Computational Psycholinguistics
Lecture 4: language production and grammatical choice

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ESSLLI 26
University of Tübingen
21 August 2014
Language production and grammatical choice
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Language production and grammatical choice
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Language production and grammatical choice

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Language production and grammatical choice
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- e.g., intended meaning: *I’d like a beer*
Language production and grammatical choice

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Language production and grammatical choice

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I’d like a beer

Where can I get a beer?
Language production and grammatical choice

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  *I’d like a beer*    *It’s pilsville time*

  *Where can I get a beer?*
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  It’s pilgrville time
  Grass is green
  I’m in Germany
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  I’d like a beer  It’s pilsville time  Grass is green
  Where can I get a beer?  I’m in Germany  Garr!
  [Mime beer-drinking]

- Not all these alternatives are equally likely to successfully communicate the intended meaning!
Grammatical choice
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• It has proven productive to focus on how speakers choose among tightly delimited sets of alternative utterances
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Grammatical choice

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  - Example: the *dative alternation*
    
    *Terry gave the exhausted traveller from France a silver dollar.*
    
    *Terry gave a silver dollar to the exhausted traveller from France.*
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    \[\text{Terry gave a silver dollar to the exhausted traveller from France.}\]

- Basic question: what factors of general theoretical interest successfully predict which variant the speaker chooses?
Grammatical choice

• It has proven productive to focus on how speakers choose among tightly delimited sets of alternative utterances
  
  • Example: the dative alternation

  *Terry gave the exhausted traveller from France a silver dollar.*

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• Implicit assumptions:
Grammatical choice

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- Basic question: what factors of general theoretical interest successfully predict which variant the speaker chooses?
- Implicit assumptions:
  - The variants are (near-)meaning equivalent
  - The variants are generally *available together* to the speaker
Case studies in grammatical choice
Case studies in grammatical choice

• The dative alternation
  
  *Terry gave* the exhausted traveler from France *a silver dollar.*
  *Terry gave a silver dollar to the exhausted traveler from France.*

• Optional *that*-deletion in relative clauses
  
  *I know the family you feed.]*
  *I know the family* **that** you feed.

• Optional *to*-deletion in the DoBe construction
  
  *The least we should do is make it as much fun as possible.*
  *The least we should do is *to* make it as much fun as possible.*

• Methods:
  
  • Multivariate statistical corpus analysis
  • Probabilistic computational modeling
  • Controlled behavioral experiments
Case study #1: the dative alternation

- Terms used with the dative alternation:

<table>
<thead>
<tr>
<th>Structure Type</th>
<th>Example</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prepositional Dative Structure</td>
<td>... gave [toys] [to the children]</td>
<td>V NP PP</td>
</tr>
<tr>
<td>Double Object Structure</td>
<td>... gave [the children] [toys]</td>
<td>V NP NP</td>
</tr>
<tr>
<td>Dative PP:</td>
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</tr>
<tr>
<td>Dative NP:</td>
<td>... gave [the children] [toys]</td>
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</tr>
<tr>
<td>Theme:</td>
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</tr>
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</table>

(Bresnan et al., 2007; Goldberg, 2006; Kako, 2006; Myslin & Levy, in prep)
Case study #1: the dative alternation

PD: …gave [toys] [to the children]
DO: …gave [the children] [toys]
Case study #1: the dative alternation

- Two schools of thought

PD: ...gave [toys] [to the children]
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Case study #1: the dative alternation

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  1. The two variants *subtly differ in meaning*

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Case study #1: the dative alternation

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  - The two variants *subtly differ in meaning*
    - Prepositional dative signals *transfer of location*

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```plaintext
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     ✓ \textit{That movie gave me the creeps.}
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       - ✗ That movie gave the creeps to me.
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     • Experimental (Kako, 2006):
       • The rom gorped the blick to the dax.
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  - *The rom gorped the blick to the dax.*
  - *The rom gorped the dax the blick.*
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       - \(\ast\) That movie gave the creeps to me.
     - Experimental (Kako, 2006):
       - The rom gorped the blick to the dax.
       - The rom gorped the dax the blick.
       - How likely is gorping to involve moving something?
Case study #1: the dative alternation

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2. General processing preferences govern the alternation
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2. General *processing preferences* govern the alternation

• Alignment of the following preferences with linear order

PD: ...gave [toys] [to the children]
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Case study #1: the dative alternation

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```
Case study #1: the dative alternation

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2. General *processing preferences* govern the alternation
   • Alignment of the following preferences with linear order
     • discourse-given < discourse-new
     • short < long

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Case study #1: the dative alternation

2. General *processing preferences* govern the alternation
   - Alignment of the following preferences with linear order
     - discourse-given $<$ discourse-new
     - short $<$ long
     - definite $<$ indefinite
Case study #1: the dative alternation

