CONDITIONS ON ACQUISITIONAL MODELS

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Nine conditions that may be placed on acquisitional models are that they must: (1) specify their domain, (2) demonstrate applicability across language types, (3) represent only the information actually available to the child, (4) include inputs and outputs in a proportion corresponding to their observed proportions, (5) include inputs and outputs in a sequence corresponding to their observed sequence, (6) make plausible assumptions regarding psychological processes, (7) make testable assumptions regarding psychological processes, (8) give evidence for the learnability of the proposed grammar, and (9) demonstrate the ability of the system to generate the output. A model is presented that attempts to satisfy these nine conditions for one area of linguistic development--the acquisition of morphophonology. The functioning of the model is sketched in terms of a dialectic cycle for the processes of application, monitoring, and acquisition. The system of application is based on a competition between rote, analogy, and combination. The discussion notes ways in which the model addresses each of the nine conditions noted above.

Key words: Acquisition; linguistics; morphology; simulation.

1. Introduction

Although the formulation of a model of learning is a primary goal of psychological theory, learning theory as it is presently constituted tells us little about the acquisition of complex skills in humans. The situation is particularly problematic in the areas of language development and cognitive development where difficulties in formulating acquisitional models have forced researchers to turn their attention to detailed accounts of processing rather than models of actual development [1, 19]. Perhaps the major reason for this state of affairs is the fact that acquisitional models are subject to a wide array of fairly stringent *a priori* conditions. The present paper calls attention to nine of these conditions that must be satisfied by an acquisitional model. Some previous attempts to satisfy these conditions will be illustrated by an examination of the computational and mathematical models of language acquisition that have been proposed by Anderson [1], Biermann and Feldman [3], Braine [4], Gold [13], Hamburger and Wexler [14], Harris [15], Horning [17], Kelley [18], Klein and Kuppin [20], Miller [23], Pao [26], Reeker [28], Salveter [29], and Siklossy [31]. The second section of the paper outlines an acquisitional system called the dialectic model [22] that attempts to satisfy each of these conditions. The third and final section summarizes the general case for the use of computational models in the study of language acquisition.

2. Nine Conditions on Acquisitional Models

Chomsky [10] has characterized the language acquisition problem in terms of three components: the primary linguistic data, a language acquisition device, and an output grammar. We will refer to these three components as: environmental inputs (I), acquisitional strategies (A), and linguistic production systems (P). From a psycholinguistic point of view a fourth component must be added: these are the behavioral outputs (O) of the production systems. Finally, a statement regarding scope (S) must be included in any given model in order to delineate the types of outputs or production systems it seeks to explain. Thus, any given acquisitional theory can be expressed in terms of a quintuple of components $\langle S,I,A,P,O \rangle$. Any given characterization of this quintuple must also meet a set of conditions (C) which outline the minimal standards for an acceptable model. The present paper proposes, in an informal fashion, nine specific candidate members of the set (C). This listing is not intended to be exhaustive, and it is clear that some important conditions (particularly those relating to individual differences and linguistic variation) have been overlooked. However, the nine conditions proposed here are the ones which have received the most attention in discussions of acquisitional models.

2.1 Conditions on Scope

The general task of specifying the scope of an acquisitional model is subject to two specific conditions: the domain condition and the universality condition. The first condition, the *domain condition*, is that the model must specify the class of phenomena it is designed to predict. Most computational models of language acquisition have satisfied this first condition without difficulty, although the actual domains that have been chosen for study vary quite widely. For example, Hamburger and Wexler concern themselves with the acquisition of syntactic transformations, Salveter examines the development of lexical semantics; MacWhinney focuses on the acquisition of morphophonology, while Braine, Harris, Kelley, Miller, Reeker, and Siklossy focus on the acquisition of phrase-structure.

The second condition, the *universality condition*, requires that the model be applicable to languages of widely different structural types. Siklossy addresses this problem by illustrating how his program can learn simple structures in Russian. Anderson shows how his program can acquire some simple structures in French. However, most researchers in this area have simply failed to address this crucial issue, apparently assuming that their approach is universally applicable.

2.2 Conditions on Inputs and Outputs

The specification of the shape of the inputs to the model and the outputs from the model is subject to three further conditions: the representation condition, the proportion condition, and the sequencing condition. Thus, the third condition on acquisitional models, the *representation condition*, holds that proposed representations must encode both inputs and outputs in such a way that they include all of the information actually available from the stimulus and nothing more. Several models seem to make too strong assumptions about the inputs available to the child. Harris assumes that the input includes information on the part of speech of each word. This assumption seems quite implausible. Kelley's model and Hamburger and Wexler's model both assume that the child receives complete semantic interpretations of all sentences from the non-linguistic context. Although there is good evidence that children use semantics in parsing sentences [24], the notion that they derive a complete non-linguistic interpretation seems much too strong.

