Modeling Acquisition of a Torque Rule on the Balance-scale Task

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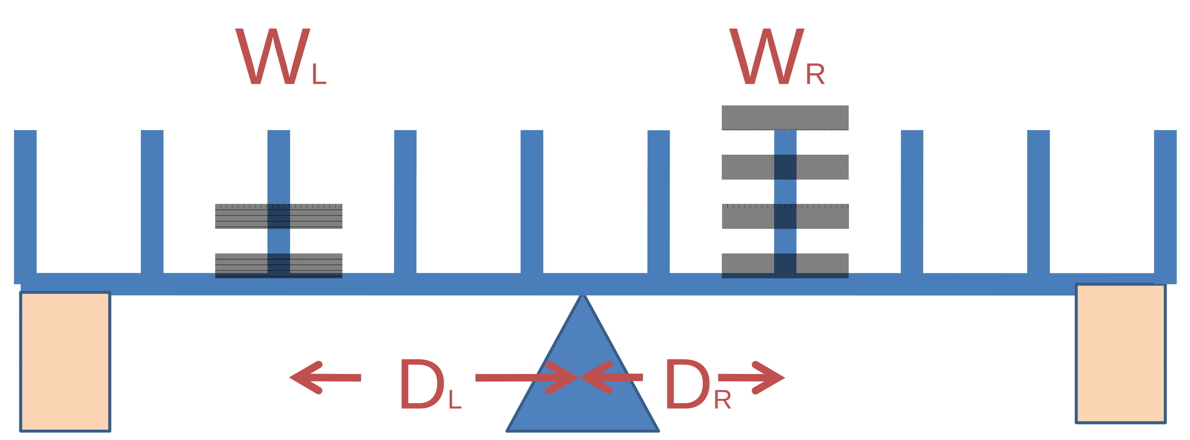
Balance scale task



Which side will drop?

Four stages seen in children (Siegler, 1976):

1) predicting the side with more weights to descend;
2) when the weights are equal on both sides, also predicting the side with greater distance to descend;
3) predicting correctly when weight and distance cues both forecast the same result; performing at chance when these cues conflict
4) being correct on at least 80% of balance-scale problems.

Two rules that yield more than 80% correct on Siegler's set (Stage 4 performance) :

Addition rule: $W_L + D_L$ <?> $W_R + D_R$ ✗

Torque rule: $W_L \times D_L$ <?> $W_R \times D_R$ ✓

Problem: Only the <u>torque rule</u> is always correct, but past research has not distinguished the two (Quinlan et al. 2007)

Goals:
1. Show that a computational model of the balance-scale task can develop a genuine torque rule
2. Diagnose addition & torque problems

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Computational model

Modules use Cascade-Correlation neural networks (Fahlman & Lebiere, 1990)

Intuitive network

(Similar to: Shultz, Mareschal, & Schmidt, 1994)

Task: learn balance scale problems by example (stop at 350 epochs)
Inputs: W_L, D_L, W_R, D_R
Output/target: Which side drops
Train set: 90% bias towards equal distance problems, expands by one pattern per epoch (100 patterns initially)

Confidence network

Task: learn if intuitive network is accurate, at 350 epochs
Inputs: W_L, D_L, W_R, D_R
Output/target: (2 – Error made by the intuitive network) / 2
Train set: intuitive network set + 25 unseen torque problems

Selection module (Combination)

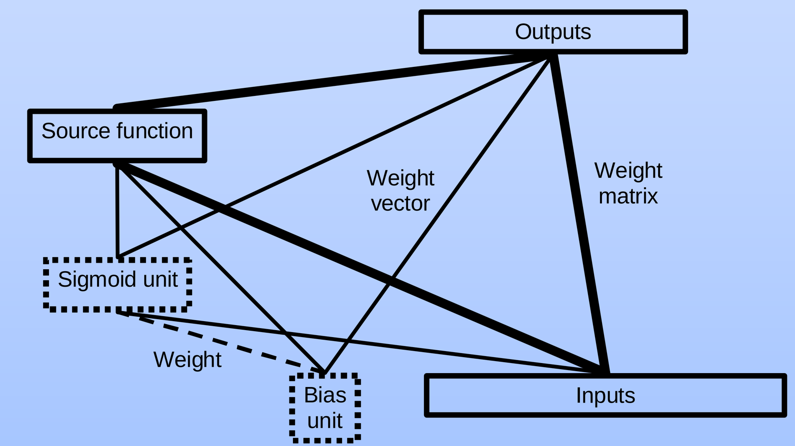
Choose intuitive network if confidence is sufficient, choose torque-rule answer otherwise

Torque-rule network

Knowledge-based cascade-correlation (KBCC: Shultz & Rivest, 2001)
Rationale: Modeling the rapid acquisition of a torque rule, as taught in secondary-school science courses, as knowledge-based
Task: learn balance scale problems with a torque rule available as prior knowledge
Inputs: W_L, D_L, W_R, D_R
Output/target: Which side drops
Train set: intuitive network set at 350 epochs + 25 unseen torque problems