Two schools of thought

2. General processing preferences govern the alternation

- Alignment of the following preferences with linear order
  - discourse-given ≺ discourse-new
  - short ≺ long
  - definite ≺ indefinite
  - animate ≺ inanimate

PD: …gave [toys] [to the children]
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2. General *processing preferences* govern the alternation
   - Alignment of the following preferences with linear order
     - discourse-given $<$ discourse-new
     - short $<$ long
     - definite $<$ indefinite
     - animate $<$ inanimate
     - pronoun $<$ full NP

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     • definite < indefinite
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     • pronoun < full NP

Evidence: univariate corpus analysis
(Collins, 1995)
Case study #1: the dative alternation

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Case study #1: the dative alternation

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Evidence: *multivariate corpus analysis*
Case study #1: the dative alternation

- Two schools of thought

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Evidence: multivariate corpus analysis

\[ b_{\text{verb}} \sim N(0, \sigma_b^2) \]
\[ \eta \sim \alpha + \sum_i \beta_i x_i + b_{\text{verb}} \]
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\[ P(\text{prepositional dative}) \]

\[ \eta \]

-4 -2 0 2 4

0.0 0.4 0.8
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\[ \begin{array}{l|l}
\text{Predictor } x_i & \text{Coefficient } \beta_i \\
\hline
\log \text{Recipient Length} & 1.31 \\
\log \text{Theme Length} & -1.17 \\
\text{Recipient Animacy} & 2.14 \\
\text{Theme Animacy} & -0.92 \\
\text{Recipient Discourse Status} & 1.33 \\
\text{Theme Discourse Status} & -1.76 \\
\text{Recipient Pronominality} & -1.54 \\
\text{Theme Pronominality} & 2.2 \\
\text{Recipient Definiteness} & 0.8 \\
\text{Theme Definiteness} & -1.09 \\
\end{array} \]

(My implementation of the analysis of Bresnan et al., 2007)
Face-off between two theories
Face-off between two theories

- The “construction grammar” theory: *subtle meaning differences* govern the dative alternation
Face-off between two theories

• The “construction grammar” theory: *subtle meaning differences* govern the dative alternation

• The “processing-optimality” theory: *general syntactic processing ease* governs the dative alternation
Face-off between two theories

• The “construction grammar” theory: subtle meaning differences govern the dative alternation
• The “processing-optimality” theory: general syntactic processing ease governs the dative alternation
• How do we distinguish among the two theories?
Face-off between two theories

• The “construction grammar” theory: subtle meaning differences govern the dative alternation

• The “processing-optimality” theory: general syntactic processing ease governs the dative alternation

• How do we distinguish among the two theories?

• How would you do an experiment to tell?
Our approach

(Myslin & Levy, in prep)
Our approach

- Perhaps *both* are right!
Our approach

• Perhaps both are right!
• What would such a theory look like?

(Myslin & Levy, in prep)
Our approach

- Perhaps *both* are right!
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Our approach

• Perhaps *both* are right!
• What would such a theory look like?

• Let’s go one step farther and treat this as a *directed graphical model*, or Bayes Net!

(Myslin & Levy, in prep)
When processing explains form away
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- Joint influence of meaning and processing on syntactic form:
Joint influence of meaning and processing on syntactic form:

- We could test this theory by directly modeling \( P(F|M, P) \)
When processing explains form away

- Joint influence of meaning and processing on syntactic form:

  $M \rightarrow F \rightarrow P$

- We could test this theory by directly modeling $P(F|M,P)$
- But we’ll go one step further
When processing explains form away

• Joint influence of meaning and processing on syntactic form:

  $M \rightarrow F \leftarrow P$

• We could test this theory by directly modeling $P(F|M,P)$
• But we’ll go one step further
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When processing explains form away

- Joint influence of meaning and processing on syntactic form:

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Experiment 1

The zarg prolted the cherid to a really gromious flig.

Which is more likely?

- The cherid is in a new place. (LOCATIVE inference)
- The cherid has a new owner. (POSSESSIVE inference)

(Myslin & Levy, in prep)
## Experiment 1

| Sentence                                           | S  | \(P(S|G)\) |
|----------------------------------------------------|----|-------------|
| The zarg prolted [the cherid] to [a really gromious flig]. | PO | high       |
| The zarg prolted [the flig] [a really gromious cherid]. | DO | high       |
| The zarg prolted [a really gromious cherid] to [the flig]. | PO | low        |
| The zarg prolted [a really gromious flig] [the cherid]. | DO | low        |

Which is more likely?

- The cherid is in a new place.  
- The cherid has a new owner.

