Title

Contrasting Models of Object Permanence

Journal

Proceedings of the Annual Meeting of the Cognitive Science Society, 18(0)

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Publication Date

1996

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Object Permanence

According to Piaget (e.g., Piaget, 1958) object permanence forms the basis of our understanding of objective space. Through gaining the understanding that objects continue to exist independently of direct perception, infants also begin to understand that they themselves are independent objects within an objective space. While many would agree that having a notion of object permanence is essential for an adult understanding of spatial relations, there is less agreement on what should constitute evidence of object permanence and how it should be measured.

Piaget's now classic studies relied on active retrieval of a hidden object as the measure of knowledge. That is, the infants had to be able to act on the knowledge of hidden objects that they may have. In the last 15 years, a different research paradigm has appeared. These studies have used passive responses such as surprise as a measure of the infants knowledge (see Baillargeon, 1993 for a review). The key idea in these studies is to violate some physical property of a hidden object. If the infants show surprise at the violation, then it is inferred that they remember the hidden object and understand that the object has maintained the physical property that was violated. The new methodology revealed that infants have much greater knowledge of hidden objects than that which they are able to demonstrate in retrieval tasks. This apparent developmental lag between infant's knowledge of hidden objects and their ability to act on that knowledge is a key question of infant cognitive development.

A third research paradigm was pioneered by T. G. R. Bower (1974). This approach relied on observing infant responses to visual tracking events in which an object passed temporarily behind an occluding screen. Knowledge of the hidden object was inferred from the infant's response to surreptitious changes in the object's features and spatial temporal properties while it was behind the screen. Bower argued that visual tracking was an active response with minimal motor task demands. However the reliability of the results obtained through this method is still open to question.

Computational Models

A number of computational models have been built to explore the development of object permanence. These are process models of infants' performance on object permanence tasks. The goal is to describe the nature of the knowledge representations and the mechanisms which operate on these representations during the tasks. As models of development they should not only describe performance, but also provide an account in terms of the mechanisms of development. Ideally, they might also incorporate general principles which would be extendible to aspects of cognition other than the immediate task being modeled.

In this talk, I will discuss three models. The first two are symbolic rule based models and the third is a connectionist model. The symbolic models (e.g. Prazdny, 1980, Luger, Bower, and Wishart, 1983; Luger, Wishart, and Bower, 1984) were developed to account for the visual pursuit data described by T. G. R. Bower (Bower, 1974). The symbolic models differ in that they base their explanation of the infant behaviors on different underlying theories of information processing.

Prazdny (1980)

Prazdny suggested that there are three levels of representation for objects. The highest level is a conceptual level and the other two are perceptual levels. The conceptual level is the only level to have access to both feature and spatial-temporal information. An Object-Description (OD) is generated by the conceptual level. The OD binds together attributes (e.g., color, size, position, trajectory) into a single structure and labels it with a name. If new perceptual information arrives which is inconsistent with the existing OD, a second OD is generated. Predictions (expectations) based on both ODs are then tested in order to select the best description.

Knowledge is stored in the form of IF-THEN assertions. In particular, IF-ADDED and IF-REMOVED procedures are used to implement expectation behaviors when the state of an object changes (e.g., it disappears after occlusion). Although the perceptual levels are not actually implemented, it is suggested that sensory information enters the system in the form of a snapshot of the visual scene. The lowest perceptual level processes the scene over a single snapshot interval. The next perceptual level abstracts across several snapshots thereby generating trajectory representations. Part of the infant's quirky behavior is explained in terms of competition between this perceptual level representation of trajectory and the conceptual level representation. Finally, although no direct mechanism for development is implemented, it is suggested that development is driven by a streamlining process in which specific rules are combined to produce a single more efficient rule.

Luger *et al.* (1983, 1984)

Luger's models implements Bower's Identity Theory of object permanence (Luger, Bower, and Wishart, 1983; Luger, Wishart, and Bower, 1984). This theory suggests that young infants understand that objects continue to exist, but that they have difficulty keeping track of objects. Young infants generate a large number of separate object representations for what adults would encode as a single object. The main idea of this model is that infant behaviors can be described by the use of 5 action rules subsumed under 3 conceptual rules. Luger et al. describe the three conceptual rules, but remain non-committal about how the action rules might interact. Hence these authors believe that there is a complete dissociation between the conceptual level and the response level. The conceptual rules are:

Rule 1: An object is a bounded volume of space in a particular place OR on a particular path of movement.

Rule 2: An object is a bounded volume of space of a certain size, shape, and color which can move from place to place among its trajectories. (Note that this rule now integrates feature information with spatial temporal information)

Rule 3: Two or more objects cannot be in the same place OR on the same path of movement simultaneously UNLESS they share a common boundary.

This model is implemented as a PROLOG program. A set of facts is used to make up an object knowledge structure from each temporal snapshot. Each of the conceptual rules is embedded in a separate recursive PROLOG statement. The goal of the statement is to assert the permanence of an object. To do this, the model tests the validity of a number of facts. The last of its conditionals is to move over and test again. The level 1 rule tests for: the location, whether the object has volume, and whether it is occluded. It then moves on to the next position. The level 2 rule adds in a test for the object's features before testing for intact boundaries. Finally the level 3 rule adds another test of features after testing for intact boundaries. As a result, the Level 1 model sets up a new representation of the object every time there is a change in spatial temporal information. The Level 2 model only sets up a new object token when there are changes in the feature representation. Finally the Level 3 models do not set up a new object representation when two objects are contiguous. Again, no specific developmental mechanism is proposed, but it is thought to be driven by the acquisition of procedures that lead to more cost efficient representations.

Mareschal, Plunkett, and Harris (1995)

Mareschal *et al.* describe a connectionist model of the development of object permanence. The model is in the form of a modular network. Units that are shared by modules act as gateways through which information can flow from one module to the other. Information enters the network through a retina that is homogeneously covered with feature detectors. Based loosely on neuropsychological data, the model implements two information pathways: (a) a feature pathway, and (b) a spatial-temporal pathway. The Object Recognition Module uses an unsupervised algorithm to develop a spatially invariant feature representation of the object whose image is projected on the retina. The Trajectory Prediction Module processes the spatial-temporal properties of the object image. This module learns to predict what the next position of the object image will be. Finally, The Response Integration Module recruits and integrates the internal representations developed by the other modules as and when required by an appropriate response task.

Knowledge of past events is stored gradually in the connection weights between the units. A representation of the current object event is stored in the form of a pattern of activation across a band of units. Development occurs thorough the gradual accumulation of knowledge (small changes in connection weights). An implication of the model is that performance on object permanence tasks reflects the ability to internally represent an event, but also the ability to decode successfully that representation into an appropriate action. Both information processing steps need to be learned.

Discussion

The most immediate difference between these models is that the existing symbolic models do not provide a transition mechanism. In contrast, it is the essence of the connectionist model to describe development. Representations in the network emerge through learning. However, it is important to understand that the connectionist networks are not just *tabula rasa* learners. The representations that are developed depend both on the nature of the interactions with the environment, but also on innate knowledge constraints in the form of architectural constraints (determining how information is segregated and recombined) as well as mechanisms (determining the type of information that can be extracted from the environment).

The symbolic models are descriptive models of competence at any one stage. They are not models of the processes of development. Even if a mechanism for rule development was devised, it would have to be more than just a means of passing from one level of description to the next for the model to be a meaningful model of infant development. A connectionist model is a model of the mechanisms involved in changing the knowledge representations. In some sense the knowledge representations are almost secondary to the developmental process.

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