The fourth condition, the *proportion condition*, stipulates that each type of input must be included in a proportion corresponding to its occurrence in actual input to the child. The fifth condition, the *sequencing condition*, requires that inputs be arranged in sequences that correspond to those in real input. On the output side, the model must generate forms whose shape matches real child output in terms of both its proportions of output types and its sequence. Neither of these conditions have been addressed in any systematic way by any of the existing models of language acquisition. However Gold [13] has shown that changes in the sequencing of inputs can radically alter the performance of a model.

2.3 Conditions on Acquisitional Strategies

Any characterization of the fundamental strategies used by the language acquisition device must satisfy a sixth and a seventh condition: the plausibility condition and the testability condition. The sixth condition, the *plausibility condition*, holds that it is necessary to demonstrate the psychological plausibility of the various acquisitional strategies utilized by a given model. This is to say that assumptions regarding processing strategies must be in accord with psychological data on human cognitive functioning. Looking over earlier models, we find at least five highly questionable assumptions that have been made by some, but not all, researchers. These questionable assumptions are that:

1. *Children acquire grammar by learning whole sentences*. This assumption is made by Anderson, Gold, Harris, and Siklossy. Reeker, on the other hand, argues that a better approach to early syntax sees it as the slow addition of building blocks to phrase-structure.
2. *Children can add, delete, or otherwise radically modify whole grammars*. Mechanisms for such radical modification are proposed by Horning, Klein and Kuppin, Pao, and Salveter. However, extensive radical changes in the form of the grammar are never reported in child language data.
3. *Learning proceeds on the basis of classes rather than items*. Recent studies in both child language [5, 21] and the role of the lexicon in the grammar [6] have shown that many rules are based not on whole classes, but on individual items. However, the procedures utilized by Anderson, Hamburger and Wexler, and Siklossy provide no role for lexical information. On the other hand, the models proposed by Braine, Kelley, and Reeker do allow for the learning of lexically-based rules.

4. Children can learn through overt correction. Brown and Hanlon [7] have shown that overt correction has little impact on acquisition. However, Gold's notion of "informant" presentation and Pao's notion of delimiter presentation both seem to assume overt correction of the child by the adult.
5. Linguistic forms are either learned or not learned. Most of the models (with the exception of Horning [17]) assume that a child either accepts a rule or rejects it. However, the actual data on acquisition show extensive periods of competition between forms and slow changes in rule strength. Moreover, it is clear that one negative instance cannot unseat a well-learned rule. Thus we have no case of the rejection of strong rules in adulthood, although several of the models would predict such rejections.

The seventh condition that may be placed on a proposed set of acquisitional strategies is the testability condition. Here the problem is to formulate all assumptions in a way that allows them to be tested empirically. Of course, if a testable assumption fails to hold up against empirical testing, it is then seen to violate the plausibility condition. Failures to satisfy the testability condition are usually due to the formulation of routines with no apparent behavioral consequences. Examples of such covert processes include the "clean-up heuristics" proposed by Klein and Kuppin and the processes of rule merger and "bracketing" proposed by Anderson.

2.4 Conditions on Production Systems

The last two conditions that must be satisfied by any acquisitional model involve the relation of the proposed production system (i.e., the grammar) to the input, on the one hand, and the output on the other. Thus, the eighth condition on acquisitional models, the learnability condition, is a condition on the mapping of the input onto a production system. The most explicit formalizations of this condition can be found in Feldman [12] and Hamburger and Wexler [14]. Demonstrations of learnability usually take certain properties of the target production system for granted and then attempt to show that, given a set of inputs, the proposed acquisitional strategies are capable of learning a production system with the assumed properties.

The ninth condition on acquisitional models is the generativity condition. From the viewpoint of psycholinguistic theory, each proposed production system for the child at each point in his development should be capable of generating a set of output data that correspond to real data. Thus, from the viewpoint of psycholinguistic theory, acquisitional models must meet the condition of "weak generative adequacy" [9]. It is important not to read the generativity condition too narrowly. Relevant output data include not only the utterances spontaneously produced by the child, but also those produced in controlled psychological experiments. In particular, any proposed production systems must be able to account for the kinds of morphological and syntactic productivity that occur in children's use of new lexical items [2, 22]. At the same time, a production system must be so restricted that it contains only procedures which are both plausible (condition 6) and testable (condition 7). Thus conditions 6 and 7 must be seen as applying to proposals regarding production systems as well as proposals regarding acquisitional strategies.

