Learning Morphological Productivity as Meaning-Form Mappings

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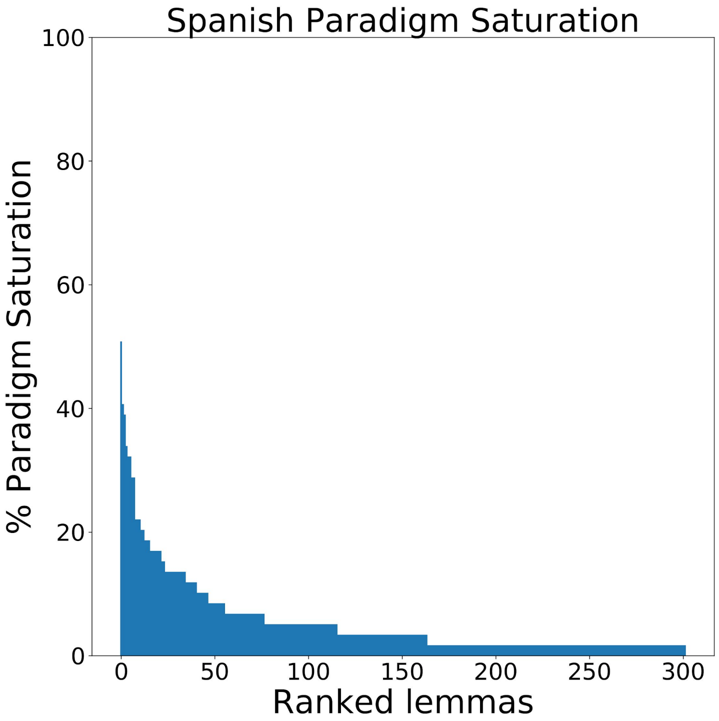
The Problem

- Children learn the entirety of verbal morphology from very sparse input
- They have no explicit information as to whether their language is agglutinative or fusional
- This is a mapping problem:

  Semantic features ➜ morphological features



Our Approach

- We collect child-directed verb forms from CHILDES for English and Spanish
- We annotate these using UniMorph tags
    - UniMorph provides person, number, tense, etc; we consider this an approximation of the child's semantic knowledge
- We apply the Tolerance Principle recursively on the data to pick out larger and smaller patterns (more on this later)

Outline

- Data + Spanish Basics
- Tolerance Principle + Model
- Results

Data

Data: Spanish and English

- **Spanish: 989 inflected forms, 302 lemmas**
  - Sampled from FernAguado corpus by frequency
  - Example:
    - tener   V;IND;PRS;2;SG   tienes
- **English: 3,953 inflected forms, 1,285 lemmas**
  - Sampled from Manchester, Wells, and Belfast corpora by frequency
  - Example:
    - bake   V;V.PTCP;PRS   baking
- Frequency is correlated with irregularity in English, but not Spanish (Fratini et al. 2014)

Spanish Basics

- 3 main classes of verbs: *-ar*, *-ir* and *-er* (defined by infinitive form)
    - *-ar* is largest class (62% of our data vs. 24% *-er* and 14% *-ir*)
    - Mappings often correspond to its behaviour
- Tense and person+number are often indicated separately in an agglutinative fashion
    - E.g., ***-ria*** = **COND**, ***-ra*** = **FUT**, ***-ba*** = **IPFV** (-ar verbs), and ***-s*** = **[2; SG]**
    - So ***-rias*** = **[COND; 2; SG]**, ***-ras*** = **[FUT; 2; SG]**, ***-bas*** = **[IPFV; 2; SG]**

Model

The Tolerance Principle (Yang, 2016)

$$e \leq \theta_N = \frac{N}{\ln N}$$

N = the number of words to which are eligible to take a rule

e = the number of those words to which the rule does not apply

Example: 100 past-tense English verbs; 20 don't take ***-ed***. 100/ln100 = 21.7. 20 < 21.7 so **PST** ➔ ***-ed*** passes the Tolerance Principle

Model Overview

- GCD application of the Tolerance Principle
- Recursive application of the Tolerance Principle
- Multi-pass application of the Tolerance Principle

Method: GCD approach

- **Possible suffixes** = substrings of length ≤ 5 at the end of an inflected form
    - e.g., possible suffixes of *ama**remos*** are ***-remos**, **-emos**, **-mos**, **-os**, **-s***
- **Possible features realized by each suffix** = all possible subsets of the provided feature set
    - e.g. possible features for **[IND; PRS; 3; SG]** could be **[IND], [IND; PRS], [IND; PRS; 3], [IND; PRS; 3; SG], [PRS], [PRS;3] ...**
- Use a **GCD approach:** find smallest feature-set that maps to a suffix
    - Do a pass of the TP from feature-sets to suffixes
    - For each suffix that was mapped to, find the intersection of all features that mapped to it
    - Keep adding features by frequency until a mapping from the features to suffix passes

Example: GCD approach using the Tolerance Principle

In Spanish, ***-mos*** = **[1;PL]**, which we obtain as follows:

1. Do a pass of the TP from feature-sets to suffixes
    - This yields mappings such as **[1; PL]** = ***-mos***, **[1; PL; FUT]** = ***-ramos***, **[1; COND]** = ***-riamos***
    - Some of these (e.g. **[1;COND]**) are underspecified, others are overspecified
    - We cannot learn agglutinativity from these mappings alone

