The Input for Syntactic Acquisition: Solutions from Language Change Modeling

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Psychocomp Workshop at ACL 2005
June 29th, 2005

Road Map
I. Introduction
II. The Acquisition Proposals: Restrictions on the Learner
III. Old English Change
IV. The Population Model
V. Results and Conclusion

Introduction: Big Picture
• What we want to explore: the relation between human language acquisition and machine learning
  • similarities: probabilistic/statistical methods (psychologically plausible)
  • differences: acquisition is more finely tuned (small changes can have large effects over time)
• Data Sparseness: How much data does it take to get the job done? Especially if it’s a learning system with very particular constraints on how learning takes place.

Introduction: Investigating the Input to Syntactic Acquisition
• traditional methods of investigating the input to syntactic acquisition won’t work (ethical & logistical issues)
• having a population of simulated learners allows us to restrict the input any way we like and see the effects on the learners

Introduction: This Work
• simulated learners follow an acquisition model inspired by Yang (2003, 2000) - probabilistic access of multiple grammars
• use a population of these simulated learners to provide empirical support for two proposals from acquisition literature that are resource-sparing:
  • data must be unambiguous
  • data appears in simple clauses
Introduction: Using Language Change

- **language change** as a metric of successful **population-level acquisition**
- Logic: if simulated population with these input restrictions behaves as real population historically did, then simulated acquisition process is similar to real acquisition process
- Using data from Old English shift from a strongly Object-Verb order distribution to a strongly Verb-Object order distribution between 1000 and 1200 A.D.

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Acquisition: Unambiguous Triggers

- adult grammar = a specific set of values for universal linguistic parameters (Chomsky 1981)
- **acquisition** = the process of determining those values
- **unambiguous trigger** (Dresher 1999, Lightfoot 1999, Fodor 1998): data that can only be parsed with one value

Acquisition: Degree-0 Clauses

- **Proposal**: Children heed the data in **simple** clauses only (Lightfoot 1991, simple = degree-0)

That clever boy thought that the giant was easy to fool.

Unambiguous Triggers: The Good and the Bad

- **Advantage**: **Resource sparing**. No need to test $2^n$ grammars on every piece of data. Restriction to specific cues in the data that correspond to only n different parameters
- **Danger**: **Data sparseness**. May not be much data that is unambiguous.

- An **unambiguous** trigger for the value p1 of parameter $P$ can be parsed only with value p1 and not value p2, no matter what other parameter values (a1 or a2, b1 or b2, c1 or c2...) are used
- Corresponds to exactly one parameter $P$ and can only alter the value of $P$ (bypasses Credit Problem noted in Dresher (1999))
**Degree-0: The Good and the Bad**

- **Advantage**: degree-0 data is messier = language change
- **Danger**: compounding the potential data sparseness problem once combined with ambiguous triggers

**Old English Change**

- Shift in Old English word order between 1000 and 1200 A.D. from a strongly OV distribution to a strongly VO distribution (YCOE, PPCME2)
  - **OV** order (Beowulf 625)
    - He God thanked
    - "He thanked God."
  - **VO** order (Alcin De virtutibus et vitiis, 83.59)
    - Heo clannad þa sawe þæs radendan
    - He purified the souls of the advising ones.

**Old English Change: Degree-0 Unambiguous Triggers**

- **OV** order unambiguous trigger
  - \( v_1(\text{Object Verb}) \) or \( v_1(\text{Object Verb-Marker}) \)
- **VO** order unambiguous trigger
  - \( v_1(\text{Verb Object}) \) or \( v_1(\text{Verb-Marker Object}) \)
- appropriate O-language order + unambiguous parse

**Old English Language Change: Ambiguous Triggers**

- ambiguous utterances
  - Subject | Verb | Object
  - heo clannad þa sawe þæs radendan
  - he purified the souls of the advising ones.

