Modelling the Stages of the Object Concept in Infancy

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Abstract

A model is presented for the three stages of development of the object concept in infancy identified by Bower and Wishart in their research. The stages are described by sets of PROLOG clauses that interpret object structures representing the phenomena interpreted by the infants themselves. Three experiments are presented and the behavior of the PROLOG model is described for each stage of development. Motion, rest and boundedness of objects are hypothesized as the invariant aspects of perception that both explain the behavior of the infant and constitute the theoretical underpinning of the PROLOG model.

I. Introduction

Over the past ten years the research group at the Department of Psychology of the University of Edinburgh lead by T.G.R. Bower has focused on the development of the object concept of infants. This work is reported in publications by Bower (1967, 1972, 1974, 1981) by Bower and associates (1973, 1981) and by Wishart (1979). This research has identified three stages of development of the object concept in infants. Furthermore, this research has lead to the hypothesis of rest, motion, and boundedness as the perceptual invariants that provide explanation for the stages of development of the object concept in infants.

The three stages identified in the Bower/Wishart research, along with a summary of the behaviours associated with each stage will be presented in the next section (II). The following section (II) presents the PROLOG model of the three stages and includes the models trace on three experiments. Finally, IV, some comments are given on our approach to the modelling of infants' development of the object concept.

II. A Summary of the Psychological Evidence

During recent years the research group lead by T.G.R. Bower at the Department of Psychology of the University of Edinburgh have run many studies focusing on the development of the object concept by infants. The conclusions, and a summary of this research is presented by Wishart (1979). Wishart describes each of the three stages by a set of rules and a set of behaviour patterns found in the infants that give evidence of the existence of the rules.

Rule 1, which corresponds to Piaget's stages I and II, (1936, 1937, 1946) is stated;

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

It immediately 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 the infant as a tranformation of the original object rather than as a replacement by another object (Bower, 1974).

The search behaviour evidence for rule 1 may be summarized as follows: A) to find a stationary object look for it in the place where it usually is. When the object has started to move and the subject looks to the place the object formerly occupied a "place error" (Bower, Broughton and Moore, 1971) occurs. B) to locate a moving object, look for it along its path of movement. When the object has in fact stopped and the subject continues to follow its path a "movement error" (Bower and Paterson, 1973) occurs.

Rule 2 describes the second stage of development, corresponding to Piaget's III - V stages (Piaget 1936, 1937, 1946). Rule 2 states:

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

Now 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 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. Thus the total or partial occlusion of the object will still cause problems for the stage 2 infant.

Search behaviour for the stage 2 infant will include finding an object by searching for it in its usual place, <u>or if it has moved</u>, along its path of movement. Since featural information is incorporated in this rule for identifying an object any event sequence violating the perceptual integrity of the object (as when the object is covered by a cup or any other occluder) will be treated by the infant as the replacement of the original object by another object. Thus behaviour in this situation will be: to find an object that has mysteriously disappeared remove the obejct that has replaced it; or more specifically to find the disappearing object remove the object which is in the place where the desired object was last seen.

Rule 3, corresponding to Piaget's stage VI, (Piaget 1936, 1937, 1946) can be stated as follows:

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

Here, the identity rule is essentially the same as in rule 2 but is modified to fit with the infants experiences of the consequences of interactions between objects.

For an infant working with only rule 1, an object which moves then stops or working with rules 1 and 2 an object 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. 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 this understanding he/she may succeed in "solving" problems involving spatial relationships between two or more objects. These successful search strategies are, however, highly specific to particular problem situations and do not lead to success in other conceptually similar tasks (Wishart, 1979).

Thus, Bower and Wishart hypothesize that the infant developes 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 infants attempts to relocate objects and explains the erroneons behaviour seen on the traditional object permanence tasks. As one rule is replaced by the next the infant comes closer to appreciation of the independent 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 in virtually any event sequence without risk to its unique identity.

A PROLOG model of three rules described above will be given in the next section along with the results of several experiments showing the model interpreting different perceptual situations.

III. The PROLOG Model and Three Experiments

The computational description of the object permanence phenomenon is written in PROLOG a very high level computer language (Warren and Periera, 1977). The action of PROLOG is of a unification algorithm operating on a set of record structures, or alternatively a resolution theorem prover operating over a set of Horn clauses.

PROLOG (for Programming in logic) record structures are of two general forms: a set of facts and a set of inference rules. The PROLOG facts are used to build the "object structure" for the description of the object at each period of time. This will be accomplished by a set of "snapshots" of the object to be described below. As an example of facts we might say "loc(objn, x, y, z, t), color (objn, cl, t) or size (objn, sz, t) "to indicate that a certain object called "objn" has location coordinates "x,y,z," has color "cl" and size "sz" at time "t". Facts such as these will make up the object structure for each snapshot.