3. The Dialectic Model

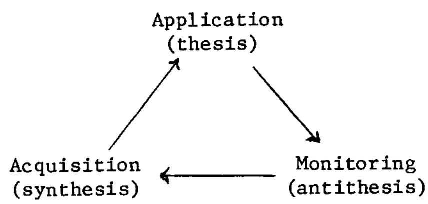
In this section, we will examine the structure of an acquisitional model proposed by MacWhinney [22]. This model is currently implemented in PL-1 on the Burroughs 5700. At several points in the discussion we will note the ways in which this model attempts to meet the nine major conditions outlined above. The model, which is called the dialectic model, has been formulated to account for the acquisition of the morphophonological patterns of human languages. Thus, the model meets condition 1 (domain) by limiting its scope to the system of morphophonology. Morphophonological patterns govern the ways in which the sounds of words change when they are inflected. For example, the /f/ of the word wife in English is altered to a /v/ in the plural form wives. This alteration is a morphophonological fact. Although English makes little use of either inflections or morphophonology, other languages have extremely complex systems of morphophonology. In an attempt to meet condition 2 (universality), the model has been applied to data from ten languages in four different languages families.

The model is presently formulated as an account of morphophonological development, but there is reason to believe that the model may be applicable to other areas of language acquisition as well. The following account of the operation of certain parts of the model is based on MacWhinney [22]. For a much fuller account of the model and for a summary of the cross-linguistic data on the acquisition of morphophonology the predictions of the model, please consult that monograph.

3.1 The Dialectic

In its essence the model is fairly simple, although in its detail it is somewhat complex. The model begins by adopting three basic terms from dialectic philosophy. These are the notions of a thesis, an antithesis, and a synthesis. A thesis is something that is produced by the child, while an antithesis is some piece of information that does not jibe with the thesis. For example, a child may say the word wifes and, moments later, remember that he should have said wives. In this case the thesis would be the initial form wifes and the antithesis would be the second form wives. When a child encounters such an opposition between a thesis and an antithesis, he attempts to construct a synthesis to resolve the opposition. In the case of the *wifes - wives example, the child attempts to decide under what conditions an /f/ can be altered to a /v/. The pattern governing this alteration is a new synthesis. In general, development can be viewed as the continuous construction of new syntheses to resolve disequilibria between theses and antitheses.

Each of the three basic terms (i.e., thesis, antithesis, synthesis) can be associated with one of the basic processes of the model. The three processes are: application, monitoring, and acquisition. The thesis is generated during the process of normal language use or application. The results of this normal application are then subjected to a process of monitoring. Monitoring provides the system with information on the extent to which its goals have been attained. In some cases, monitoring may detect an antithesis to the thesis formed by application. When this occurs, the system is in disequilibrium. Equilibrium can be restored by the process of acquisition which searches for a new synthesis to resolve the conflict between the thesis and the antithesis. This newly formed synthesis then may be used as a thesis in subsequent application. Thus, there is a continuing resolution of opposites which results in the dialectic cycle given below:



This cycle is operative both in verbal expression (production) and verbal reception (comprehension). The next three sections briefly examine each of these three processes. A simple Hungarian example is given which traces the model through some of the details of processing.

3.2 Application

Discussions of the abilities underlying the child's ability to use his language have focused on three central strategies: rote-memorization, productive combination, and analogical formation. Some writers have stressed the importance of rote; others have attributed language application to analogy; still others have viewed language application as use of the ability to produce forms by combination. The dialectic model makes the somewhat weaker claim that rote, combination, and analogy constitute alternative means of producing morphophonological formations.

The central characteristic that distinguishes rote processing from other forms of processing is that rote processing is non-analytic [27]. Forms that are learned by rote and applied by rote are never broken up into their component pieces or decomposed in any way. In the area of morphophonology, rote learning of words treats inflections as if they were integral parts of the root. For example, the child may learn that the Hungarian word pipák means "several pipes" without realizing that the suffix /k/ codes plurality. By learning words in this way, the child effectively ignores the entire system of morphology, since he learns words as wholes rather than as combinations of smaller units. In the simulation of the dialectic model, rote forms are stored in a long-term memory file called File 1.

