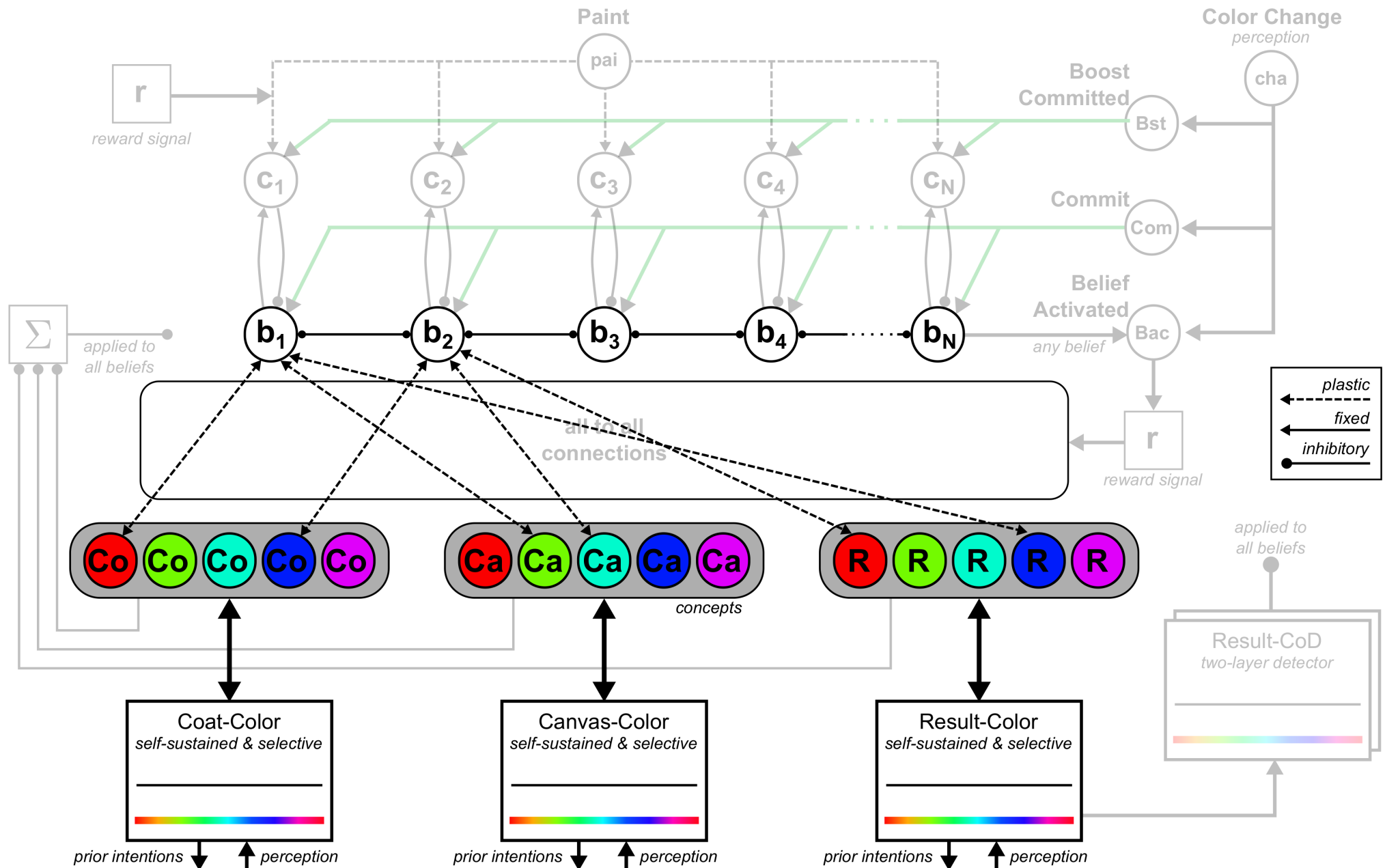
Representing a belief



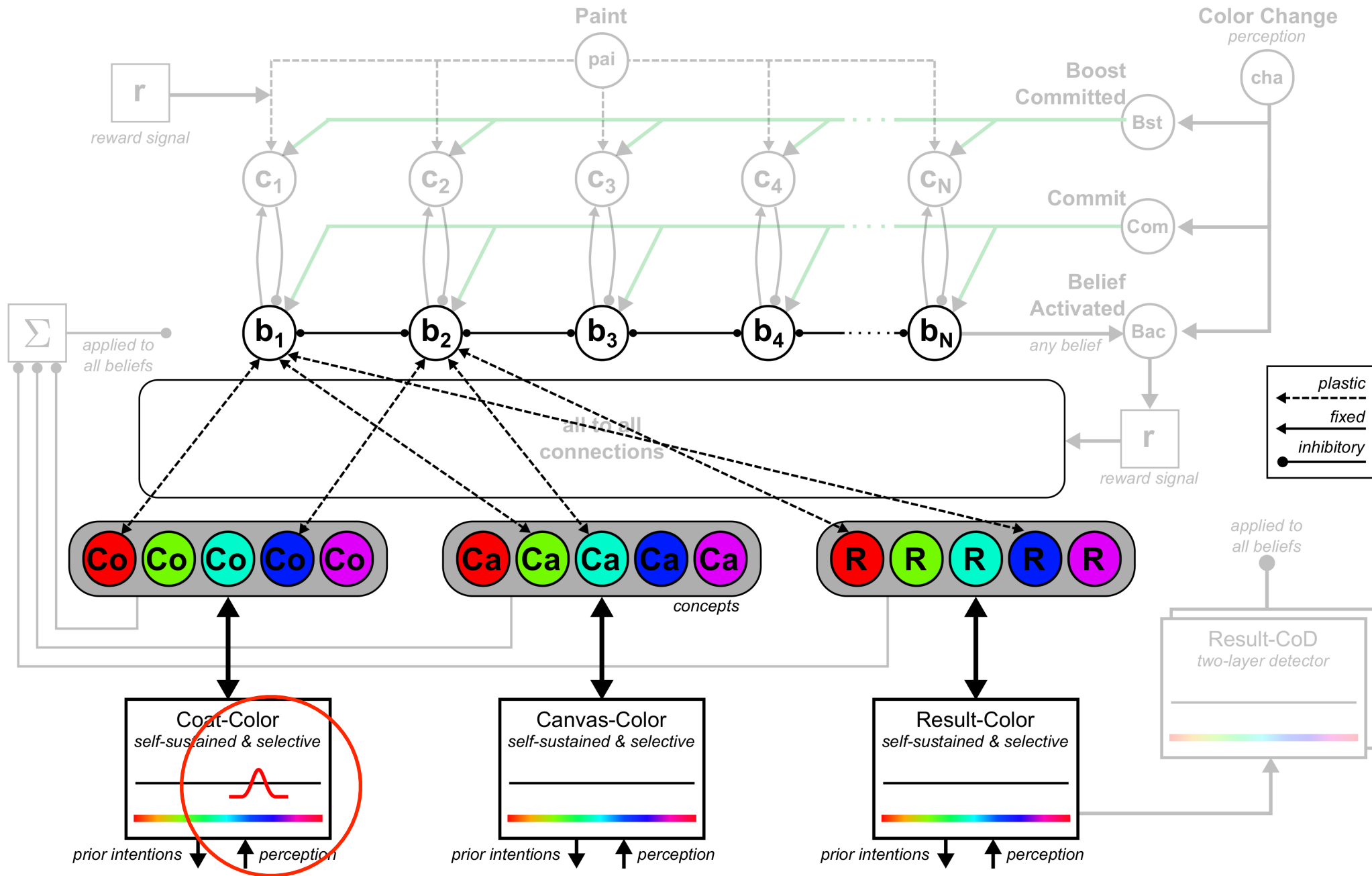
Representing a belief



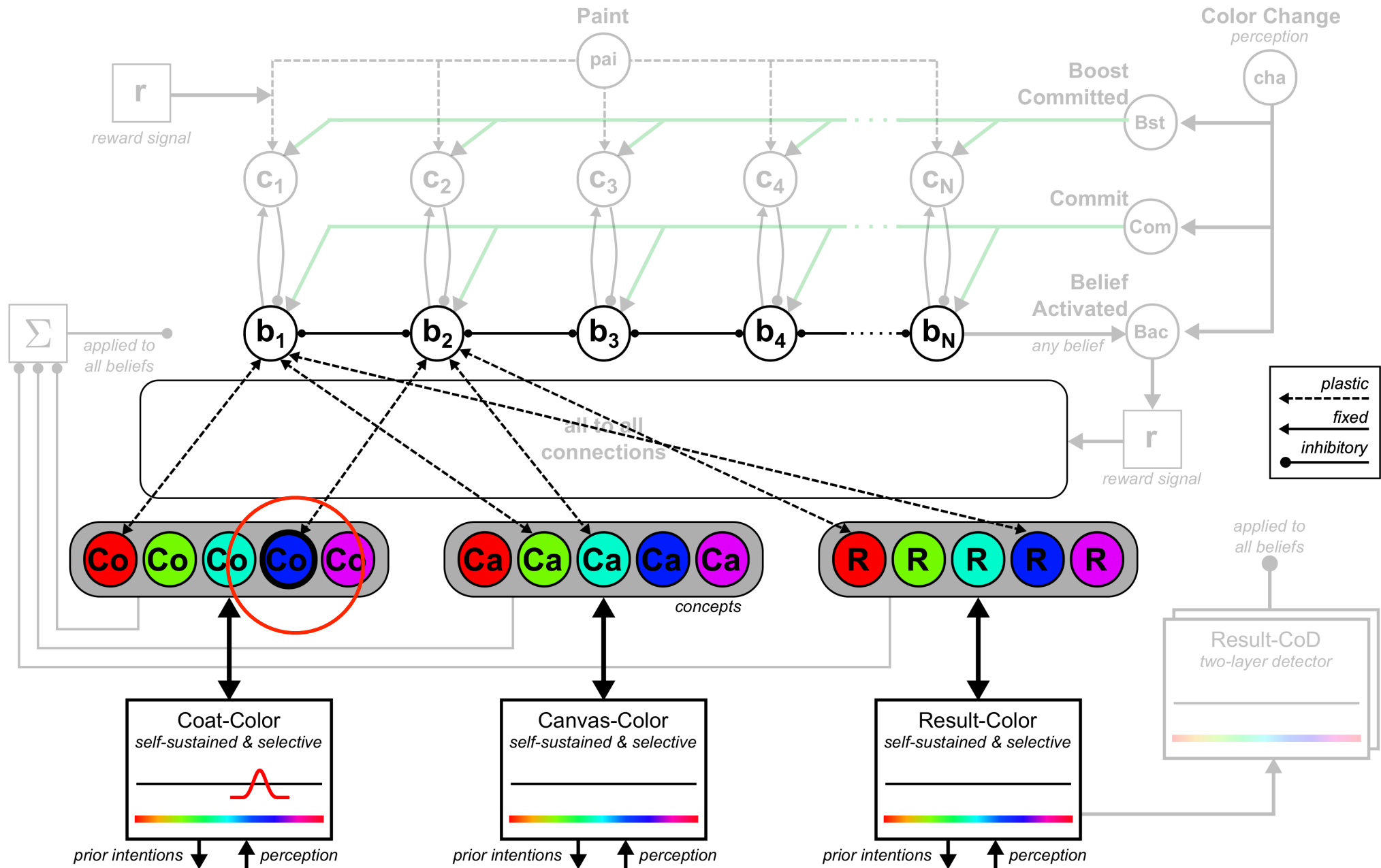