PROLOG rules are of the form A ⊢ B, C, D which may be described procedurably as "to do A attempt to do B and C and D". B, C, and D may be facts, as above, checked to be true or may themselves be rules that lead to the proof or performance of B, C and D. For example, the three stages of development will be described each by a PROLOG clause containing further calls to describe perceptual checks, boundary violations, anticipations, and so on. These will be given in some detail below.

Thus the computational model will consist (1) of a set of snapshots made up of object structures designed to portray the perceptual information available at any period of time and (2) the set of rules descriptive of each stage of development of the infant. Figure 1 portrays the snapshots for experiment 1 where an object moves back and forth across a field of vision. The object is a red rectangular sold resting at location 60, 4, 10 (X, Y, Z coordinates. All action takes place in the first octant of 3-dimensional cartesian space with the viewing infant at location (60, 0, 0)). After remaining in place for three periods of time the object moves, taking five periods of time, to location 80, 4, 10. Resting for three periods of time it travels back to 60, 4, 10 in five periods of time. After repeating this same sequence again it moves off in the opposite direction. S(n) in figure 1 is meant to indicate the snapshot corresponding to period of time n. Each of the experiments will be described in a similar sequence of snapshots.

A description of the PROLOG rules modelling each stage of development is now given. As noted above, these will be made up of a sequence of inferences describing perceptual competencies, expectations, etc. Rather than give PROLOG code (which is available from the first author to anyone interested) we list rather 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 immdediately preceeding object structures found, cf(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 preceeding object.

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 continuity of boundedness acorss snapshots.

e) Based on the object at S(n) and S(n-1) construct an appropriate expected location at time S(n+1).

Stage 2.

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

Stage 3.

The competencies of stage 3 include all those at stage 1 and in addition consults the new perceptual check of stage 2 not only as in stage 2 (between c) and d)) but again if any boundary violations have been detected (after (d) of stage 1).

The a priori committment of this model of development should now be clear. Two issues are important: first, there is no interaction between the percept of an object and the cognizing subject that in any way changes the nature of the percept. Rather, the changes come in the subjects' transformation or interpretation of this percept.

Secondly, this committment of the fundamental integrity of the percept allows description of its origins and presence according to a number of differing theories (Marr, 1978; Ullman, 1978). This program does not parse retinal arrays to detect edges or perform figure ground separation. (However, it does detect boundary violations such as partial occlusion, see experiments two and three below). Further, the perception of motion and changes of motion by calculating differences in positions over time is an irrelevant implementation detail, that is, like feature extraction, how this is accomplished by the human is an empirical question to be answered by researchers considering these aspects of human response.

We hypothesize that the symbolic output of the feature and motion detection mechanisms is available to the cognizing subject. We emphasize the descriptive adequacy of the internal symbol structures and the interpretative adequacy of the subjects manipulation of such symbol structures. Further, the changes in the computational rules expressing the interpretative adequacy of infants at various stages of development (are hypothesized to) offer explanation of that development.

Experiment 1 is described above in figure 1 and its explanation. The snapshots for experiment 2 are given in figure 2. Here the object, a green cube, is at rest at location (0, 8, 10) for the first 5 time periods. It then begins to move to the right (constant velocity) for times 6 through 20. During this period it is partially occluded by a rectangular solid located at (3 2, 4, 6). The partial occlusion lasts from times 12 through 15. The green cube then rests at location 64, 8, 10 for 5 time periods before beginning its movement back behind the occluder to its original location (0, 8, 10) where it rests for five time periods before the experiment ends.

Experiment 3 is identical to Experiment 2 except that the green cube changes to a red sphere and back to a green cube with every succeeding 5 time periods. That is, it is a green cube for time periods 1 to 5, 11 to 15, 21 to 25, 31 to 35 and 41 to 45 and red sphere otherwise. In experiment 2 as the infant proceeds through the stages, he/she will perceive fewer objects while in experiment 3 stages 1 and 2 the opposite will occur.

To summarize then, a set of object structures were created to describe each of the three experiments noted above. Then, in each instance the PROLOG model of each developmental stage was run on these object structures. The results of these simulations are described below.

Table 1

	OBJECT NUMBER	TIME	REASON
Stage 1	1	1	object at rest
	2	6	object in motion
	3	12	boarder violation
	4	15	end violation
	5	21	object at rest
	6	26	object in motion
	7	31	boarder violation
	8	34	end violation
	9	41	object at rest
Stage 2	1	1	object at rest
	2	12	boarder violation
	3	15	end violation
	4	31	boarder violation
	5	34	end violation
Stage 3	1	1	object at rest

Table 1. The results across all stages of experiment 2

Table 2

	OBJECT NUMBER	TIME	REASON
Stage 1	Same as Stage 1, Exerperiment 2		
Stage 2	1	1	object at rest
	2	6	change color, type
	3	11	change color, type
	4	12	boarder violation
	5	15	end violation and change color, type
	6	20	change color, type
	7	25	change color, type
	8	30	change color, type
	9	31	boarder violation
	10	34	end violation
	11	35	change color, type
	12	40	change color, type

Stage 3 - Same as Stage 2 without changes 4, 9 and 10, i.e., boarder violations are ignored unless there is also a color, type change.

