A Computational Description of the Stages of Development of Object Identity by Infants*

by

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Abstract

This paper is in two parts: I, a brief description of the *identity* theory of the development of the object concept and a computational model that describes the three stages of that theory and, II, the running of that model on two experiments important in the analysis of development of the object concept. The model is designed to help determine which parameters in the development process might best explain changes within the object comprehension skills of infants. The discussion presents a set of perceptual invariants that can be used: a), to describe changes between developmental stages and, b) offer the potential for a cost/gain metric for that development.

The model is written in PROLOG, a very high level computer language. Detailed descriptions of PROLOG (6)(15) and further uses of PROLOG to model problem solving skills (7) may be found elsewhere.

I. Identity Theory and the Computational Model

The *identity* theory proposed by Bower and Wishart (1)(16) to explain the developmental stages of the object concept suggests that the conceptual problem which underlies these stages for young infants is one of object *identity* rather than object *permanence*. A basic idea of object reality (including some idea of permanence) is assumed to be present in infants from birth (1); the infant is seen as having difficulty in maintaining the identity of an object throughout an event sequence. This difficulty is present whenever the event entails temporary disappearance of the object (4), and is particularly acute if the sequence involves close interaction with any other object (16).

In this theory, development is seen as a progressive refinement of the infant's rules for attributing identity to an object over time. The infant moves from the simple recognition that an object is the same object at different times and in different places, through to more elaborate notions which define identity in a much stricter sense, with the object not only being recognized as perceptually the same but as identical in the sense of being one and the same object when involved in any event sequence, i.e., the same and only such object involved.

Each change in development level means that the infant can maintain the identity of an object over increasingly complex event sequences. Each new identity rule reduces the population of "objects" with which the infant must deal and therefore represents a considerable cognitive achievement.

These rules and the psychological evidence for their validity are outlined below (for a fuller account, see (16)).

Rule 1, which corresponds to Piaget's stages I and II, (10) (11) is stated:

An object is a bounded volume of space in a particular place or in a particular path of movement.

It follows from this rule that two objects cannot be in the same place and that two objects cannot be on the same path of movement. A violation of rule 1, such as replacement of a stationary object by a totally different object, will be treated by this level of infant as a transformation of the original object rather than as a replacement by another object (1).

Application of this rule in search tasks would lead to the following search behaviors:

- to find a stationary object, look for it in the place where it usually is.
- to locate a moving object, look for it along its path of movement.

When an object that was stationary begins to move and the subject looks back to the space the object previously occupied what has become known as a *place error* occurs (2). When a moving object has in fact stopped and the subject continues to follow its path, a *movement error* occurs (3).

Rule 2 describes the second stage of development and corresponds to Piaget's stages III-V (10)(11):

An object is a bounded volume of space of a certain size, shape, and color which can move from place to place along trajectories.

Place and movement errors no longer take place because they are mediated by the perceptual features of the object, which were ignored in the application of rule 1. It is still true that two objects cannot be in the same place

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or on the same path of movement at the same time, i.e. that the *bounded volume* of space that *defines* the object cannot be violated. Total or partial occlusion of the object still causes problems for infants operating with rule 2.

Search behavior for this level of infant will include finding an object by searching for it it its usual place, or if it has moved, along its usual path of movement. Since perceived information is incorporated in this rule for identifying an object, any sequence of actions violating the perceptual integrity of the object, as when the object is covered by a cup or some other occluder, will be treated by the infant as the replacement of the object by the new object. Behavior in this situation will be:

— to find an object that has mysteriously disappeared, remove the object replacing it, and with experience,
— to find the disappearing object, remove the object which is in the place where the desired object was last seen.

This will allow the infant to succeed in Piaget's stage III-IV or IV-V tasks, but does not represent any true understanding of spatial interactions between objects.

Rule 3 corresponds to Piaget's Stage VI (10)(11):

Two or more objects cannot be in the same place or on the same path of movement simultaneously unless they bear a spatial relationship to each other which involves the sharing of common boundaries.

The third identity rule is essentially the same as rule 2 but is modified to fit with the infant's experiences of the consequences of interactions between objects. Thus, for an infant working with only rule 1, an object which moves then stops or which enters into a spatial relationship with another object in such a way as to lose or mask its identifying boundaries will have disappeared mysteriously. With rule 2, only the latter kind of event will cause identity confusion and erroneous search behavior. Not until acquisition of rule 3 can the infant understand that a spatial relationship between two objects does not violate the identity of either. Prior to the acquisition of rule 3, the infant does not understand that a spatial relationship between two objects does not violate the identity of either.

