

Modeling the integration of active inference and sense of agency for self-other distinction

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Introduction & Questions

The motor system may be involved differentially in processing self-action and other-action, indicating a role in social cognition (Schütz-Bosbach et al., 2006).

We strongly rely on the predictability of our own body to be able to not only identify our own hands or arms, but also to differentiate between our own and other's actions (Sidarus et al., 2013; Colonius & Diederich, 2004; van der Weiden et al., 2015; Hillock-Dunn & Wallace, 2012).

Here, we present a Bayesian model of a sensorimotor system based on a prediction-based processing hierarchy of active inference and free energy minimization.

As of yet, it is not clear how self-other distinction is reflected in, or possibly even constituted by the sensorimotor system.

- What role does it play in distinguishing social actions of the self and the other?
- What are the underlying prediction-based processes?
- And how do they interact with higher-level cognitive processes like mentalizing to solve the social differentiation problem?

Computational modeling

Hierarchical Predictive Bayesian Update

C: Schema layer

- Clusters similar sequences in so-called schemas

S: Sequence layer

- Represents sequences of actions for observation and production (**common coding** (Prinz, 1997))
- Evaluates timing and action predictions for each sub-goal of the action sequence

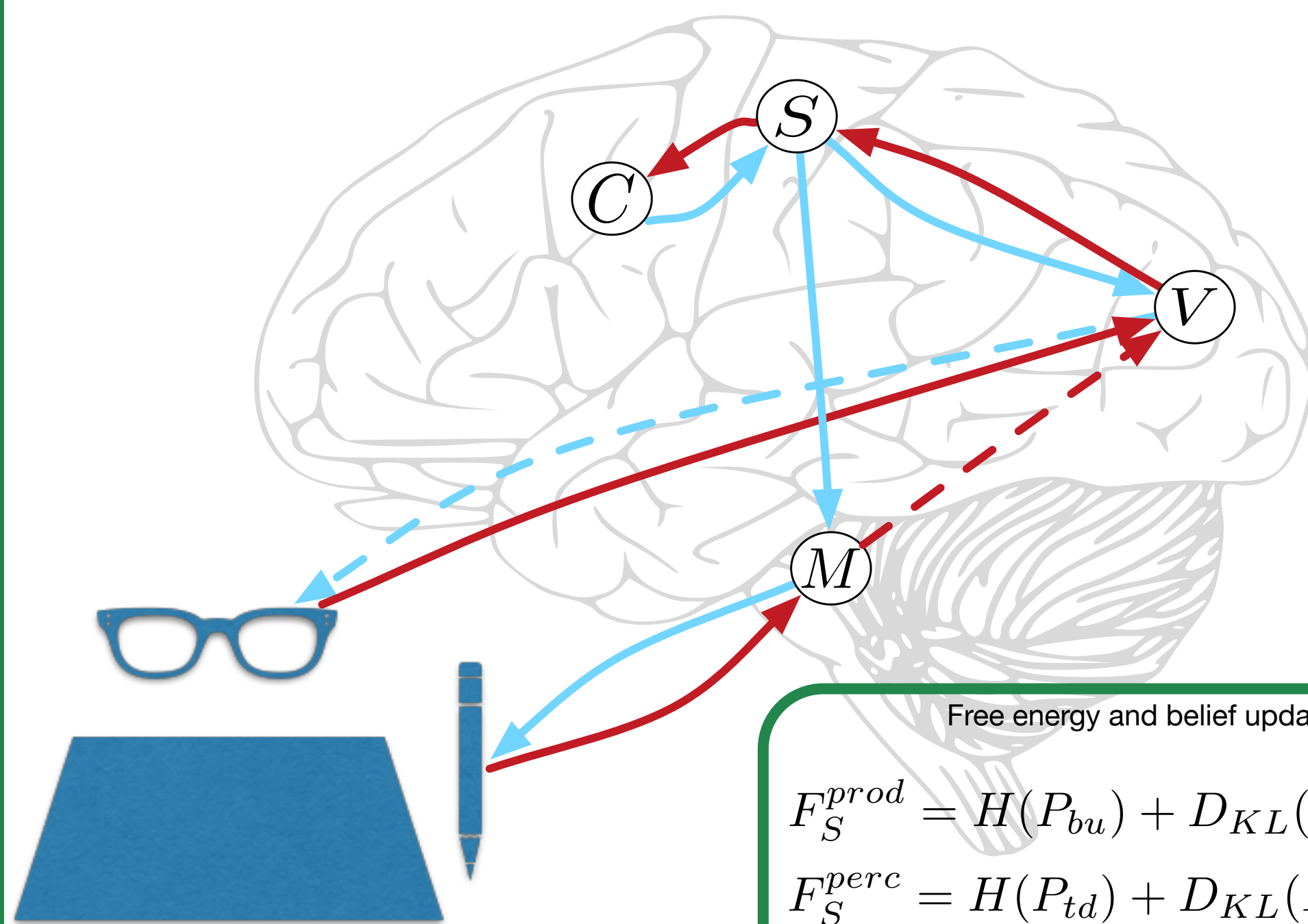
V: Vision layer

- Perceives hand writing as sequences of movement vectors and timings
- Filters for salient movements (increasing free energy)

M: Motor layer

- Perceives movement in differential joint angles
- Realizes active inference through reflex arcs (in the form of Dynamic Movement Primitives (Ijspeert et al., 2013))

- We model the perception and production of so-called **motor beliefs** (of **handwritten digits**) in a sensorimotor hierarchy
- Our modeling approach is based on free energy minimization and active inference (Kilner et al., 2007; Friston et al., 2010) in **Predictive Processing** (Clark, 2013)



