Cognitive Modeling of the Acquisition of a Highly Inflected Verbal System

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Abstract

How do children cope with the general regularities that govern language while keeping track of the exceptions to them? This question has been the subject of debate for many years and it is still an open question. In particular, learning the English past tense has been studied in depth given that it is a simple problem that combines a rulelike process with many irregularities. In this paper we try to extend these studies to a quite more complex problem: the Spanish verb inflectional system. This paper presents an ACT-R model that shows the well-known U-shaped learning and mimics in many aspects the process of learning exhibited by children. Thus, our approach shows how a highly inflected morphology system can be acquired in terms of dual-mechanism theories and sheds light on the posible structures involved in general language acquisition.

Keywords: Cognitive Modelling; Cognitive Linguistics; Language Acquisition; Spanish Morphology; ACT-R

Introduction

Language acquisition has been one of the central topics in Cognitive Science. However, it is still an open question how children manage to discover the general patterns present in language while maintaining knowledge of the exceptions to them. Verb inflection has been studied not only because it is an inherently interesting task but also because is an isolable subsystem in which grammatical mechanisms can be studied in detail, without complex interactions with the rest of language. Verb inflection is independent of syntax, semantics or phonology given that no aspect of these three other subsystems works differently with regular and irregular verbs. Furthermore, the particular phenomenon of U-shaped learning that presents the irregular inflection acquisition proccess lead us to the interesting question of what are the causes for that U-shaped learning and, going beyond, how we humans deal with the general regularities that govern language while keeping track of the exceptions to them. There are two main accounts to these questions. On the one hand, the so-called dual-mechanism theories posit that knowledge is somehow dissociated. Irregular forms are stored in memory as entries in the mental lexicon while regular forms are computed by rules. On the other hand, single-mechanism theories argue that a single representational system, usually an associative memory, is enough to explain verb inflection. Both theories present some problems and thus, the controversial debate is far from settled.

English past tense inflection has been the focus of attention of many studies in the last years. However, not much work has been done to widen these studies to other languages with a much richer inflectional system. Spanish is one of these highly inflected languages. Spanish verbs can have about forty possible different suffixes (Alcoba, 1999) depending on mood, time, aspect, number or person. Moreover, this great amount of possible endings is not the only difficulty the Spanish inflectional system presents. Also its regularity is very striking compared to simpler verb systems (like that of English). In Spanish verbs, inflectional affixes are typically combined with stems and both parts of the final inflected word can be irregular. These particular features in combination with the pattern of errors presented by children suggest that the cognitive processes involved in Spanish verb inflection are more complicated than the English ones. This fact turns the modeling of Spanish verb inflections into a quite more challenging task.

In this paper we present a cognitive model of Spanish verb morphology acquisition based on dual-mechanism theories and implemented under the largely used cognitive architecture ACT-R (Anderson, 2007).

Single vs. Dual mechanism theories

Two competing classes of theories try to explain how inflected word forms are mentally represented, processed and acquired. The dual-mechanism theories (Pinker & Prince, 1988; Marcus et al., 1992; Ullman, 2001) argue that knowledge is somehow dissociated. Regular forms are built by a rule that appends an affix to the stem. Irregular forms are associatively listed in memory as entries in the mental lexicon. Within this representational framework, the three stages of U-shaped learning of irregular inflections are easily explained. In the first stage, when the regular rules are not yet available, the lexical entries of irregular forms that have been frequently heard can be retrieved. On a second stage, the regular rules are acquired and overregularization errors appear in cases in which the lexical entry for an irregular verb is not available (note that the memory retrieval process is noisy and depends on the frequency of the lexical item that is looked for). Finally, on the third stage, the overregularization errors slowly disappear as more correct examples of irregular verbs are learned. Many empirical studies have been performed that support dual-mechanism theories in many inflectional processes and some languages (Marcus et al., 1992; Clahsen, Rotweiler, Woest, & Marcus, 1992; Clahsen, Aveledo, & Roca, 2002). However, the dual-mechanism theories are still not widely accepted.