Grounding of the concept nodes



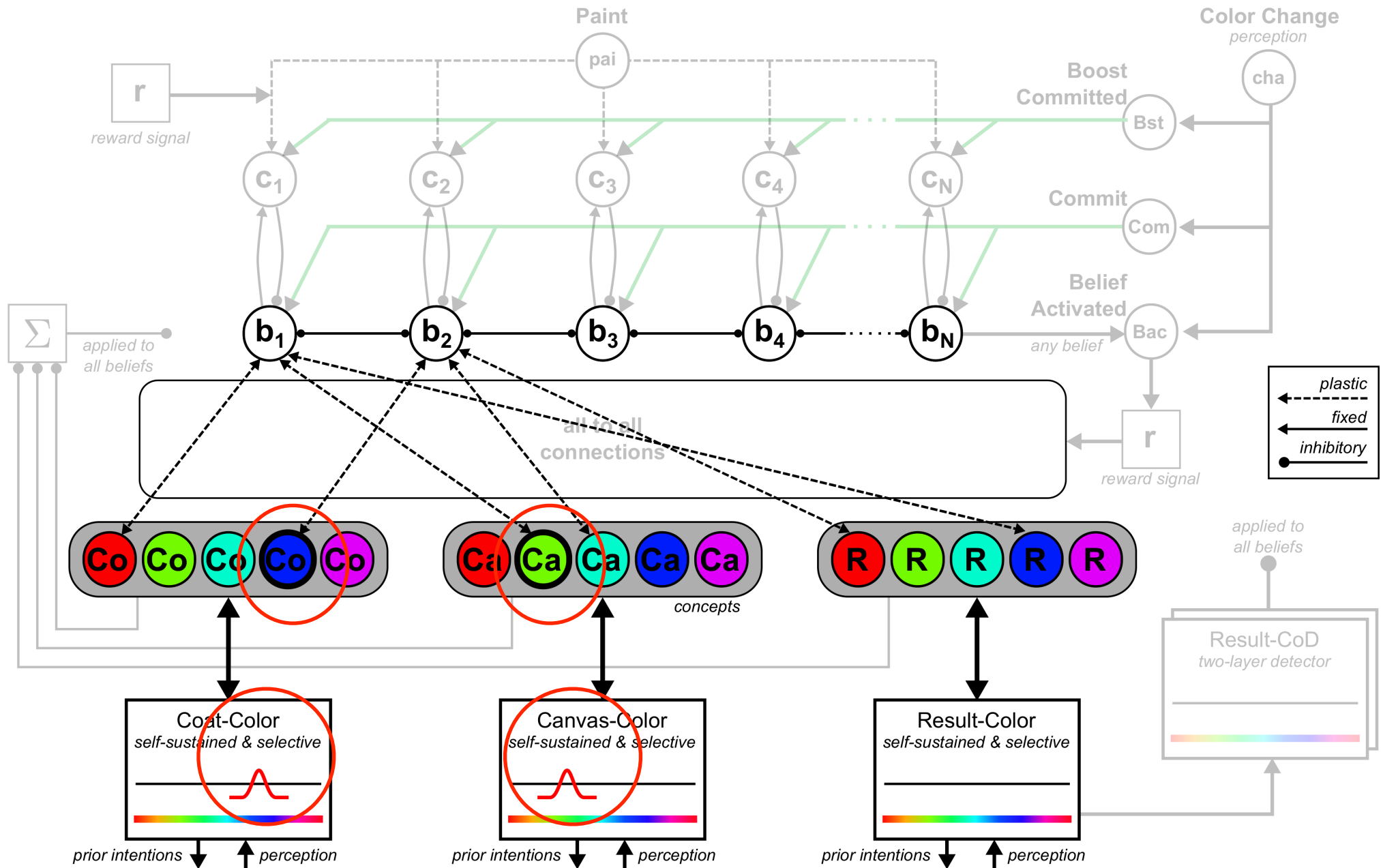
Coat color detected



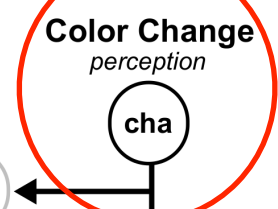