Table 2. The results across all stages of experiment 3.

Experiment 1.

Stage 1. With rest and motion errors the stage 1 model sees ten different objects. The ten objects are determined by following each object during its constant motion (or rest). When a change in motion (or rest) occurs, a new object is hypothesized. The stage 1 infant has no trouble following the changed direction of motion as long as the "new" object is within a radius of interest of the previous object.

Stage 2. With the perceptual checks of size and color only one object is seen throughout experiment 1.

Stage 3. With no boundary violation the results of stage 3 are the same as that of stage 2.

Experiment 2.

The results of experiment 2 across all stages are given in Table 1. The object number, time of object change and reason for the new object are given for each stage.

Experiment 3.

The results of experiment 3 across all stages are given in Table 2. The object number, time of object change and reasons for the new object are given for each stage.

IV. Summary and Conclusions

This paper represents a step in our continuing effort to form a computational model of infants' stages in development of the object concept (Luger et al, 1981). An alternative approach to the same problem which we will comment on below, was take by Prazdny (1980). Indeed, the attempt to model aspects of development is not new (Young, 1976) nor is the use of PROLOG to model human problem solving skills new (Luger, 1981). What we have done is describe infants development of the object concept in terms of the perceptual invariants of motion, rest and boundedness. The PROLOG rules of our three stages emply these invariances in hypothesizing objects as the same or different across each time period.

The results of our experimental study may be summarized as follows:

Experiment 1. The PROLOG model for Stage 1 produced "movement" and "place" errors each time the object either started in motion or stopped (ten objects in all). 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). Stage 2 infants only saw one object as their perceptual checks were able to determine two objects as the same if color and size measures remained constant across time. Because there were not boarder violations Stage 3 gave the same results as stage 2.

Experiment 2. Stage 1 found a new object when either motion or rest on boundedness was violated (9 in all). Stage 2 found new objects only when boundedness was violated (5 objects). Stage 3 found no new objects since perceptual checks of size and color consistency were able to overide violations of rest, motion and boundedness.

Experiment 3. Stage 1 was the same as for experiment 2: rest, motion and boundedness violations produced 9 different objects. Stage 2 overrode rest and motion violations when size and color remained constant. But the change of size and color each five time periods brought the number of objects up to 12. Stage 3, with removal of new objects for boundary violations not happening at the same time as the object tranformations, produced three fewer objects than Stage 2.

The three experiments of this study were chosen each for a reason. Experiment 1 was an experiment that Prazdny could not simulate with his model and more will be said on this below. Experiment 2 was an experiment already run with human subjects with known outcomes. In fact, results very similar to those we found will be reported by Bower and Wishart. Finally, Experiment 3 is a recent study still being tested at the University of Edinburgh by Wishart. It will be interesting to compare our results with her findings when these become available.

It should, of course, be noted that 9 or 12 objects hypothesized as present in an experimental study are not what we are calculating. The behaviour patterns of the infants indicating "surprise" or "dismay" or "occurrances different from expectations" are what we counted. (Meltzoff and Moore, 1977). These behaviours are calculated acorss populations of infants. (See the Bower/Wishart studies in the references for futher discussions of these points).

Prazdny (1980), has recently produced a computer model of the Rule 1 behaviours described above. Prazdny examined 12 Bower tracking studies, and then excluded one of them, experiment 1 here, from his analysis for reasons not entirely clear. In the other 11 experiments he suggested that the experimental results could not fully support the place movement analysis of Bower. We feel, however that our own work noted here and elsewhere (Luger et al, 1981), does support a place, movement, boundedness analysis of the data. (Prazdny, (1980) also attributed to Bower an experiment and results (experiment 7) which was never even performed by Bower or his group).

Indeed, the Prazdny paper indicates a rather more serious misunderstanding of the Bower/Wishart research when he indicates that an infant would not, being dependent on immediate visual input, look for a "missing" object, producing place and movement errors. It is central to the Bower/Wishart analysis that the infants' tracking behaviour is directed not by "direct" perceptual input but by sets of conceptual rules. The missing experiment 12 of Pragdny (1 here) demonstrates this point, the infant is tracking forward and back to an empty space, a behaviour not directed by "immediate" perceptual input.