Alternative accounts are the single-mechanism theories (Rumelhart & McClelland, 1986), also called associationism. These approaches propose that both regular and irregular forms are computed by the same representational system, an associative memory usually modeled by a neural network. Following these theories, U-shaped learning is due to changes in vocabulary. The overregularizations occur because children have heard the regular pattern with many different verbs. So, before the first overregularization occurs, the children have to be familiar with many regular verbs. However, there is little evidence for these assumptions in empirical experiments with children. Another problem of single-mechanism models is that many of them need external feedback to adjust their weights. But actually, negative evidence (corrective feedback) plays little to no role in the process of recovery (Brown & Hanlon, 1970; Marcus, 1993), so this assumption does not seem to be adequate.

How do Spanish children inflect?

From middle 80's the acquisition of verb morphology by Spanish children has been largely investigated by many authors (Hernández-Pina, 1984; Radford & Ploennig-Pacheco, 1995; Serrat & Aparici, 1999). However, a systematic and detailed study of the development of overregularization, similar to the one carried out by (Marcus et al., 1992) for the English past tense, was not carried out until 2002 by (Clahsen et al., 2002). In this study the authors try to shed light on the question of whether or not the dual-mechanism model extends to Spanish child language. The study consisted of 64 samples of spontaneous speech from 15 children covering the age period of 1;07 to 4;07 (see (Clahsen et al., 2002) for a detailed breakdown of the data). There are longitudinal data from 4 children in the relevant age range and cross-sectional samples from 11 children.

Table 1 (extracted from (Clahsen et al., 2002)) shows the types of errors present in the children's speech and their frequency distribution.

Table 1: Distribution of error types in the study of (Clahsen et al., 2002)

A.	Stem Errors		B.	Suffixation Erros	
I.	Overregularizations	116	I.	Overregularizations (132)	
				a. 1st conj. Overapplications	8
				b. Conj.-internal regularizations	124
II.	Irregularizations	1	II.	Irregularizations	0
III.	Other errors	3	III.	Other errors	1
Totals		120	*Totals*		133

The first error type is overregularization. In such cases, an irregular stem or suffix is substituted by a regular one. As predicted by dual-mechanism theories, overregularizations are the main kind of errors that children present. Suffix overregularization errors are divided into two subtypes: overapplications of 1st conjugation suffixes to verbs pertaining to the other conjugations (for example, the second conjugation verb *tra-er*[1] (to bring) is sometimes conjugated in past as *traj-é** instead of *traj-e*, due to the 1st conjugation suffix *-é* is overapplied). The other suffix overregularization error is produced by substituting an irregular suffix by the regular suffix corresponding to its conjugation.

[1]Stem and suffix are shown separated in Spanish verb forms.

Also as predicted by dual-mechanism theories, irregularization errors are almost inexistent. Irregularization errors in the stem occur always with verbs that present irregular forms in the verbal paradigms for this same tense. No verb with a completely regular paradigm was irregularized. For example a child said *cay-í** (I fell) instead of *ca-í*. This is atributed to an overapplication of the third person stem (the third person inflection is: *cay-ó*) to the first person.

Making a deeper analysis of the errors, it is also important to note that the stem formation and inflectional processes are dissociated in Spanish children language. There exist mixed errors in which children combine correct irregular stems with incorrect inflectional endings (for example, to conjugate the third person singular of the immediate past of the verb *ven-ir* (to come), some children say *vin-ió** (he came) instead of *vin-o*) which is accepted to support that different processes come into play to form the two different parts of the final inflected word. This dissociation supposes a great difference with the English inflectional system. This fact significantly increases the complexity of the task and consequently, the complexity of the model compared to other similar models of the English past tense (Taatgen & Anderson, 2002).

U-shaped learning

The study of (Clahsen et al., 2002) clearly extends to Spanish the results obtained by (Marcus et al., 1992) for English. The development of irregular verb acquisition is not guided by a linear learning function but by a U-shaped learning function in which three stages can be clearly distinguished.

In a first stage, the child is able to inflect very little verbs but the inflected irregular verbs are correct. In a second stage, the children have acquired some kind of knowledge about the regular rule and start to overapply it to irregular verbs. In the third stage, the overregularization errors diminish until mastery is achieved. The learning of regular verbs is quite simpler. Children start inflecting correctly a very low number of regular verbs and their performance steadily grows until they master the task.