Activates color/role concept node



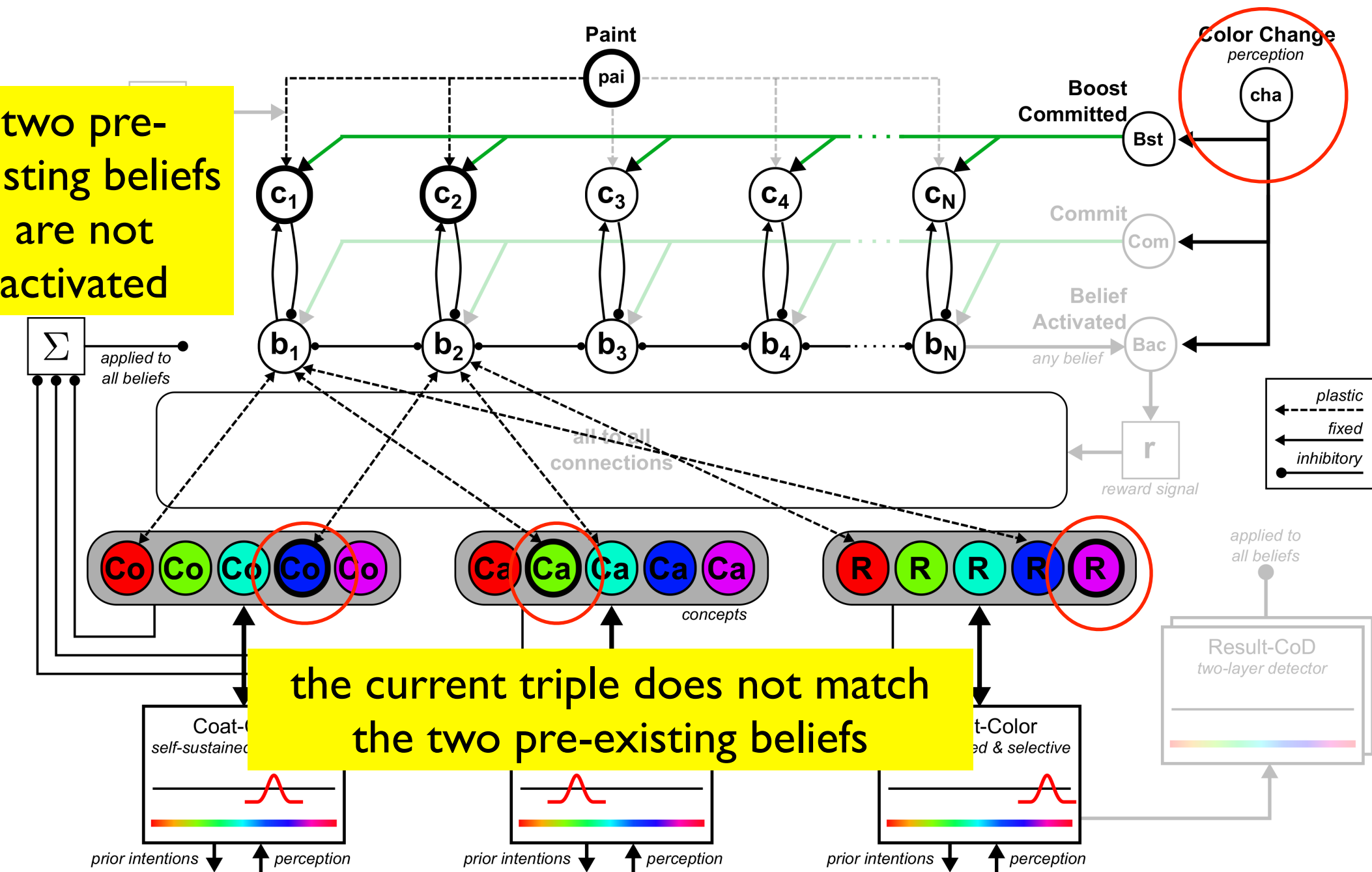
Coat and canvas color concepts activated



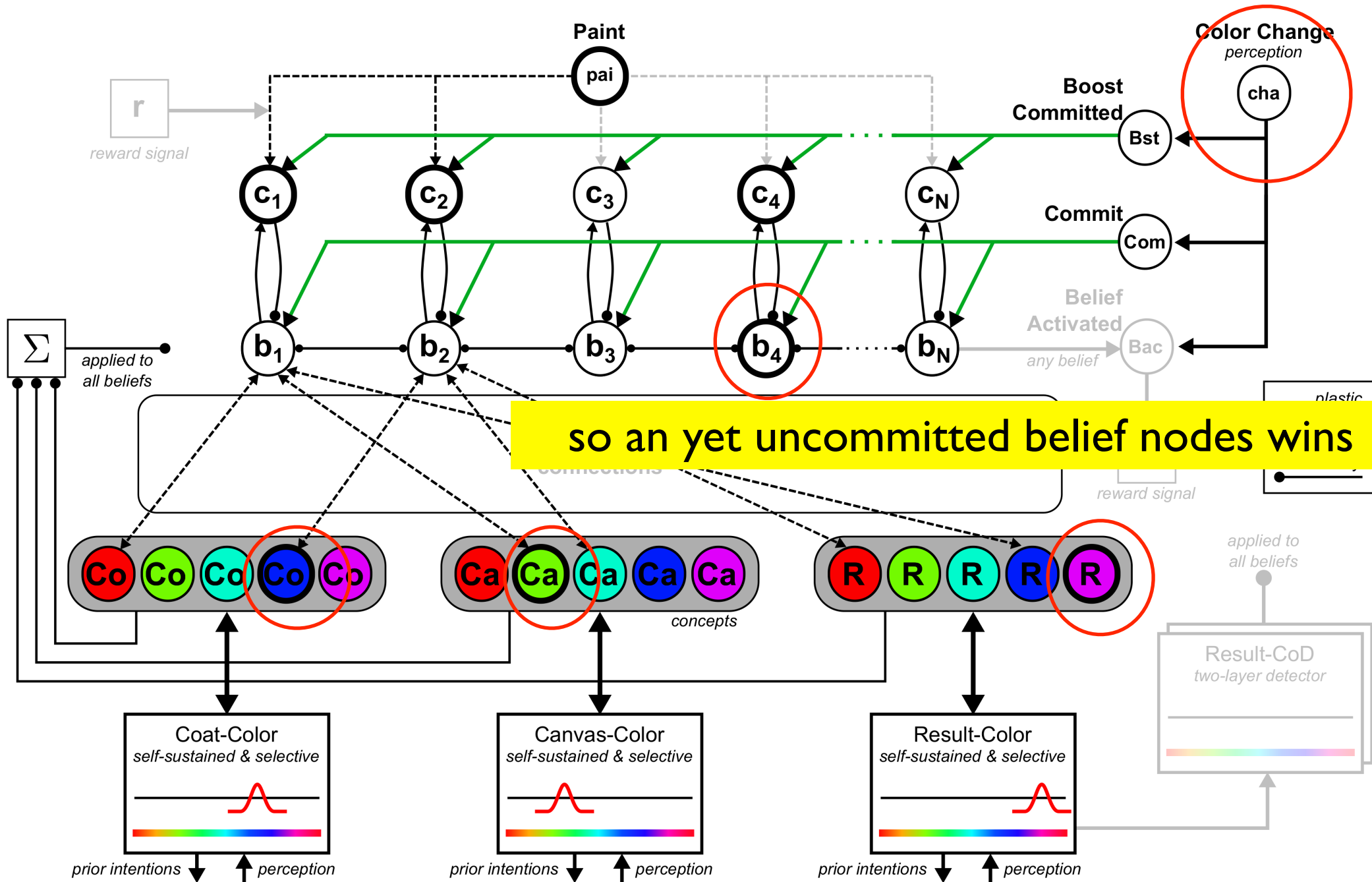