We hypothesize that the cost of coping with multiple objects is overcome by the gain in discovering new perceptual invariants, these we see in our rules for each subsequent stage. New invariants at later stages mitigate the increasing costs of coping with the same phenomena at a more primitive stage of development.

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Footnote

1. Although this paper does not elaborate on the distinctions between object permanence and object identity interpretations of object concept behaviours, the authors' bias towards identity theory should be made clear. A basic notion of object permanence (i.e., of the continued existence of objects when unperceived) is assumed to be present from very early on (Bower, 1967); according to identity theory, it is the step-like discovery of the precise spatio-temporal nature of that existence which lies behind the sequence of errors found in standard object concept tasks, not the development of a notion of permanence *per se*.

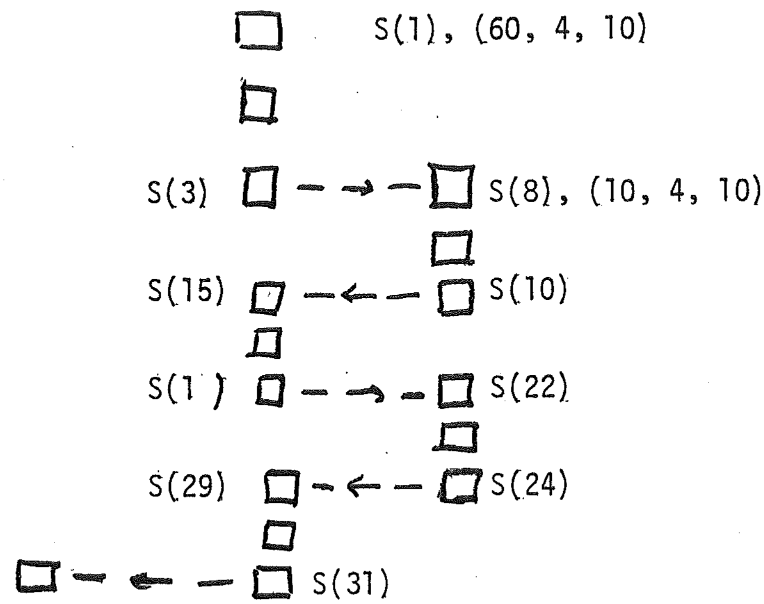

Figure 1. The snapshots of Experiment 1, where (x,y,z) represents the location and S(n) indicates the snapshot for time period n.

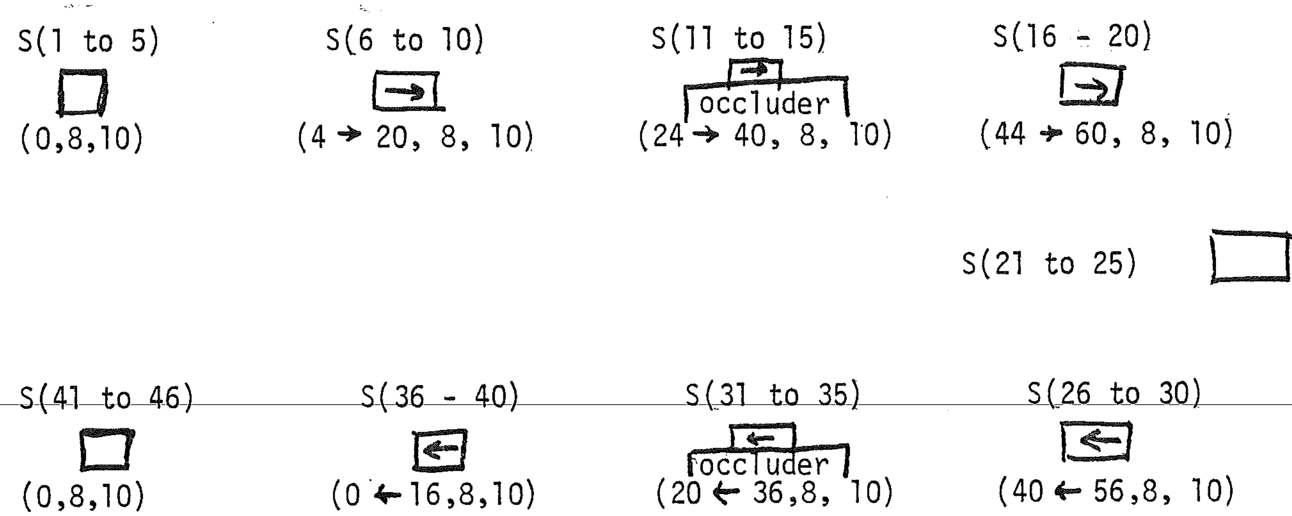

Figure 2. The snapshots and locations for experiment 2. (X1 → X2, Y, Z) represents the X-coordinate change y and Z remaining constant.

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