The model

In this paper we propose a dual-mechanism model implemented in the ACT-R cognitive architecture. The core components that are used for the model, including the declarative and procedural memory systems, are parts of the ACT-R architecture, which has been largely validated through extensive separate experiments not only related to language. Moreover, the main processes used, like instance-based learning and the use of analogy, are part of the ACT-R modeling tradition. The two basic strategies of memory retrieval and analogy are neither specific to the task of producing a past tense nor even specific to language but general domain cognitive strategies:

- Memory retrieval: This strategy simply consists in retrieving a fact from declarative memory.
- Analogy: This strategy forms the required knowledge using a similar retrieved fact as a template. As stated by (Salvucci & Anderson, 1998), analogy is probably one of the dominant human strategies for problem solving and discovery.

It is important to note that the strategies we suppose that children have at the moment they start learning a language are very basic strategies common to many cognitive tasks. Note that, at the beginning, the proposed model has nothing similar to a regular rule to inflect regular verbs. The proposed model will learn them later on as a specialization of the analogy strategy. These initial strategies are similar to the ones proposed by (MacWhinney, 1978; Taatgen & Anderson, 2002), who claimed that the basis of the learning of the regular rules is analogy.

Detailed description

The two main components of the model are described as declarative-memory chunks and production rules. The declarative-memory chunks represent verb forms as follows.

VERB-FORM

ISA	VERB-TENSE
INFIN	CANTAR
CONJ	AR
INFIN-STEM	CANT
MTA	IND-PAST-PERF
NP	S3
STEM	CANT
SUFFIX	Ó

The chunk is of type VERB-TENSE. Its infinitive is *cantar* (to sing) and the infinitive stem and conjugation are *cant-* and *-ar* respectively. Moreover, given the characteristics of the Spanish verb inflectional system, it is necessary to store the mood, time and aspect of the verb form (in the slot MTA, the value IND-PAST-PERF stands for indicative mood, past tense, perfective aspect) and the number and person of the represented verb form (in the slot NP, the value 3S stands for third person, singular). The verb form corresponding to the information represented on the precedent slots is represented by the STEM and SUFFIX slots. Note that when the goal is to obtain a verb form, these two slots start with a NIL value and the task of the model is to fill them.

Procedural memory stores the strategies that guide the inflection process. As stated before, two basic strategies are the core of the model. However, given the dissociation between stem formation and inflectional processes that Spanish verb inflection presents, these strategies are also dissociated in different rules that try to form the stem or to find the correct suffix. The main rules of the model are:

- Rule 1 (verb form retrieval): When the model tries to find the verb form of a given verb with given MTA and NP slots, this rule simply tries to find a chunk in declarative memory that shares the INFIN, MTA and NP slots with the given one.
- Rule 2 (stem retrieval): This rule tries to find the stem of the goal verb form. To do that, it looks for a chunk in the declarative memory with the same INFIN and MTA slots.
- Rule 3 (stem analogy): When the model tries to find the verb form of a given verb, this rule just copies the INFIN-STEM of the goal verb form on the STEM slot only if the INFIN-STEM and the STEM slots of an arbitrary retrieved (i.e. the verb with a highest activation) verb are the same.
- Rule 4 (suffix analogy): This rule tries to find out the correct suffix of the goal verb form. To do that, it looks for a chunk in the declarative memory with the same CONJ, MTA and NP slots and, if the slots INFIN-STEM and STEM of the retrieved form are the same, it copies the value of the SUFFIX slot to the SUFFIX slot of the goal verb form.

These four rules cover the two basic strategies of the model and the two processes that Spanish speaking people are supposed to use when trying to inflect a verb. Figure 1 shows the processes that our model uses to inflect a verb. Dashed lines means that these processes are not available when the model starts working but they are learnt during the running.

