**Discovering and Teaching Optimal Planning Strategies**

*Falk Lieder*\*+*, Frederick Callaway+, Paul M. Krueger, Priyam Das, Thomas L. Griffiths, Sayan Gul*

How should we think and decide, and how can we learn to make better decisions? To address these questions we formalize the discovery of cognitive strategies as a metacognitive reinforcement learning problem [1]. This formulation leads to a computational method for deriving optimal cognitive strategies [2] and a feedback mechanism for accelerating the process by which people learn how to make better decisions. Previous work found that metacognitive feedback can enable people to more quickly learn to plan more when they initially planned to little and to plan less when they initially planned too much [3]. Here, we refine this approach to develop an intelligent system that teaches people optimal planning strategies. Our training program combines a novel process-tracing paradigm that makes people's latent planning strategies observable [4] with an intelligent system that gives people feedback on how their planning strategy could be improved. The pedagogy of our intelligent tutor is based on the theory that people discover their cognitive strategies through metacognitive reinforcement learning. Concretely, the tutor's feedback is designed to maximally accelerate people's metacognitive reinforcement learning towards the optimal cognitive strategy. A series of four experiments confirmed that training with the cognitive tutor significantly improved people's decision-making competency: Experiment 1 demonstrated that the cognitive tutor's feedback accelerates participants' metacognitive learning. Experiment 2 found that this training effect transfers to more difficult planning problems in more complex environments. Experiment 3 found that these transfer effects are retained for at least 24 hours after the training. Finally, Experiment 4 found that practicing with the cognitive tutor has additional benefits over simply telling people the optimal planning strategy. These findings suggest that promoting metacognitive reinforcement learning with optimal feedback is a promising approach to improving the human mind.

[1] Krueger, P.M., Lieder, F., & Griffiths, T.L. (2017). Enhancing Metacognitive Reinforcement learning using reward structures and feedback. In Proceedings of the 39th Annual Meeting of the Cognitive Science Society. Austin TX: Cognitive Science Society.

[2] Callaway, F., Gul, S., Krueger, P.M., Griffiths, T.L., Lieder, F. (2018). Learning to select computations. Uncertainty in Artificial Intelligence: Proceedings of the Thirty-Fourth Conference.

[3] Lieder, F., Krueger, P.M., Callaway, F., & Griffiths (2017). A reward shaping method for promoting metacognitive learning. The 3rd Multidisciplinary Conference on Reinforcement Learning and Decision Making.

[4] Callaway, F., Lieder, F., & Krueger, P.M. & Griffiths, T.L. (2017). Mouselab-MDP: A new paradigm for tracing how people plan. The 3rd Multidisciplinary Conference on Reinforcement Learning and Decision Making.

\*corresponding author (email: [falk.lieder@tuebingen.mpg.de](mailto:falk.lieder@tuebingen.mpg.de))

+equal contribution