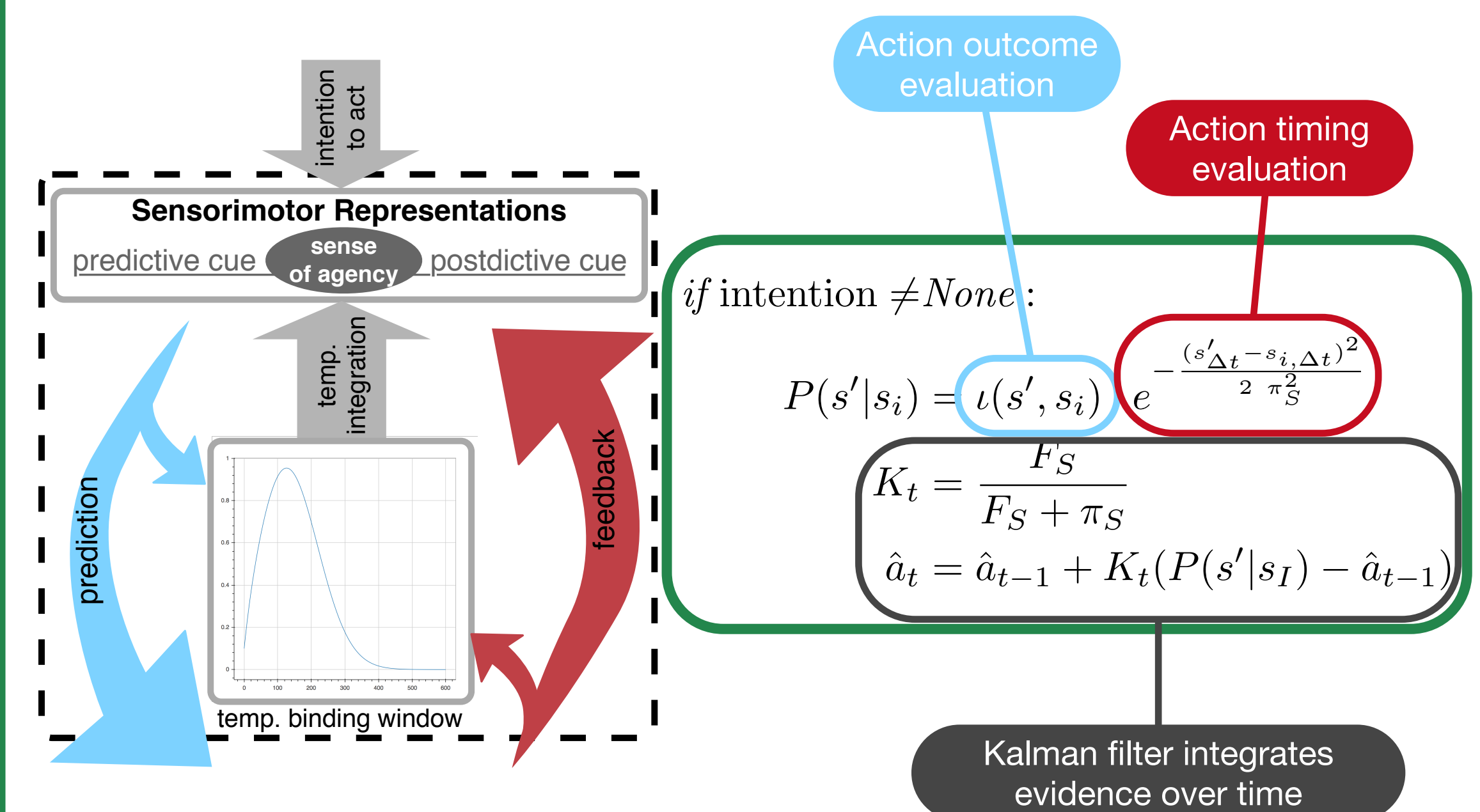
Free energy and belief update

$$\begin{aligned} F_S^{prod} &= H(P_{bu}) + D_{KL}(P_{bu}||P_{td}) \\ F_S^{perc} &= H(P_{td}) + D_{KL}(P_{td}||P_{bu}) \\ K_t &= \frac{F_S}{F_S + \pi_S} \\ P_t^{prod}(S) &= P_{td} + K_t(P_{bu} - P_{td}) \\ P_t^{perc}(S) &= P_{bu} + K_t(P_{td} - P_{bu}) \end{aligned}$$

Me or You?