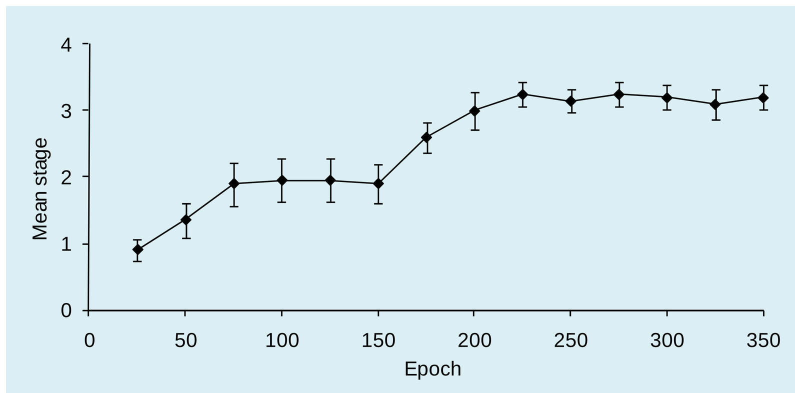
$$TD = (w_r d_r) - (w_l d_l)$$

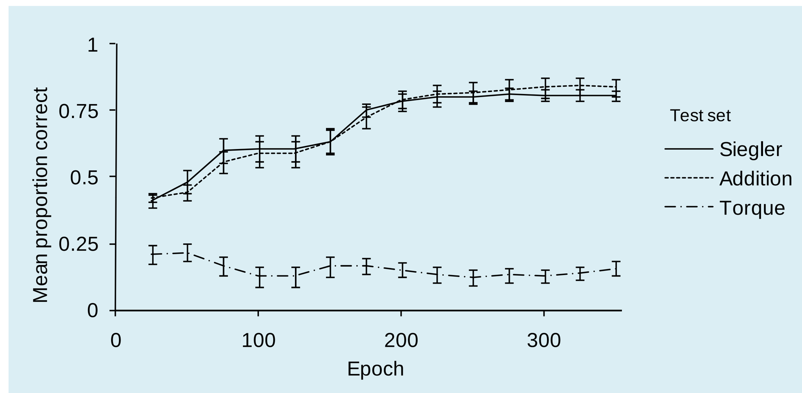
$$TR = \frac{1}{1+e^{-4TD}} - 0.5$$



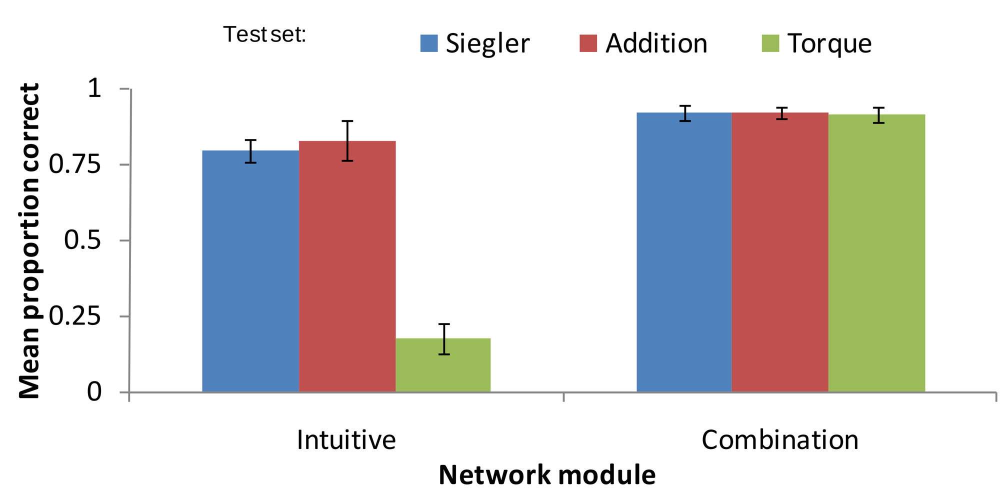
Results

Learning in intuitive network captures stages 1 to 3





Adequate performance on torque problems with torque-rule and selection module



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Conclusion

Computational models that include Knowledge-based cascade-correlation (KBCC) networks progress through all four stages seen in children, ending with a genuine torque rule that can solve problems only solvable by comparing torques

References

Boom, J., Hoijtink, H., & Kunnen, S. (2001). Rules in the balance: Classes, strategies, or rules for the balance scale task. Cognitive Development, 16, 717-735.

Fahlman, S. E., & Lebiere, C. (1990). The cascade-correlation learning architecture. In D. S. Touretzky (Ed.), Advances in neural information processing systems 2 (pp. 524-532). Los Altos, CA: Morgan Kaufmann.

Quinlan, P. T., van der Maas, H. L. J., Jansen, B. R. J., Booij, O., & Rendell, M. (2007). Re-thinking stages of cognitive development: An appraisal of connectionist models of the balance scale task. Cognition, 103, 413-459.

Shultz, T. R. (2003). Computational developmental psychology. Cambridge, MA: MIT Press.

Shultz, T. R. (2006). Constructive learning in the modeling of psychological development. In Y. Munakata & M. H. Johnson (Eds.), Processes of change in brain and cognitive development: Attention and performance XXI. (pp. 61-86). Oxford, UK: Oxford University Press.

Shultz, T. R., Mareschal, D., & Schmidt, W. C. (1994). Modeling cognitive development on balance scale phenomena. Machine Learning, 16, 57-86.

Shultz, T. R., & Rivest, F. (2001). Knowledge-based cascade-correlation: Using knowledge to speed learning. Connection Science, 13, 1-30.

Shultz, T. R., & Takane, Y. (2007). Rule following and rule use in simulations of the balance-scale task. Cognition, 103, 460-472.

Siegler, R. S. (1976). Three aspects of cognitive development. Cognitive Psychology, 8, 481-520.

van der Maas, H. L. J., & Jansen, B. R. J. (2003). What response times tell of children's behavior on the balance scale task. Journal of Experimental Child Psychology, 85 141-177.

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