Although there is a good evidence that the child produces many morphological formations through rote, there is also evidence that rote cannot be the only device in the child's arsenal of morphophonological strategies. If the child produced all forms by imitation or rote, errors would seldom occur. But, in fact, the child speech is full of morphophonological errors. For example, children say foots instead of feet and goed instead of went. The traditional account of such errors views them as cases of analogy. According to this account, goed is formed on analogy with hoed, according to the proportion: hoe : hoed :: go : goed. In our Hungarian example, the form pipák could be produced through an analogy like labda : labdák :: pipa : pipák. Children also often produce the erroneous form *pipak. This form could also be attributed to analogy, but any such analogy would be fairly implausible, i.e., hajó : hajók :: pipa : *pipak.

Linguists have used the term analogy to refer to several different strategies. For example, Saussure [30] speaks of an analogic form as "a form made on the model of one or more forms in accordance with a definite rule." However, this definition ignores the distinction between three very different strategies: simple analogy, extended analogy, and combination. The first of these three strategies produces one morphological formation on analogy with another. This is what we will treat as simple analogy. Simple analogy involves the processing of only two items: the target item the child is trying to produce and the basis or referent item on which he is basing the analogy. The second strategy is what we will call extended analogy. This strategy produces target formations on the basis of a pattern which derives from the regularities present in some larger array of items. Thus, the central difference between simple analogy and extended analogy is that simple analogy is based on one item whereas extended analogy is based on a pattern inherent in a group of items. Both simple and extended analogy involve two basic steps. First, the child must search his lexicon (i.e., File 1) to find an item or items to serve as the basis. Then he must analyze the phonological representation of the basis and apply the results of this analysis to the target form.

When the two processes of rote and analogy are taken together, they can explain nearly every individual morphological formation produced by a child. All correct forms can be attributed to rote. Nearly every incorrect form or neologism can be attributed to analogy. Although this dual-process account explains nearly all morphological formations when considered individually, it fails to explain certain patterns that arise when morphological formations are compared within the whole system or across time (see [22]). Assuming, then, that at least some morphological formations are produced by some third process, what might this process be? The suggestion being offered here is that this third process involves a procedure called combination. Combination differs from analogy in regard to its use of long-term memory structures. When analogy extracts a pattern from a basis, this pattern is not stored for future reference. By definition, analogies are produced on the spur of the moment and leave no trace in long-term memory. If a form is produced on the basis of the stored trace of some previous analogy, then, by definition, it is produced not by analogy, but by combination. In other words, it is the formation of long-term memory structures that serves to distinguish combination from analogy. In the simulation of the model, these long-term structures are the morphophonological rules stored in Files 4 and 5.

Combination involves four sub-procedures: search, linearization, selection, and modification. To illustrate the operation of these procedures, let us take the formation of the Hungarian form pipák as our example. Processing begins with the semantic representation "pipe + plural." The search process then examines the three lexical files (Files 1, 2, and 3) for relevant lexical items. The root pipa "pipe" is found in File 3, the root file. Then the suffix -ok ~-ek ~-ök ~-k "plural" is found in File 2, the affix file. Next, the child has to decide whether these two items should be ordered as k + pipa or as pipa + k. From earlier processing, the child has learned that -k is a suffix. This information now determines the choice of the order pipa + k. The representation is then:

$$\text{pipa} + \left\langle \begin{matrix} \text{ok} \\ \text{ek} \\ \text{ök} \\ \text{k} \end{matrix} \right\rangle$$

A File 5 selection production then selects -k as the correct variant of the plural suffix because the root ends in a vowel. The form is now:

pipa + k

Finally a File 4 modification production of the shape a → á / ___ + X alters pipak to pipák.

Thus we see that the program can generate the form pipák in three different ways: by rote, by analogy, or by combination. The choice of one process over another is governed by a general system of competition based on the strengths of the individual productions that was originally proposed by Herbart [16]. Both the system of competition and the effect of phonetic predispositions on morphophonology are discussed in MacWhinney [22]. Together, these three processes compose a production system designed to meet conditions 2 (proportion), 3 (sequencing), 8 (learnability) and 9 (generativity). The changing proportions of the different forms during development are simulated in the output protocols. These proportions are determined by the changing relative strengths of rote, combination, and analogy in the context of the general system of competition. In regard to condition 8, the learnability of the specific procedures involved in combination is the chief area of interest. However, formal demonstrations of the learnability of these operations must be postponed to future publications. The present section has focused instead on the generativity condition by showing how, taken together, rote, analogy, and combination suffice to generate the observed output. The plausibility (condition) and testability (condition 7) of the production system presented above and the acquisitional system to be presented below have been demonstrated by evidence from child errors as well as data on acquisitional sequences [22].