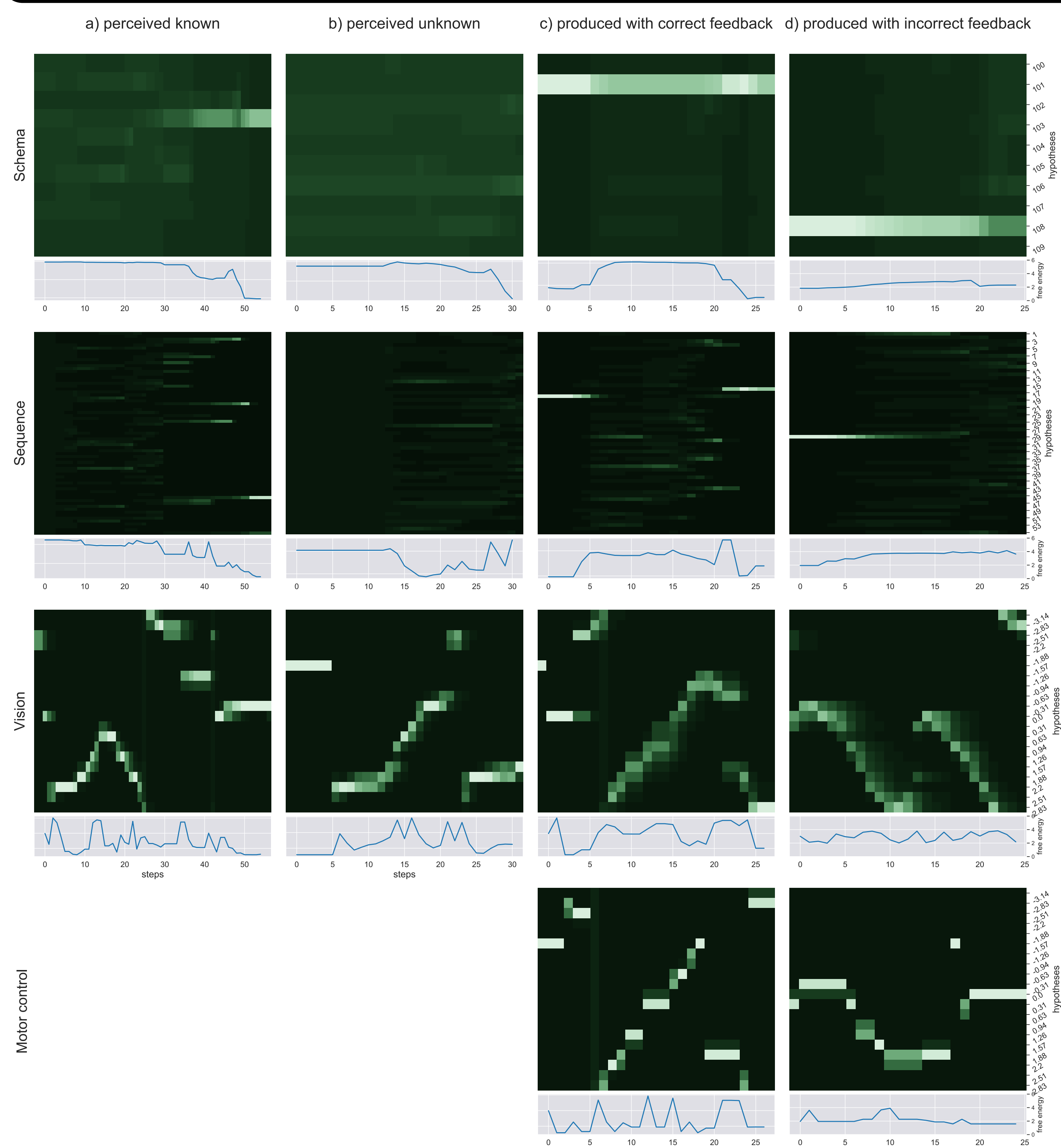
An integrated model of self-other distinction evaluates sense of agency for actions and their outcomes (Kahl & Kopp, 2017; 2018).

- A **postdictive** process works with higher-level causal beliefs like the intention to act and temporal binding to infer the consistency of the action outcome
- A **predictive** process evaluates if the predicted and the perceived action outcome match
- Both processes evaluate an action sequence production over time, accumulating evidence for or against sense of agency