In summary then, Bower and Wishart hypothesize that the infant develops a progressively more comprehensive set of rules for recognizing and maintaining the identity of an object over time. The staged acquisition of these rules both directs the infant's attempts to relocate objects and explains the erroneous behavior seen on the traditional object permanence tests. As one rule is replaced by the next, the infant comes closer to the appreciation of the invariant properties of individual objects. At maturity these rules will be sufficiently developed to allow an object to interact in common space with any other object without risk to its unique identity.

A first attempt at computer simulation of this period of cognitive development has already been made and is reported in (8). That paper deals only with the first two of the three hypothesised stages of development, comparing the output of the computer model with data collected in five Bower et al studies of infants' responses to simple object movements. The present paper describes the modeling of all three stages of development in two experiments.

A description of the PROLOG (6)(15) rules modeling each stage of development is now given. Rather than PROLOG code we list the competencies, expectations, etc. that make up the rules for each stage of development.

Stage 1.

a. Focus on a location. This location has been *constructed* from the locations of the immediately preceding object structures found (see (e) below).
b. Find an object within a fixed distance of where focused. If an object cannot be found report failure and look back to the preceding object found (the previous *snapshot*).
c. Check the object for interest, seeing if it has volume or mass. This is done by considering two slightly different views of the object.
d. Check if all boundaries are intact. This is done by checking the integrity of the boundary within the snapshot.
e. Based on the object at snapshot (n) and snapshot (n - 1) construct an appropriate expected location for snapshot (n + 1).

Stage 2.

The competencies and expectations of stage 2 are almost identical to those of stage 1, as one might expect, except that a check occurs between (b) and (c) above comparing further perceptual relationships (size, color, shape) between the object at snapshot (n - 1) and the object found at snapshot (n).

Stage 3.

The competencies of stage 3 include all those at stage 2 and in addition the perceptual check of stage 2 is made both between (b) and (c), as in stage 2, and after the boundaries are scrutinized, after (d) above.

Experiments are run by our program in two independent steps: the creation of the set of snapshots of object structures that represent the physical experimental situation and then the analysis of these object structures by the rules of a particular developmental stage.

Our two steps, creation and analysis, provide for (in fact have an a priori commitment to) an independence of the object structure and its perception. This means that there is no interaction between the percept of an object and the subject that in any way changes the nature of the percept. The changes come in the subject's interpretation of that percept. This commitment to the primacy of perception allows description of its origins and presence according to a number of differing theories (6)(13).

II. The Experiments and Discussion

Two experiments are described in this paper. All three stages of the model are tested on each of these experiments. The snapshots for the experiments are described in Figures 1 and 2.

In experiment 1 (Figure 1) a yellow sphere of radius 4 is located at (60,4,10) at time 1. (60,4,10) marks the (x - left/right,y - up/down,z - depth) coordinates of a 3-dimensional cartesian space. The sphere remains stationary for three time periods (or snapshots) and then moves to the right (with respect to the infant who views the scene from the point (60,0,0)). After moving for three time periods the sphere arrives at (72,4,10) where it again rests for three time periods before moving left and back to the starting point (60,4,10). This same sequence of rest and motion is repeated three more times. Then, instead of moving off to the right as usual, the sphere moves to the left for three time periods, comming to rest at location (48,8,10). Here the experiment ends.

Experiment 2 (Figure 2) has two objects, a green cube and an occluder which the infant views from position (36, 0, 0). The occluder, in this case a black platform of length 8, height 6 and depth 6, remains centered at location (36, 4, 6) for all time periods. (A platform is not conventionally thought to be an occluder. However infants produce the same sequence of behaviors with platforms as they do with more traditional occluders such as screens or tunnels (10)(16)). The green cube of length 4, height 4, and depth 4 remains at location (4, 8, 10) for the first five time periods. From times 6 to 20 it moves right, with respect to the infant, until it rests at location (68, 8, 10). While passing to the right the bottom boundary of the cube is obscured by the platform from time 11 to 15. After resting at (68, 8, 10), the object retraces the path back to the original starting place (4, 8, 10), repeating the partial occlusion in the middle of the path.

Each experiment of this study was chosen for a reason. Experiment 1 was an experiment Prazdny (12), in his computational description of certain Bower and Wishart experiments was unable to model. Experiment 2 of this study is an experiment already run with human subjects with known outcomes. In fact, results very similar to those described below have been reported by Bower and Wishart (4)(16). The second experiment is also important in current work at Edinburgh designing a cost/gain model of development (see below).

