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Perceiving affordances: A computational investigation of grasping affordances

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Abstract

The Grasping Affordance Model (GAM) introduced here provides a computational account of perceptual processes enabling one to identify grasping action possibilities from visual scenes. GAM identifies the core of affordance perception with visuo-motor transformations enabling one to associate features of visually presented objects to a collection of hand grasping configurations. This account is coherent with neuroscientific models of relevant visuo-motor functions and their localization in the monkey brain. GAM differs from other computational models of biological grasping affordances in the way of modeling focus, functional account, and tested abilities. Notably, by learning to associate object features to hand shapes, GAM generalizes its grasp identification abilities to a variety of previously unseen objects. Even though GAM information processing does not involve semantic memory access and full-fledged object recognition, perceptions of (grasping) affordances are mediated there by substantive computational mechanisms which include learning of object parts, selective analysis of visual scenes, and guessing from experience.

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1. Introduction

The notion of affordance was introduced by James J. Gibson to single out resources for action that the environment provides an animal with (Gibson, 1979). Gibson's original notion and its more recent interpretations (Chemero, 2003) presuppose that an animal is capable of *perceiving* some features of its environment as resources for acting. A computational model of what it is to perceive an affordance is introduced here in connection with the specific repertoire of hand grasping actions. Roughly speaking, this model identifies the core of affordance perception with visuo-motor transformations enabling one to associate features of visually presented objects to a collection of hand grasping configurations.

The visuo-motor transformations posited in the computational model for grasping affordances introduced here (called from now on Grasping Affordance Model or GAM for short) are coherent with a wide variety of behavioral and neurophysiological data concerning humans and monkeys. In addition to this, GAM provides computational explications of neuroscientific accounts of visuo-motor transformations occurring in visual and motor areas of human and monkey brains. In the first place, GAM fits neurophysiological data on the macaque's brain cortex, as far as the brain processing of object-directed actions (such as grasping, holding, and manipulating) is concerned. These data suggest that the anterior intraparietal area (AIP) is crucially involved in coding object affordances, and distributing this information to motor areas of the macaque cortex (Murata, Gallese, Luppino, Kaseda, & Sakata, 2000). Second, GAM is coherent with functional models of brain areas which have been found to deliver afferent signals to

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AIP, insofar as these models do not recruit perceptual object recognition, planning, and decision-making functions (Creem & Proffitt, 2000; Milner, 1998). Third, visual processing inputs to AIP are modeled in GAM in accordance with the analysis of the ventral visual stream provided by Reisenhuber and Poggio in their "Standard Model" (Riesenhuber & Poggio, 2000). Fourth, GAM is coherent with the hypothesis that the strong efferent pathways from AIP to F5 (Rizzolatti & Sinigaglia, 2008) support some sort of *direct* activation link from perceptual feature detection to the control of object-directed actions.

The affordances that an animal is able to perceive and use depend on the perceptual and motor endowment of its species, its individual developmental stage, learning history and capabilities. Learning and generalization abilities with respect to past experience seem to play a significant role in monkey sensory-motor control mechanisms. The versatile character of these mechanisms is witnessed by the wide range of sensory-motor associations that monkeys are able to perform. Notably, this behavioral ability persists upon presentation of many kinds of unknown/novel objects, thereby suggesting that monkeys are able to perform robust generalization, based on past experience with perceived object properties, and crucially involving AIP functionalities. In GAM, relatively robust generalization abilities are achieved by means of a learning process which enables one to associate object features to hand shapes.

Overall, the experiments on GAM reported here corroborate the broad idea that, in general, perceiving affordances does not require logical inference, access to semantic memory, and full-fledged object classification processes. Nevertheless, GAM suggests that perceptions of (grasping) affordances are mediated by learning of object parts, selective analysis of visual scenes, and guessing from experience.

2. Model constraints, architecture, and implementation

Some functional requirements for a computational model of grasping affordances may be isolated on the basis of neurophysiological findings and models about sensory-motor circuits in the macaque's brain cortex that crucially involve area AIP. Additional constraints may be specified on the basis of a reflection on computational models accounting for some AIP functionalities.

2.1. Neuroscientific and computational sources of model constraints

Brain areas in the macaque parietal and motor cortex have been shown to be involved in a series of sensory-motor transformations, such as the mapping into appropriate actions of visual information about objects and their location in the visual scene (Rizzolatti & Sinigaglia, 2008). Moreover, strong neural pathways may be identified between parietal areas and those posterior motor cortex regions that have come to be known as parieto-dependent motor areas. In particular, the AIP-F5 parieto-frontal circuit appears to play a crucial role in the visual guidance of hand grasping and manipulation movements, and AIP is more specifically identified as prominently involved in the coding of grasping affordances (Rizzolatti & Sinigaglia, 2008). Moreover, along the neural pathway starting from primary visual cortex (V1) and reaching into F5 via AIP, visual information is likely to be transformed into motor information without the intervention of cortical areas involved in higher-level perceptual and cognitive functions, such as those concerning perceptual recognition and semantic knowledge of objects in the visual scene (Creem & Proffitt, 2000; Milner, 1998).

Experimental evidence shows that in AIP, just like in F5, there are neurons with motor responses (Murata et al., 2000), which become active when the monkey carries out grasping movements of some specific kind (for example, precision grasp or full hand grasp). These neurons were found to respond to congruent visual stimuli too, becoming active at the sight of objects whose shape, size, and orientation are compatible with the specific grasp they motorically code for. Thus, when a graspable object is visually presented to the monkey, the activation of AIP neurons is hypothesized to recall appropriate grasping actions. AIP was identified as a prominent cortical area involved in the coding of grasping affordances chiefly in view of these behavioral properties.

The interaction between AIP and premotor area F5 is the main focus of the computational model FARS (Fagg & Arbib, 1998), functionally accounting for cortical processes involved in generating and executing grasping plans. This model, however, does not provide a computational account of how inputs to area AIP are actually produced. Affordances are, as a matter of fact, "programmed" into this model, by hard wiring connections from artificial neural units representing neurons in areas PIP and IT to units which represent neurons of area AIP. The connectivity between these units is designed on the basis of behavioral compatibilities, so that an AIP unit which is selectively active for some specific grasp type and hand aperture receives inputs from units which hold input parameters of objects towards which grasp and aperture of the same kind are usually directed. Moreover, the model does not specify how these input parameters are computed from visual input. Thus, the availability of suitable processes for computing these parameters is presupposed, and visual information transformations occurring along the path from V1 to AIP are presupposed too. These comprehensive assumptions are appropriate in the context of the FARS model, which is chiefly concerned with the generation and execution of grasping plans, but not equally so in a computational model which aims at accounting for processes enabling one to extract affordances from visual inputs. For this reason – and unlike the FARS model – a model of (grasping) affordance perception must include an account of significant visuo-motor transformations occurring on the path from V1 to AIP.

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