Simulations

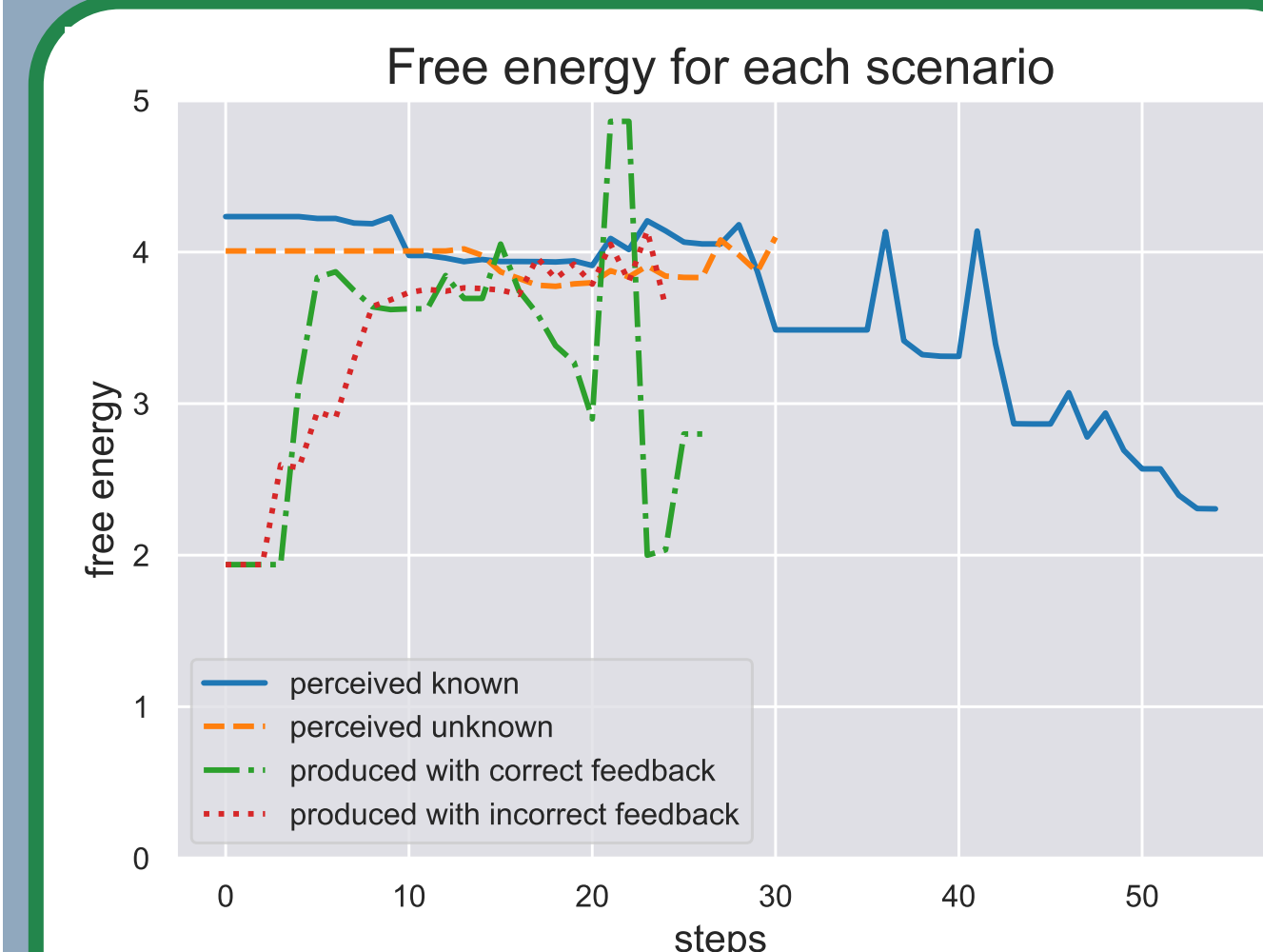
Hierarchical dynamics during scenario simulations



Scenarios

- Perception of a **known** sequence of actions to write a 5
- Perception of an **unknown** way to write a 4, and no fours are known
- Writing a 9 with correct visual and proprioceptive feedback
- Writing a 1 with correct temporal and spatial **proprioceptive feedback**, but with temporal and spatial **visual feedback of a different digit** (here a 3)