this triple does not match the two pre-existing beliefs



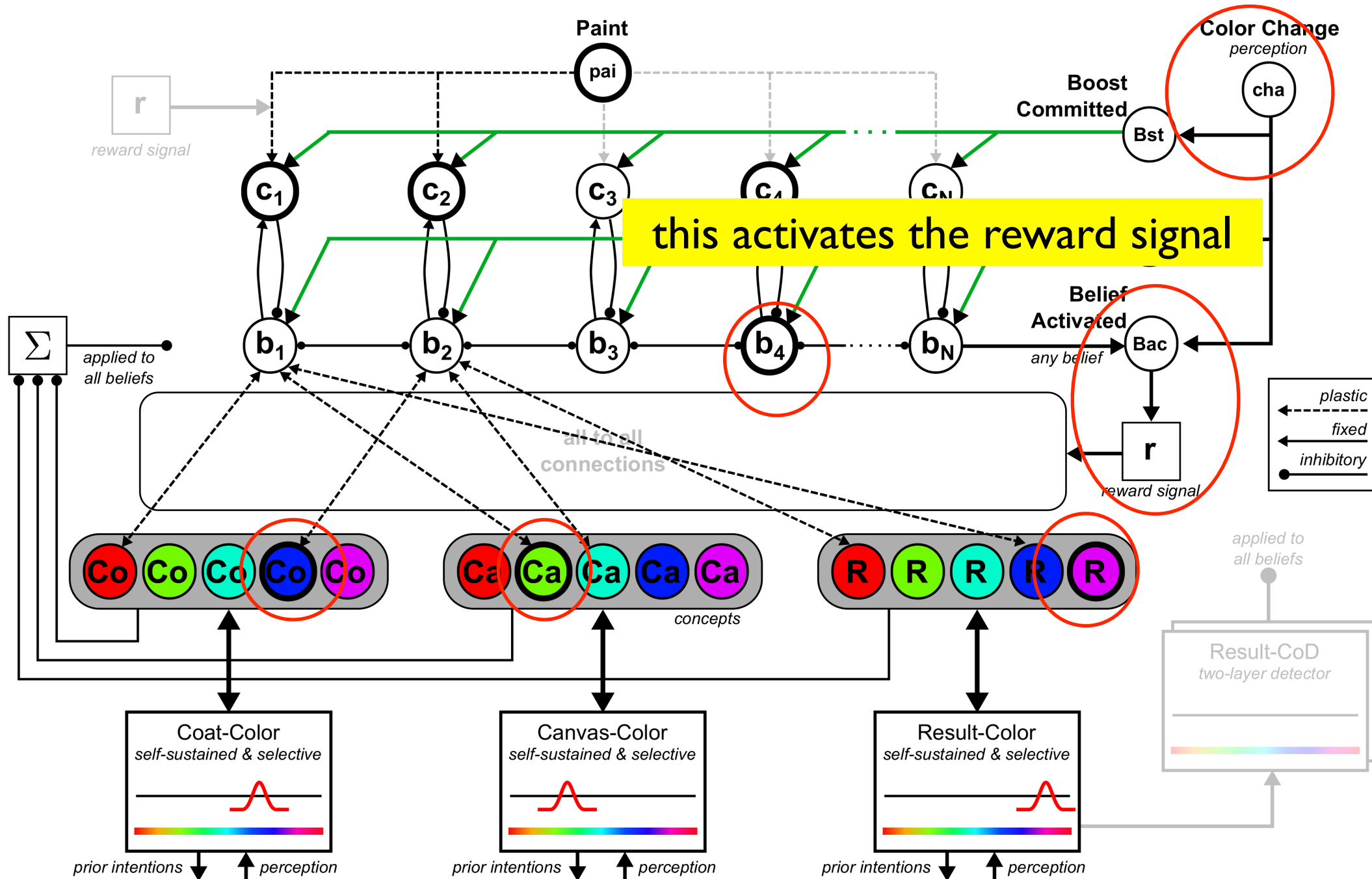
Commit nodes activated, task active