Learning in ACT-R consists in the production of new rules. New rules are created by collapsing two rules that are applied in succession into a single rule. The basic idea is to combine the tests in the two conditions into a single set of tests that will recognize when the pair of productions can be applied. Also the actions of both rules are combined into a single action that will have the effect of both. The resulting rule is therefore a specialization of the two parent rules. The specialization, which is of particular interest, occurs when Rule 3 (stem analogy) fires first and Rule 4 (suffix analogy) fires secondly. In this case, the corresponding suffix is substituted into the rule, producing one of the regular rules. For example:

IF	the goal is to inflect a verb with CONJ = ’AR’ MTA = ’IND-PAST-PERF’ NP = ’S3’
THEN	set the SUFFIX slot to ’Ó’ copy the INFIN-STEM slot to the STEM slot

Note that one of these rules has to be learned for each combination of the values of the slots CONJ, MTA and NP, given that each regular suffix is different. Also it is important to note that the initial utility of the learned rules is very low. This means that newly created rules are not used just after being learned. It is necessary to reinforce the utility of this rule. This reinforcement occurs every time the rule is recompiled because its two parents fire consecutively. This way, the most

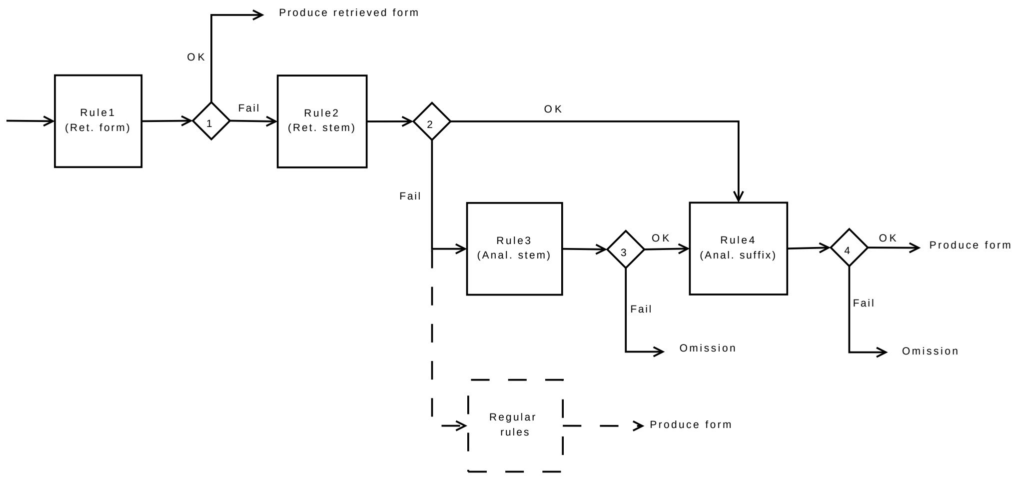


Figure 1: Processes used by the model. Dashed lines show processes that have to be learnt.

useful rules (the ones that are recompiled many times) are finally used by the model and those rules created just by chance are practically forgotten by the model. Moreover, ACT-R provides a way by which useful rules are reinforced: utility learning. This process reinforces the rules that have been used to reach to a specific inflection. When the model cannot inflect a verb, it propagates a lower reward than the one it propagates if the verb is inflected. This seems to be natural given that, when the model could not inflect a verb, it could not "say" what he wanted to "say". However, the reward received when a verb is inflected incorrectly is exactly the same as the one that is received when a verb is inflected correctly given that the model cannot know whether his production is correct or not. Note that one of the most important criticism to many connectionist models is that they need some kind of external feedback while, as stated before, it is widely accepted that children do not receive feedback when talking to their parents. Thus, the unique feedback our model receives comes from itself.

How does the model inflect?

Data and Procedure

The data we used as the input for the model consists of the verbs contained in the Spanish Verb Inventory[2] (SVI, (Rivera, Bates, Orozco-Figueroa, & Wicha, 2009)) which is made of 50 of the earliest acquired common Spanish verbs, with conjugations across person, number and 4 verb tenses (imperfect, immediate past, future, and present indicative), for a total of 920 unique verb forms. Future tense forms were discarded given its low frequency of use on child language and also imperfect forms were discarded given that they do not present almost any irregularity. So the final input for the model consists of the 220 immediate past forms and the 250 present tense forms of the Spanish Verb Inventory. Each of these forms has its associated frequency of use on children language.

In order to perform the different experiments we followed the design given by (Taatgen & Anderson, 2002). Every 200 simulated seconds two words are presented for perception and one word is selected for generation. These words are selected based on the frequency distribution given in the SVI. Also following the design of (Taatgen & Anderson, 2002), in each simulated month, approximately 1300 past tenses are produced. This number is chosen somewhat arbitrarily, but the model is not critically dependent on the exact rate of production.