Results & Conclusion

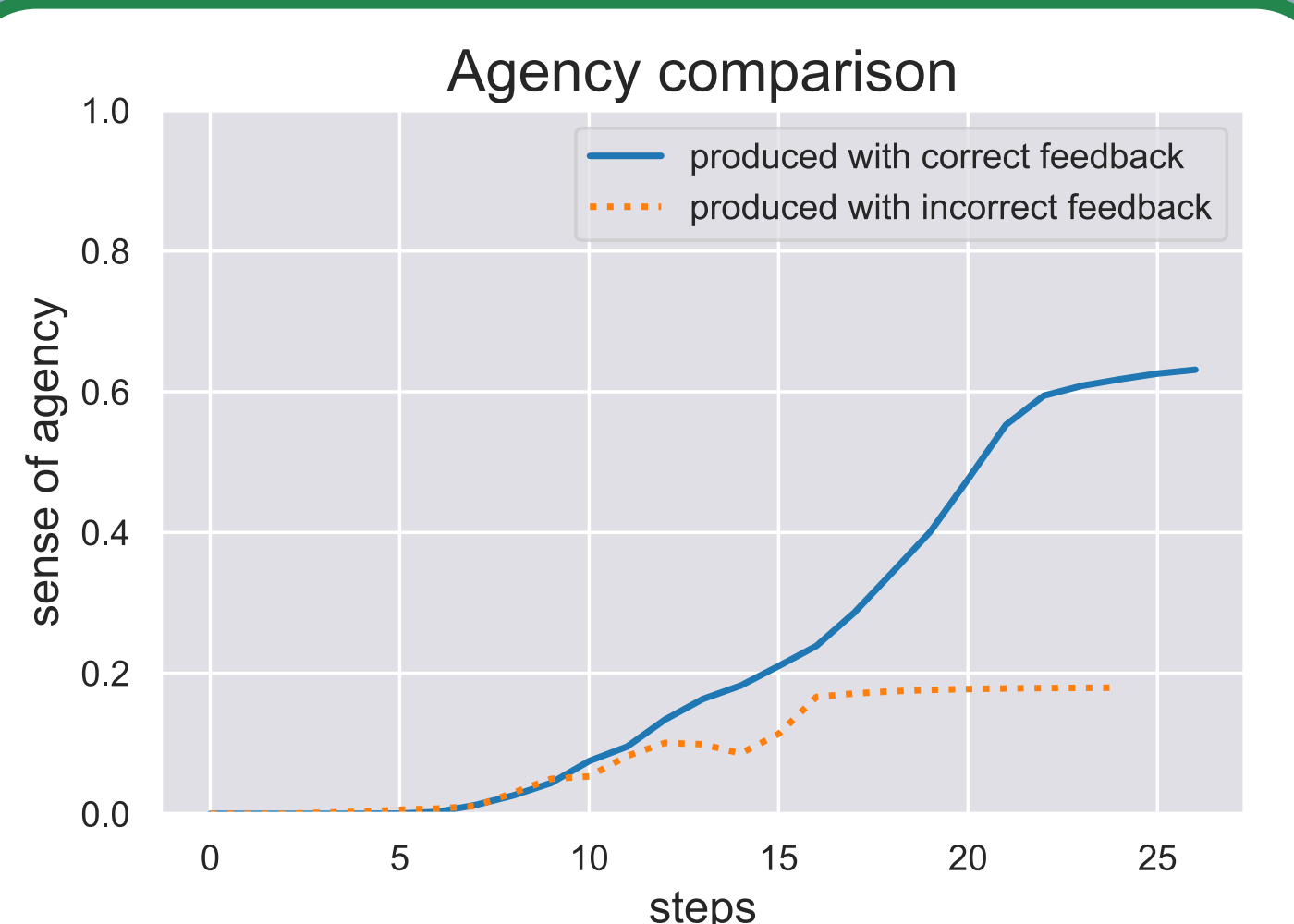


Free energy **can** be minimized during:

- the perception of a known action sequence (a)
- the production of an action with predicted feedback (c)

Free energy **cannot** be minimized during:

- the perception of an unknown action (b)
- the production of an action that elicits correct proprioceptive feedback, but contradicting visual feedback (as in social situations) (d)



Sense of agency was estimated during action production in scenario **c** and **d**:

- A strong estimate of sense of agency can be inferred for scenario **c**
- But it remains at a low level of 0.2 in scenario **d**, where predictions of produced actions are met with contradicting visual feedback

Conclusion

- Modeling a sensorimotor hierarchy based on free energy minimization and active inference allows to integrate a sensorimotor account of sense of agency.
- We proposed and evaluated an account of active inference based on temporal and spatial predictions that also act as cues for a sense of agency and self-other distinction.
- Higher-level cognitive processes like mentalizing, predictions of sensory precision and the intention to act can have a strong impact on the integration of sense of agency.

References

- Schütz-Bosbach et al. (2006) van der Weiden et al. (2015) Ijspeert et al. (2013) Clark (2013)
Sidarus et al. (2013) Hillock-Dunn & Wallace (2012) Kilner et al. (2007) Kahl & Kopp (2017)
Colonius & Diederich (2004) Prinz (1997) Friston et al. (2010) For more information, please see Kahl & Kopp (2018)

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