The results:

Experiment 1: The PROLOG model for stage 1 produced movement and place errors each time the object either stopped or started in motion, 15 times altogether. There was no problem following the new motion in a different direction as long as the object's locations were close enough to each other across consecutive time intervals. ("Close enough" is an empirically testable measure with infants). Stage 2 infants perceived only one object since their perceptual checks were able to determine two objects to be one and the same if color and size measures remained invariant across time. Because there were no border violations stage 3 analysis gave the same results as stage 2.

Experiment 2: Stage 1 found a new object when either motion or rest or boundedness was violated (9 in all). Stage 2, using perceptual checks, found new objects only when boundedness was violated (5 objects). Stage 3 found only one object since perceptual checks were able to override violations of boundedness.

A motivating force in the design of our model has been to demonstrate that the infant's detection of the presence or absence of different perceptual invariants across the object structures that make up the experiments offer two powerful explanatory mechanisms: First, we hypothesize that the psychological effect of the presence of such formal (i.e. internal or mental) invariants is to produce the behaviors that allow us to discern the three distinct stages of development. The infants' tracking behavior is directed not by *direct* perceptual input (14) but by three sets of conceptual rules discerning the invariants found across the object structures of the experiments.

Second, we hypothesize that the high cost of coping with multiple *objects* (non integrated perceptual phenomena) at one stage of development gives way to a more economical accounting with the discovery of new perceptual invariants at the next stage. The discovery of new invariants provides a more parsimonious explanation for the same phenomena. This cost/gain explanation for between stage development is the main focus of our continuing research, with the model and with real babies. At present we know that infants exposed to tasks like experiment 2 described above show accelerated development through the stages. The acceleration is manifested not only in simple, visual tracking tasks such as this experiment but also in transfer tasks involving manual search (16).

The fact of acceleration in the transfer tasks gives us confidence that the changes induced by tracking experience are conceptual changes rather than changes in sensori-motor skill. Our hypothesis is that the motive force of change is the conceptual gain associated with the reduction in the number of phenomena the cognitive system must deal with at each successive stage. The 'cost' of this 'gain' is the increased load the perceptual system must bear.

With both experiments there is a clear gain: Experiment 1 presents an object in motion and at rest and then changing direction. The youngest infants perceive a new object each time the rest or motion change. These multiple objects are *unified* by the perception of color and shape invariance at stage 2. Similarly, in experiment 2 multiple phenomena are perceived as the object starts, stops, and shares boundaries with the platform. Again the invariant aspects of the object, even as it shares a common space, allow the more advanced infant to perceive a single object at rest, moving, and sharing boundaries.

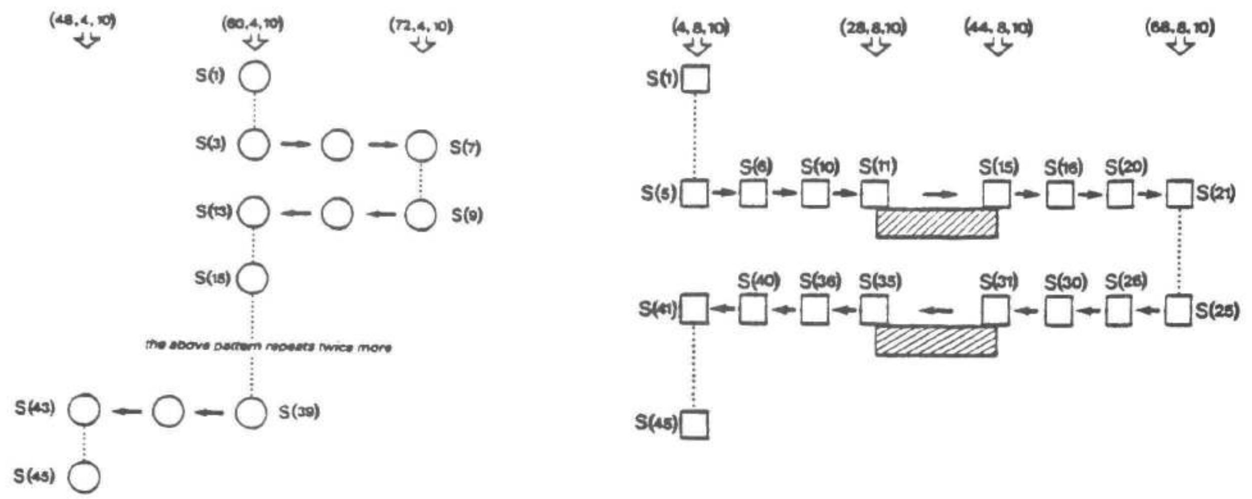

Figure 1 (l) and Figure 2 (r). S(i) represents the ith snapshot or time period for the experiment and (x,y,z) describes the location of the object in 3-dimensional space.

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