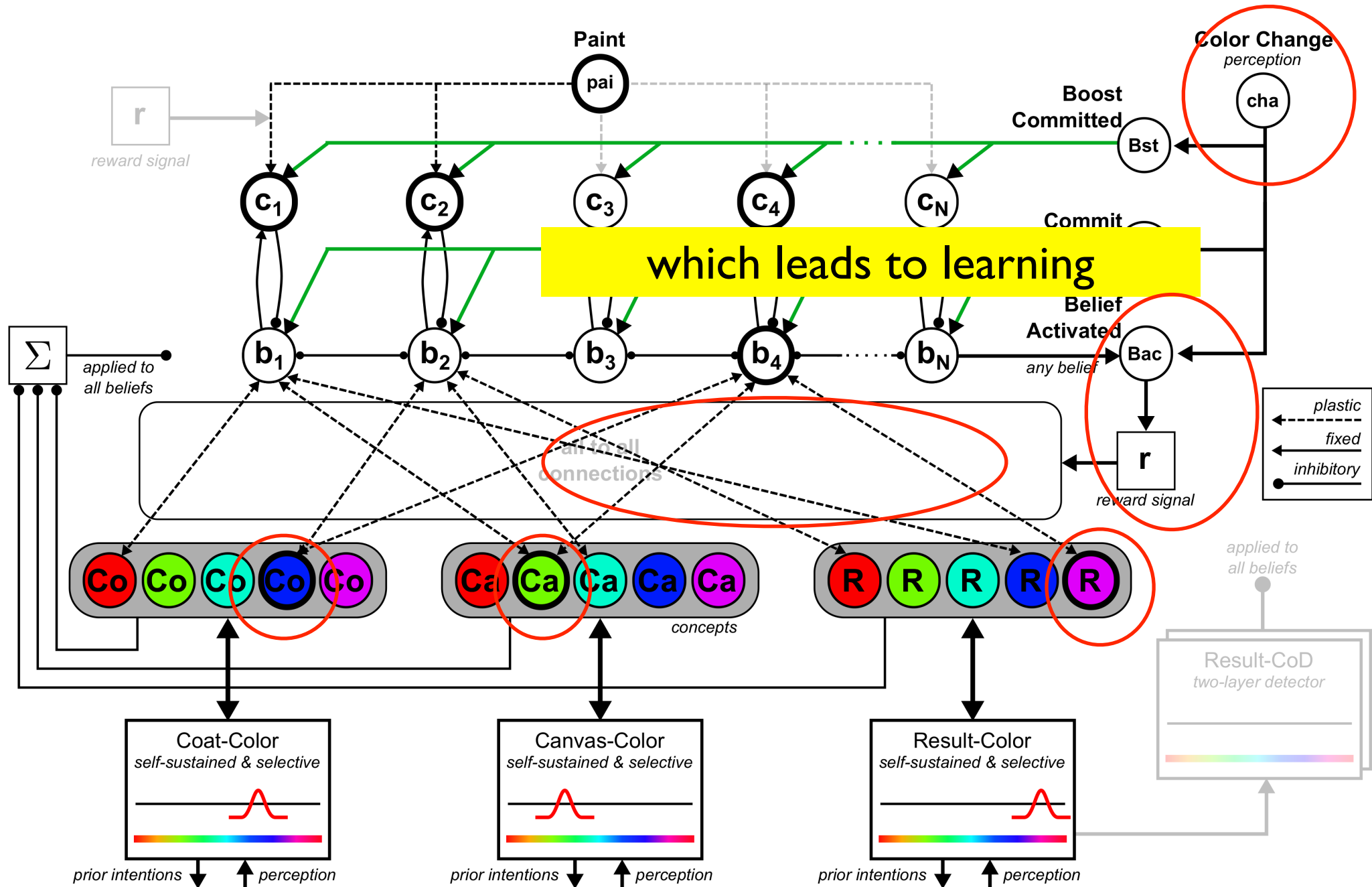
Commit nodes activated, task active



Commit nodes activated, task active



Commit nodes activated, task active



Autonomous learning

- act while aiming to learn (~task)
- recognize an opportunity for learning (~reward)
- map current experience to prior experience to update learning
- capacity to activation learned patterns ~ nodes
~enables that activation

Conclusion

- DFT is absolutely open to learning...
- in fact, it's strength is access to autonomous learning!
- most “NN learning” is not autonomous (and not learning)
- autonomous learning is hard and yet poorly understood