Example: GCD approach using the Tolerance Principle

2. For each suffix that was mapped to, find the intersection of all features that mapped to it
    - For ***-mos,*** say this suffix was mapped to by **[1;PL], [IND; PRS; 1; PL],** and **[POS; IMP; 1]**
    - The intersection of these gives **[1]** = ***-mos***, which won't pass the TP

Example: GCD approach using the Tolerance Principle

3. Keep adding features by frequency until a mapping from the features to suffix passes
   - The second-most frequent feature is **PL**, and **[1; PL]** = ***-mos*** passes

Method: Recursive Application of the TP

- We learn the broadest mappings first
  - e.g. in Spanish, **[3; SG]** = **“”**
- Then we recurse on the exceptions to these broad mappings to learn narrower mappings
  - e.g. in Spanish, **[3; SG]** = **“”** except **[3; SG; PFV]** = ***-o***
  - We learn the latter mapping by recursively applying the TP to the verbs that fail to be correctly inflected by **[3; SG]** = **“”**
- We memorize verbs that remain exceptions after recursion
  - In Spanish, we learn narrow mappings such as **[3; SG; PFV]** = ***-o*** and stem conditioned endings such as the imperfective
  - In both cases, we can predict the rule we use based on properties of the lemma or features
  - However, we can’t do the same for *ser*, so we memorize its inflected forms

Method: Multi-Pass Application of the TP

- In agglutinative languages, more frequent features are realized closer to the end of the inflected form
  - e.g. in Spanish, person & number are always realized at the end and are most common
- We consider feature categories (person, number, mood, tense, aspect) in order of decreasing frequency
- At each pass, we constrain GCD mappings to the given feature category/categories and recurse on these before moving to the next one
  - In Spanish, we learn person-number endings and their productive exceptions first.
  - This includes **[3; SG]** = **“”** and **[3; SG; PFV]** = ***-o***, which is learned via recursion at this pass
- We remove the suffixes we’ve learned at a given pass from the inflected forms before moving on to the next pass
  - After removing Spanish person-number endings, we learn mappings such as **[COND]** = ***-ria***

Model Overview

At each pass, constrained by feature categories:

- Do a GCD pass of the Tolerance Principle
- Recurse on exceptions
- Memorize anything left

Results

Results: English

Broad Mappings				
Features	**Defau.**	**Alternations**	**Ct.**	**Ex.**
First Pass				
PRS	∅		2573	*walk*
Second Pass				
3	∅		1717	*walk*
2	∅		571	*walk*
1	∅		554	*walk*
Third Pass				
PL	∅		1454	*walk*
SG	∅		1422	*walk*
Fourth Pass				
NFIN	∅		22	*walk*

Narrow Mappings				
Features	**Defau.**	**Alternations**	**Ct.**	**Ex.**
First Pass				
PTCP, PRS	ing	e → ing	643	*pleasing*
3 SG PRS	s		372	*walks*
Second Pass				
3 PL PST	ed	y→ied,e→ed	367	*pleased*
3 SG PST	ed	y→ied	139	*tried*
2 SG PST	ed	y→ied,e→ed	203	*walked*
1 SG PST	ed	y→ied,d→t	136	*built*
1 PL PST	ed	y→ied	67	*cried*

Results: Spanish

Broad Mappings				
Features	**Default**	**Alterns.**	**Ct.**	**Ex.**
First Pass				
3 SG	∅		227	*ama*
3 PL	n		103	*aman*
1 PL	mos		51	*amamos*
2 PL	is		10	*amais*
PRS 1 SG	o		163	*amo*
PRS 2 SG	s		129	*amas*
Second Pass				
IND	∅		651	*ama*
IMP	∅		127	*ama*
NFIN	r		146	*amar*
COND	ria		16	*amaria*
Third Pass				
PRS	∅		492	*ama*
FUT	ra		20	*amara*
Fourth Pass				
IPFV	ia	a→aba	65	*amaba*

Narrow Mappings				
Features	**Default**	**Alterns.**	**Ct.**	**Ex.**
First Pass				
SBJV PRS 3 SG	e	i → a	13	*ame*
POS IMP 3 SG	e	i → a	14	*ame*
IND PST 3 SG PFV	o		72	*amo*
SBJV PRS 3 PL	an		2	*coman*
POS IMP 3 PL	an		2	*coman*
IND PST 3 PL PFV	ron		23	*amaron*
POS IMP 1 PL	emos		3	*amemos*
SBJV PRS 1 PL	emos		3	*amemos*
POS IMP 2 PL	d		2	*amad*
SBJV PRS 1 SG	e	i → a	14	*ame*
IND PST 1 SG PFV	e	i → i	18	*ame*
COND 2 SG	rias		2	*amarias*
SBJV PRS 2 SG	es	i → as	33	*ames*
IND FUT 2 SG	ras		3	*amaras*
IND PST 2 SG IPFV	ias		9	*comias*
IND PST 2 SG PFV	ste		10	*amaste*
Second Pass				
IND FUT 1 PL	re		2	*amaremos*

Discussion + Future Work

- Segmentation and generation
  - Our model may be extended to be competitive on computational linguistics and NLP morphological tasks
- Developmental plausibility
  - Our model learns rules in a similar order to children
  - Does it exhibit U-shaped development?
- Non-verbal morphology
  - Derivational or German nouns

Thank you!!

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