Results

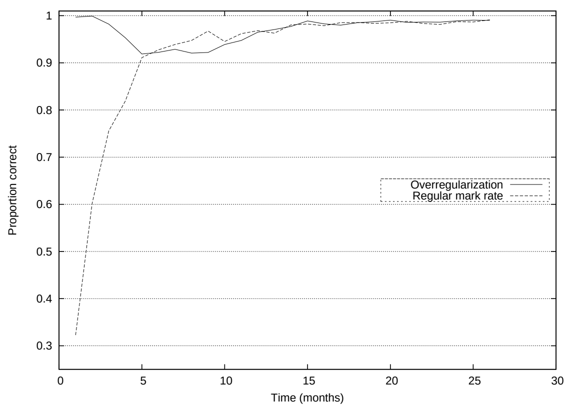
As stated before, the great majority of errors done by children are overregularization errors while only a few errors were due to irregularization of regular forms. According to (Clahsen et al., 2002), more of the 90% (94.7% in the stem and 92.5% in the suffixes) of the errors done by children are overregularization errors. Our model also presents a similar unbalanced distribution of errors between irregular and regular forms. The 93.3% of errors were overregularization errors. Moreover, the irregularization errors are mainly of the same kind of the ones done by children. As stated before, no verb with a completely regular paradigm was irregularized.

Figures 2(a) and 2(b) show the learning curves of the model and of María, one of the children from the study of (Clahsen et al., 2002) (It is important to note that the other children on that study have similar learning curves). Figure 2 shows the overregularization rate and the regular mark rate as they are usually plotted. Overregularization equals the number of correct responses on irregular verb forms divided by the sum of correct irregulars and irregulars inflected regularly. The regular mark rate shows the number of correctly inflected regulars divided by the total number of regulars produced. The development of the model clearly shows the U-shaped learning curve typical of children's learning of irregular verbs. As such, the results are quite similar to the ones of María. Our

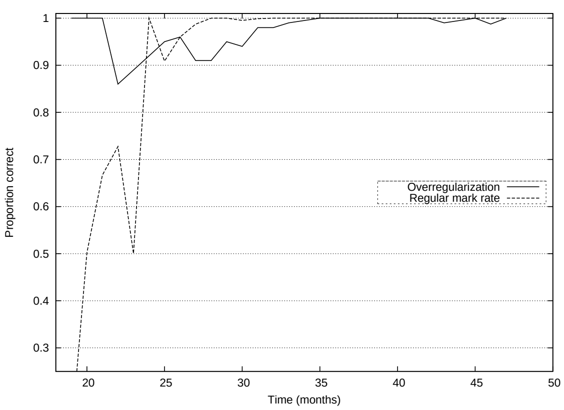
[2] Accesible at `http://crl.ucsd.edu/experiments/svi/`

model obtains a global 3.9% of overregularization, which is in line with children's performance. Spanish children studied by (Clahsen et al., 2002) present an average overregularization rate of 3.4% in the longitudinal samples and a 13.2% in the cross-sectional experiments. As pointed by (Clahsen et al., 2002) this difference could be due to the type of samples and the semi-structured style of the records.

Not only overregularization errors of our model are similar to the ones done by children. The percentage of irregularization errors done by our model was 0.5% while in children, overregularizations amount to 0.4% and in both cases no verb with a completely regular paradigm was irregularized.



(a)



(b)

Figure 2: Overregularization and regular mark rate presented by the model (a), and by María (b)

In order to better understand why U-shaped learning is achieved, we should go through the model's functioning in some more detail using some examples of irregular and regular vebs: a very frequent irregular verb form such as *pued-e* (he can) with a frequency in the SVI of 19269, a very frequent regular verb form such as *deb-e* (he should) with a frequency of 6955, a low frequency irregular verb form such as *jueg-an* (they play) with a frequency of 201 and a low frequency regular form such as *salt-a* (he jumps) with a frequency of 252.

At the beginning the model has no regular or irregular examples, so it fails every time it tries to inflect a verb. Gradually, high-frequency irregular verbs increment its activation on the declarative memory. If the model tries to inflect one of these high-frequency verbs, the retrieval strategy will find the correct form on declarative memory. On that first stage analogy usually fails given that it needs a regular form to work as a template. Regular forms are not as frequent as irregular forms (see that *deb-e* has a frequency of almost a third of the frequency of *pued-e*) and their activation is lower and so, analogy is not available on a first stage. Thus, verb forms such as *deb-e* or *salt-a* cannot be inflected. Moreover, there are no overregularization errors given that the source of overregularizations is also analogy. These facts explain the first stage of the U-shaped learning.