**Old English: Verb Markers**

- Sometimes, a Verb-Marker (particles ('up'), negatives ('not'), some closed class adverbials ('never'), non-finite complements ('shall...perform')) (Lightfoot 1991) will be next to the Object so the utterance is unambiguous.
  - **underlying OV order**
    - þa shot Paulus his heafod up
    - then lifted Paul his head up
  - **underlying VO order**
    - þa shot Paulus up his heafod
    - then lifted Paul up his head

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Old English: Ambiguous Input
(YCOE and PPCME2 Corpora)

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Degree-0 % Ambiguous</th>
<th>Degree-1 % Ambiguous</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 A.D.</td>
<td>76%</td>
<td>28%</td>
</tr>
<tr>
<td>1000 - 1150 A.D.</td>
<td>80%</td>
<td>25%</td>
</tr>
<tr>
<td>1200 A.D.</td>
<td>71%</td>
<td>10%</td>
</tr>
</tbody>
</table>

Old English Change: Degree-0 Unambiguous Triggers
• Children learn from the degree-0 unambiguous trigger distribution, which is different from the distribution in the adult population.
• Children can “misconverge”.
• Result: These small changes spread through an exponentially growing population until their effect manifests as a sharper population-level language change.

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The Model: Foundations
• Grammars can coexist during individual acquisition (Clark & Roberts 1993)
• within a population over time (Pintzuk 2002, among others)
• OV and VO grammar

• Population-level change is the result of individual level “misconvergences” (Niyogi & Berwick, 1997, 1996, 1995)
• individual linguistic behavior is a statistical distribution of multiple grammars (Yang 2003, 2000)

The Model: Multiple Grammars
• individual can access g grammars with some probability \( p_g \) allotted to each (Yang 2002, 2000)
• system with single grammar:
  \( g = 1 \quad p_1 = 1 \)
• all unambiguous triggers are from this grammar
• system with multiple grammars:
  \( g = n \quad p_1 = P(g_1), p_2 = P(g_2), \ldots, p_n = P(g_n) \)
  \( \sum p_g = 1 \)
• each grammar leaves some unambiguous triggers

The Model: Trigger Advantage
• triggers for conflicting grammars: what matters is how many unambiguous triggers one grammar has than the other in the input
• advantage: how many more unambiguous triggers in input
• Old English advantage in input (YCOE, PPCME2)

<table>
<thead>
<tr>
<th>Time Period</th>
<th>D0 OV Advantage</th>
<th>D1 OV Advantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 A.D.</td>
<td>-19.1%</td>
<td>-17.1%</td>
</tr>
<tr>
<td>1000-1150 A.D.</td>
<td>-0.4%</td>
<td>7.7%</td>
</tr>
<tr>
<td>1200 A.D.</td>
<td>-0.4%</td>
<td>-19.1%</td>
</tr>
</tbody>
</table>
The Model: Being On Time

- Metric: Old English = strongly OV from 1000-1150 A.D. and then more strongly VO by 1200 A.D. (YCOE, PPCME2)

- Is the restricted set of degree-0 unambiguous triggers sufficient to get this change to emerge?
  - Relax Unambiguous Triggers Restriction: allow ambiguous triggers in?
    - become strongly VO too soon?
  - Relax Degree-0 Restriction: allow degree-1 data in?
    - become strongly VO too late?

- Are the restricted set of degree-0 unambiguous triggers sufficient to get this change to emerge?

The Model: Individual Acquisition Implementation

- OV = 0.0 value and VO = 1.0 value
- probabilistic access function value = what percentage is VO
  - Ex: 30% VO, 70% OV = .30
- no default preference = initial setting of 0.5

- two methods that make model more psychologically plausible by relativizing data’s influence on learner, based on the prior confidence value for the appropriate grammar (the current VO access value)

The Model: Noise Filter

- Noise Filter
  - designed to separate “signal” from “noise”
  - “noise” depends on current VO access value
  - unambiguous triggers from minority grammar more likely to be construed as “noise”

  Probabilistic value of VO access = .3
  If next unambiguous trigger = VO
    - noise with 70% chance and ignored
    - signal with 30% chance and heeded
  If next unambiguous trigger = OV
    - noise with 30% chance and ignored
    - signal with 70% chance and heeded

The Model: Batch Learner Method

- Batch Learner Method
  - how many triggers to alter current value
  - how many depends on current VO access value
  - the more the grammar is in the majority, the smaller its “batch” of triggers has to be

<table>
<thead>
<tr>
<th>VO Value</th>
<th>OV Triggers Required</th>
<th>VO Triggers Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0-0.2</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>0.2-0.4</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>0.4-0.6</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>0.6-0.8</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>0.8-1.0</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>

Probabilistic value of VO access = .3
If next unambiguous trigger = VO
  - if 4th VO trigger seen, alter value of VO access towards VO
If next unambiguous trigger = OV
  - if 2nd OV trigger seen, alter value of VO access towards OV
The Model: Individual Acquisition Process

