Expectation-based processing of extraposed structures in English

Roger Levy[1], Edward Gibson[2], and Evelina Fedorenko[2]

[1]University of California - San Diego   [2]Massachussetts Institute of Technology
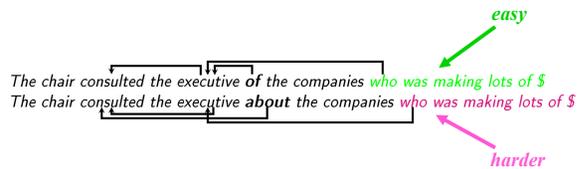
rlevy@ling.ucsd.edu, egibson@mit.edu, evelina9@mit.edu

Background & Motivation

- Big picture: processing complexity based on some combination of…
  - Memory storage & retrieval operations (Gibson 1998, 2000; Lewis 1996; Gordon et al., 2001, 2004; Lewis & Vasishth, 2005; Lewis et al., 2006)
  - Probabilistic expectations (Hale 2001, Gibson 2006, Levy 2008)
- Gibson & Breen (2003) concluded from a series of self-paced reading studies that there was evidence for complexity associated with ***processing discontinuous dependencies***:
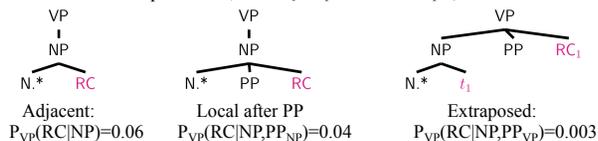 - Extraposition of a relative clause (RC) from subject across a verb (G&B expt 2):

After dinner, a musician who was hired for the wedding arrived
After dinner, a musician arrived who was hired for the wedding

  - Extraposition of RC from object across a PP (G&B expts 3 & 4):

*The chair consulted the executive **of** the companies who was making lots of $*
*The chair consulted the executive **about** the companies who was making lots of $*

- G&B expts 3&4 suggest that this difficulty is unlikely to be reducible to dependency locality or retrieval interference
- The results could be due to…
  - Derivational complexity of the extraposed structure—more transformational steps (Fodor, Bever & Garrett 1974)
  - A constraint-based cost (MacDonald, Pearlmutter & Seidenberg 1994) for the extraposed RC rule higher than that of the unextraposed RC
- Here, we will refine the interpretation of these results by suggesting that *the processing cost of these discontinuous dependencies is derived from probabilistic expectations over upcoming structure*

Expectations and extraposition

- Extraposed RCs are rare in corpora, and *unexpected in* the contexts of the above experiments *(estimated from parsed Brown corpus)*:

Adjacent:
$P_{VP}(RC|NP)=0.06$

Local after PP
$P_{VP}(RC|NP,PP_{NP})=0.04$

Extraposed:
$P_{VP}(RC|NP,PP_{VP})=0.003$

Manipulating extraposed RC expectations

- If extraposed RCs are hard because they're unexpected…
- …then making them more expected should make them easier
- Recent work (Wasow et al., 2005; Jaeger, 2006; Levy & Jaeger, 2007) has found that premodifier type can affect expectation for (in-situ) RCs

a barber…	low RC expectation
the barber…	higher RC expectation
the only barber…	very high RC expectation

- *If* premodifier-induced expectations are carried over past the continuous NP domain, we may be able to manipulate extraposed RC expectations the same way❖

Experiment Design

- We crossed *RC expectation* (low/high) with *RC extraposition* (extraposed/unextraposed)
- Example sentence: *The chairman consulted…*

Expect	Extr	
low	−	…*the* executives about the company *which was making*…
low	+	…*the* executives about the company *who were making*…
high	−	…*only those* executives about the company *which was making*…
high	+	…*only those* executives about the company *who were making*…

- We disambiguate the RC attachment weakly through the relative pronoun, and completely at the auxiliary verb (number marking on *was/were*; balanced across items)
- We predict an ***interactive effect***: high RC expectation ("only those") will facilitate RC reading, but ***only*** in the extraposed condition

Method

- Word-by-word self-paced reading
- 36 native English-speaking members of the MIT community participated

❖this prediction depends on the assumption that high RC expectation from premodifiers is not (strongly) negatively correlated with extraposition.
  - We don't have enough annotated corpus data to test this explicitly
  - But there is no reason to expect such a correlation

Results

- The differences across conditions show up in the RC onset:
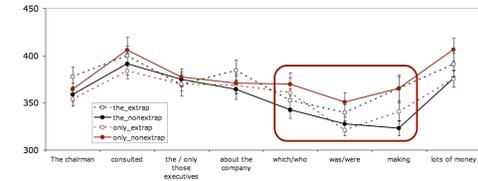
- The interaction is significant (all p's < 0.05) at the disambiguating verb (*was/were*) and also at the next region (*making*)

**=p<0.01
* =p<0.05
. =p<0.1
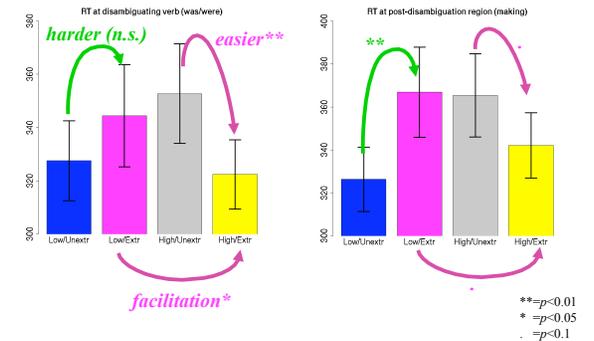
- When an RC is less expected, there is a processing penalty for the extraposed variant
- When an RC is more expected, the extraposed variant is easier
- Equivalently, increasing expectation for an RC facilitates processing of that RC despite its extraposition

Conclusions

- Syntactic expectations are not limited to the continuous-constituent/dependency domain (a novel finding)
- Strong expectations for an RC can facilitate extraposed RC processing
- The processing constraint associated with phrasal adjacency seems to be entirely reducible to syntactic expectations
- Probabilistic expectations at many levels of representation play a broader role than previously realized
- Broader outlook: couple expectation-based comprehension with a theory of weight effects in production (Wasow, 2002) to explain distribution & processing of discontinuous dependencies