After some examples have been learned the number of regular verbs with enough activation in memory steadily grows up. Analogy is now a viable strategy, as there are examples that can be retrieved as templates. These uses of analogy lead to eventually learn the regular rules. However, most of the regular rules are not yet used given that its initial utility is not sufficiently high. At this stage, if the model has to inflect the form *jueg-an*, it is very probable that the retrieval strategy fails given its low frequency. If analogy finds suitable regular forms in declarative memory (suppose, for example, that the regular form *cant-an* (they sing) has enough activation) the model will produce the overregularization *jug-an**. Thus, at this stage overregularizations start to appear. However, they are still not very frequent because the regular forms that are used by analogy are not very frequent in memory and the regular rules do not have enough utility to be fired.

As analogy continues working, the utility of the regular rules increases to a point in which they start to be used. At this point, the rate of overregularizations, which start to appear on the previous stage, reaches a maximum. In the previous stage, verb forms such as *jueg-an* are rarely overregularized because analogy needs to retrieve a regular form from memory (and usually an irregular form is retrieved given that they are more frequent). However, regular rules do not need to retrieve a regular form. Thus overregularizations are much more frequent at this stage in which regular rules have a higher utility. For the same reason, the rate of correctly inflected regular forms highly increases. On previous stages, low frequency regular forms such as *salt-a*, could not be inflected because the retrieval strategy failed and it was difficult to find a regular form to do the analogy with the stem and another regular form to do the analogy with the suffix. As regular rules do not need any memory retrieval, the model just has to fire the corresponding regular rule to correctly inflect the form *salt-a*. From this point on, analogy strategy will be used very rarely, as it has to compete with the regular rules that become now the backup strategy given that they are more efficient.

On the last stage, irregular forms are stored in declarative memory with a sufficient and stable activation. This way, every time the model has to inflect an irregular form such as *pued-e*, the retrieval strategy works blocking the regular rule. Moreover, high-frequency regular forms such as *deb-e* have a high activation at declarative memory and so, when the model has to inflect one of these forms, retrieval will be successful again. Regular rules will be used with medium and low-frequency regulars such as *salt-a*. Medium and low-frequency regulars have a lower activation and so, retrieval usually fails and they have to be inflected by the regular rules. At this point the utility of the regular rules is also high and stable, so analogy is hardly used anymore. When this stage is reached, one may judge that the model has mastered the task.

Conclusions and future work

In this paper we have presented a cognitive model of Spanish verb morphology acquisition based on dual-mechanism theories. The model we present is based on two basic strategies that neither are specific to the task of producing a past tense nor even specific to language. In fact they are general domain cognitive strategies such as memory retrieval and analogy. The core components that are used for the model, among which are the declarative and procedural memory systems, are parts of the ACT-R architecture, or part of the ACT-R modeling tradition, like instance-based learning and the use of analogy. Starting from these general strategies, the model learns the regular rules of the Spanish inflectional system while it takes into account the exceptions that represent irregular verbs. The results show that our model accomplishes to fit properly the U-shaped learning curve and some other typical aspects of the process of learning exhibited by Spanish children. Thus, our approach shows how a highly inflected morphology system can be acquired in terms of dual-mechanism theories and sheds light on the possible structures involved in general language acquisition.

Future work includes extending the declarative and procedural representations to take into account phonetic features that allow modeling the phonetic analogy processes that seem to be present in some cases. Moreover, the model could be extended to other tenses and to a wider range of ages in order to accomplish a general view of the complete process of Spanish morphology acquisition. Other trends of future work could be related to language impairments. This model could be used to model some of these impairments by modifying some of the parameters of the model. This way we can give some arguments in favor of the different hypothesis about the causes of these impairments just as these models can be used to propose some kind of therapies or methods to improve the acquisition of verb morphology and general language skills. Finally, it would be very useful to extend the existing empirical studies with children to have more data from which we can extract more general conclusions.

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