Initial setting = 0.5;
While in Critical Period
Get one input utterance from linguistic environment created by rest of the population;
If utterance contains unambiguous trigger
If utterance passes through Noise Filter;
If enough triggers seen to make batch
Alter current value;

The Model: Population Process

Initialization:
Population Age Range = 0 to 60;
Initial Population Size = 18,000;
Initialize all members to initial VO access value;
At 1000 A.D., and every 2 years after until 1200 A.D.
Members age 59 to 60 die; rest age 2 years
Create new members age 0 to 1
New individuals use individual acquisition process
to set VO access value

The Model: Population VO Access Values

- VO access value = distribution of OV and VO utterances before trigger destruction causes some utterances to become ambiguous
- historical data = distribution after trigger destruction has caused some utterances to become ambiguous

The Model: Ambiguous Triggers

(YCOE and IPCME2 Corpora)

<table>
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<tr>
<th>Time Period</th>
<th>Degree-0 % Ambiguous</th>
<th>Degree-1 % Ambiguous</th>
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<tbody>
<tr>
<td>1000 A.D.</td>
<td>75%</td>
<td>28%</td>
</tr>
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<td>1000 - 1150 A.D.</td>
<td>80%</td>
<td>25%</td>
</tr>
<tr>
<td>1200 A.D.</td>
<td>71%</td>
<td>10%</td>
</tr>
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</table>

The Model: Determining Distributions

- Degree-0 clauses have more trigger destruction and a more distorted OV/VO distribution than degree-1 clauses
- use the difference in distortion between degree-0 and degree-1 distribution to estimate the difference in distortion between degree-1 and underlying distribution

<table>
<thead>
<tr>
<th>Time Period</th>
<th>(Initialization) 1000 A.D.</th>
<th>(Calibration) 1000-1150 A.D.</th>
<th>(Termination) 1200 A.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average VO Access Value</td>
<td>0.23</td>
<td>0.31</td>
<td>0.75</td>
</tr>
</tbody>
</table>

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**Results: Sufficiency**

Average VO in Population Over Time

- **Subject Verb Object** (OV or VO + V2)

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Degree-0 VO Advantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 A.D.</td>
<td>4.8%</td>
</tr>
<tr>
<td>1000-1150 A.D.</td>
<td>5.5%</td>
</tr>
<tr>
<td>1200 A.D.</td>
<td>8.5%</td>
</tr>
</tbody>
</table>

+ VO too soon

**Results: Necessity of Unambiguous Triggers**

- allow ambiguous utterances with the right word order
- surface order VO trigger (with ambiguous parse)

**Subject Verb Object** (OV or VO + V2)

- **Recall:** Degree-1 data has a **stronger OV advantage** (stronger pull towards OV)
- **If** enough degree-1 data in input, population may not shift to a **strong enough VO distribution** by 1200 A.D.
- **estimates** from modern children’s corpora: input from adults consists of ~16% degree-1 data
  - **Is this too much?**

**Necessity of Degree-0**

- **Recall:** Degree-1 data has a **stronger OV advantage** (stronger pull towards OV)
- **If** enough degree-1 data in input, population may not shift to a **strong enough VO distribution** by 1200 A.D.
- **estimates** from modern children’s corpora: input from adults consists of ~16% degree-1 data
  - **Is this too much?**

**Results: Necessity of Degree-0**

% VO in Population at 1200 A.D.

- **VO too late**

**Conclusions: Acquisition and Change**

- **language change + quantified model = novel testing ground for acquisition proposals**
- **future work:** more sophisticated individual acquisition model involving **Bayesian updating** of a probabilistic distribution as well as for more realistic length of critical period
- **future work:** use the model to test out unambiguous triggers on other types of language change, such as Middle English Verb-Second Movement loss (Yang 2003, Lightfoot 1999, among others)

**Conclusions: Bigger Picture**

- **probabilistic learning** is psychologically realistic, and this is similar to the way machine learning is implemented now
- **small errors during learning** can add up over time (and cause language change), so human learning seems to be more sensitive and easily perturbed by “noise” during learning than machine learning
- **data sparseness:** human learning can take place even when the input is very restricted. Input serves to tune a system that already comes equipped with a lot of information about the way language works.

Also, I am incredibly grateful for the parsed corpora of Old and Middle English made available through the folks at UPenn. Without such corpora, this work would have been nearly impossible.