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Goal-Driven Models of the Sensorimotor System and their Empirical Inspiration

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In goal-driven modeling, constructing a model of the brain as a neural network begins at the macroscopic scale; i.e., brain regions and the pathways linking them build the foundation for connecting layers in neuro-inspired network architectures. The precise weights linking units in connected layers, however, emerge from optimization on an ecologically valid task constituting the goal. It is then postulated that the learned weights approximate the brain's neurocomputations given sufficient external constraints. The pivotal advantage of this approach lies in its potential to autonomously learn neural connectivity patterns, thereby circumventing the limitations of e.g., hand-engineering or neural fitting. The connectivity and network dynamics can subsequently be analyzed to generate new hypotheses about the neurocomputations underlying complex cognitive processes. These, in turn, are then to be validated against empirical data. As such, goal-driven deep learning constitutes a new complement to classical methods in computational cognitive neuroscience. The approach has already proven fruitful for modeling perception. Convolutional neural networks have, for instance, been shown to capture hierarchical processing along the ventral visual stream particularly well. Whereas goal-driven modeling in the sensory domain is becoming increasingly common, its application to sensorimotor control is hampered by the complexity of the reinforcement learning methods required to train models comprising the full sensation-action loop. To clear this hurdle, we introduce AngoraPy, a modeling library providing neuroscientists with comprehensive, coherent tools to train and validate complex recurrent convolutional neural network models of sensorimotor systems. We exemplify this framework in the context of human dexterity. To this end, a large-scale model of the human frontoparietal network (Figure 1) was developed under macroscale inspiration from data recorded in the EBRAINS MultiLevel Human Brain Atlas. We then trained the model to manipulate a cube by actuating an anthropomorphic robotic hand. The strategies the model adopted under biological constraints are qualitatively human-like. However, whether the neurocomputations employed by the network resemble human information processing remains to be validated through an analysis of the precise representations, transformations, and dynamics exhibited by the network. For this purpose, data from neuroimaging can serve as a basis for validation. Additionally, data from the BigBrain or similar resources could further inspire the model, also on the microscopic scale. For instance, cytoarchitectonics can inform the parametrization of unit-specific activation functions to model different cell types. Moreover, cell density maps can constrain bottlenecks and relative representational capacities within the model.

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