Curiosity: Emergent Behavior Through Interacting Multi-Level Predictions

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Introduction
Over the past 15 years our research group has been exploring models of developmental robotics and curiosity. Our research is based on the premise that intelligent behavior arises through emergent interactions between opposing forces in an open-ended, task-independent environment. In some early experiments we constructed a recurrent neural network model where self-motivation was "an emergent property generated by the competing pressures that arise in attempting to balance predictability and novelty" [5]. The system first focused on its error, then learned to successfully predict its error, and finally became habituated to what caused the error. This process of focusing, learning, and habituating can be seen as a rudimentary type of curiosity.

However, focusing directly on error can be problematic: one issue is that it may be intractable to focus on all dimensions of sensory error at once, and accurate prediction may be impossible in real-world, noisy environments. To better understand learning in noisy environments, a predictable task

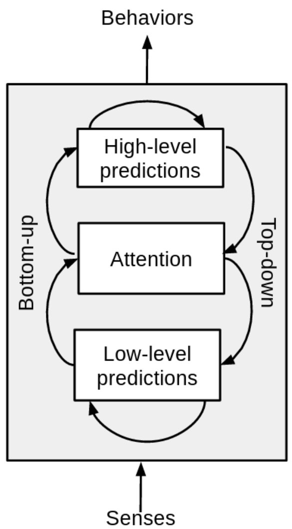

Figure 1: The proposed attention-mediated, multi-level framework. Initially, the system will be driven by errors generated by the lower-level predictions. Over time, the system will begin to develop higher-level predictions, and then attention must mediate between the levels, deciding on where to focus its curiosity.

was embedded into varying amounts of randomness [2]. Even in conditions with extreme noise (75%), networks trained with prediction of their hidden state were able to more quickly and successfully discern the signal from the noise. We believe that this type of self-awareness is necessary for developing more sophisticated behavior.

To cope with the continual flood of sensory data, which William James described as "one great blooming, buzzing confusion," we explored several hierarchical, categorization models. The first model was based on self-organizing maps [1], and we demonstrated that autonomously created categories could be subsequently activated to guide an agent's behavior. The second model was based on growing neural gas [4], and improved on the first model by allowing the topology and number of categories to emerge based on experience.

Attention-Mediated Multi-Level Framework

Our current focus is to bring these components—prediction, novelty, curiosity, self-awareness, and categorization—together to build a more complete model of development. In order to integrate these components, we propose an architecture that mediates low-level and high-level predictions via attention (see Figure 1). Attention is essential to a developmental system in order to focus resources on the most salient prediction errors. The resulting behavior is what we would describe as curiosity. This model is inspired in part by existing research that points to the importance of prediction in cognition combined with bottom-up and top-down interactions [6, 3].

Biographies

Lisa Meeden, Douglas Blank, and James Marshall all teach at small, liberal arts colleges that focus on undergraduate education. They each received a Ph.D. in Computer Science from Indiana University. Meeden and Blank both taught the first undergraduate courses focused on developmental robotics in 2003 at their respective institutions.

References

[1] Douglas Blank, Deepak Kumar, Lisa Meeden, and James Marshall. 2005a. Bringing Up Robot: Fundamental Mechanisms for Creating a Self-Motivating, Self-Organizing Architecture. *Cybernetics and Systems* 36, 2 (2005).

[2] Douglas Blank, Joshua Lewis, and James Marshall. 2005b. The multiple roles of anticipation in developmental robotics. In *AAAI Fall Symposium Workshop Notes: From Reactive To Anticipatory Embedded Systems*.

[3] Andy Clark. 2016. *Surfing Uncertainty: Prediction, Action, and the Embodied Mind*. Oxford University Press.

[4] Rachel Lee, Ryan Walker, Lisa Meeden, and James Marshall. 2009. Category-Based Intrinsic Motivation. In *Proceedings of the Ninth International Conference on Epigenetic Robotics*.

[5] James Marshall, Douglas Blank, and Lisa Meeden. 2004. An Emergent Framework for Self-Motivation in Developmental Robotics. In *Proceedings of the Third International Conference on Development and Learning*.

[6] Jun Tani. 2016. *Exploring robotic minds: Actions, symbols, and consciousness as self-organizing dynamic phenomena*. Oxford University Press.