3.3 Monitoring

The second basic process of the dialectic is monitoring. Four types of monitoring are possible. In the first type, the child checks to see if he ended up saying everything he wanted to say. This is called expressive tallying. In the second type, the child checks to see if he understood everything he heard. This is called receptive tallying. These two types of monitoring are important for the acquisition of new lexical items. A third type of monitoring, called receptive criticism, allows the child to correct incorrectly learned forms. However, it is the fourth type of monitoring, called expressive criticism, which leads to the acquisition of morphophonological rules. In expressive criticism the child produces one form by rote and another by combination. For example, the child may combine pipa and -k to form *pipak. Moments later the child finds the correct rote form pipák in File 1. The disequilibrium between the thesis *pipak and the antithesis pipák forces the child to attempt morphophonological acquisition.

It is important to note that a disequilibrated pair such as *pipak - pipák provides the child with information regarding both acceptable and unacceptable words in his language. Gold [13] has shown how information regarding both acceptable and unacceptable sentences is crucial to syntactic acquisition. The situation in morphophonological acquisition is quite parallel. But note that the information on non-words is not supplied to the child through overt correction. Rather, the child himself is the repository of the incorrect form. Thus, the objections that have been raised by Brown and Hanlon [7] to models that place reliance on overt correction are not applicable to the dialectic model.

3.4 Acquisition

Morphophonological acquisition has four component procedures: rank acquisition, modification acquisition, selection acquisition, and paradigm acquisition. Using our example of *pipak we will first illustrate in detail the operation of modification acquisition. Then we will briefly discuss the three other procedures.

Modification acquisition compares the thesis *pipak with the antithesis pipák segment by segment. The procedure first matches the /p/, then the /i/, and then the next /p/. At the fourth segment, it finds a mismatch between a and á. The modification itself is then tentatively formulated as: a → á. The procedure then looks into File 4 to see if some a → á modification already exists. If none exists, the following new modification is added to File 4:

a → á /pip ___k

Once this new modification is placed into File 4, a further disequilibrated pair like *fam - fám will have a different effect. It will serve to "prune down" the modification to:

$$a \rightarrow \acute{a} \;/\; \begin{bmatrix} +\text{lower lip} \\ +\text{closure} \\ +\text{voice} \end{bmatrix} \;\_\_ + [+\text{closure}]$$

Two more pairs such as *békas - békás and *mániaé - mániáé then prune the production into its final shape:

$$a \rightarrow \acute{a} \;/\; \_\_ + X$$

Each new pair increases the strength of the rule, whether or not the new pair changes the shape of the rule by pruning. In the case of the examples given above, convergence occurs after four trials. The data show that this rule of final /a/ lengthening is in fact learned very early. MacWhinney [22] found that children can use it productively as young as one year and eight months. However, there is also evidence that, when first learned, the rule is somewhat weak. Note that the procedure for production acquisition outlined above characterizes rule learning as a gradual process of abstraction without radical modifications or sudden reorganizations. Moreover, the core of the production is at first tightly centered on a specific lexical base and moves away from that base step by step.

The other three procedures in morphophonological acquisition are rank acquisition, selection acquisition, and paradigm acquisition. Rank acquisition works to adjust the rank of an affix that is incorrectly ordered. Thus the error *hazbaok for hazakba in Hungarian leads the child to increase the rank of ba by one. Selection acquisition works to form rules that are restricted to certain lexical items. Finally, paradigm acquisition works to acquire formal systems of conjugation and declension such as the system of gender marking in German by articles like der, die, and das.

4. Computational Models as Theories of Language Acquisition

The study of language acquisition has made real and significant progress during the last 20 years. Much of this progress has been achieved by focusing attention onto one or two of the nine conditions discussed in section 2, while ignoring the others. Research designed in this way will continue to advance the field. However, it may now be possible to begin work on a model of language acquisition that satisfied each of these nine conditions. Such a model must be explicit in regard to input, output, acquisitional strategies, production systems and overall scope. Moreover, all assumptions that are made must be testable and plausible. Finally the best model will be the one which not only demonstrates learnability, but also provides the best match to the output. It is in this last regard that computational models show their greatest promise. Because they can be designed to generate actual output, their performance can be directly compared to that of the child. The dialectic model for morphophonology constitutes one attempt to satisfy these nine conditions. At the present time work on aspects of the input conditions and on learnability is still in progress. However, the model has already succeeded in matching certain crucial aspects of rule development. Thus, although the goal of formulating a integrated acquisitional model is not yet achieved, this work has shown that progress can be made in this direction.

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