\(\text{LOCATIVE} \text{ inference}\)  
\(\text{POSSESSIVE} \text{ inference}\)

(Myslin & Levy, in prep)
Experiment 1: results

![Bar graph showing proportion of LOCATIVE inferences by grammatical probability and structure (DO vs. PO).]

| Sentence                                                                 | $S$  | $P(S|G)$ |
|--------------------------------------------------------------------------|------|----------|
| The zarg prolted [the cherid] to [a really gromious flig].                | PO   | high     |
| The zarg prolted [the flig] [a really gromious cherid].                   | DO   | high     |
| The zarg prolted [a really gromious cherid] to [the flig].                | PO   | low      |
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(Myslin & Levy, in prep)
# Experiment 2: length only

![Bar chart showing the proportion of LOCATIVE inferences for high and low grammatical probability structures. The chart compares DO and PO structures.]

| Sentence                                                                 | Structure | $S$  | $P(S|G)$ |
|--------------------------------------------------------------------------|-----------|------|----------|
| The zarg prolted [the cherid] to [the really gromious flig].              | PO        | high |          |
| The zarg prolted [the flig] [the really gromious cherid].                | DO        | high |          |
| The zarg prolted [the really gromious cherid] to [the flig].             | PO        | low  |          |
| The zarg prolted [the really gromious flig] [the cherid].                | DO        | low  |          |

(Myslin & Levy, in prep)
Definiteness only

(Myslin & Levy, in prep)
Overall results

(Myslin & Levy, in prep)
Summary

- Everyone wins!
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  • There are subtle meaning differences between PD and DO structures
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• Everyone wins!
  • There are subtle meaning differences between PD and DO structures
  • But preference for fidelity of form-meaning mapping is defeasible
  • Processing considerations can explain form away and affect strength of inferences regarding meaning
Why do people talk the way they do?

Linguistic communication involves transactions in uncertainty

But it takes place under adverse conditions:
- Auditory environment is noisy
- People’s working memory is limited
- Environment competes for attention
- Interlocutors have incomplete knowledge of each other

Yet communication seems to work most of the time

How is redundancy achieved?
Hypothesis about language use

• Surprisal: predictable (=less informative) words easier
• If processing difficulty is at all superlinear in surprisal
  ⇒ provable (through Jensen’s Inequality) that spreading out information evenly in a sentence minimizes total comprehension difficulty (Levy & Jaeger 2007)
• We call this idea *Uniform Information Density* (UID)
• Same idea can also be motivated through noisy-channel view of linguistic communication
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Ramifications for production

- Consider a Bayesian picture of recovering any aspect of language structure from a signal

\[
P(\text{Structure} | \text{Signal}) = \frac{P(\text{Signal} | \text{Structure})}{P(\text{Signal})} P(\text{Structure})
\]

- In general, a trade-off between (top-down) prior and (bottom-up) evidence
- The stronger the prior expectations for the structure, the less signal needs to be given
- Level of sound → word: vowel duration in function words is modulated by word predictability (Jurafsky et al., 2001)

<table>
<thead>
<tr>
<th>High-predictability</th>
<th>Low-predictability</th>
</tr>
</thead>
<tbody>
<tr>
<td>been a</td>
<td>compost a</td>
</tr>
<tr>
<td>with a</td>
<td>field a</td>
</tr>
<tr>
<td>where a</td>
<td>costs a</td>
</tr>
<tr>
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Case study #2: *that*-deletion in RCs

- Certain types of *relative clauses* (RC) in English are optionally introduced by the “meaningless” word *that*

> How big is the family *that* you cook for __ ?

Levy & Jaeger 2007 (see also Jaeger 2006)
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  \[ \text{How big is the family (that) you cook for } \underline{\text{__}} \ ? \]

  modifies the noun

  family

  “you cook for the family”

• Relative clauses are an important part of the infinite expressive capacity of human language (recursion)
• What governs use of the optional function word *that*?

  Levy & Jaeger 2007 (see also Jaeger 2006)
The idea of spreading out information equally has also appeared as a noisy “channel capacity” argument previously.

*Probabilistic reduction hypothesis* for phonetic realization (Jurafsky et al., 2001; Bell et al. 2003)

- See also Aylett, 1999; Aylett & Turk, 2004: *Smooth signal redundancy hypothesis*

*Entropy rate constancy* throughout a discourse (Genzel & Charniak 2002, 2003)

- Ours is the first study to examine a specific linguistic speaker-choice variable *above the phonetic level*
Spreading out information in RCs

- In an RC without *that*, the first word does two things:
Spreading out information in RCs

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Spreading out information in RCs

• In an RC without *that*, the first word does two things:

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• Inserting *that* separates these two things:
Spreading out information in RCs

- In an RC without *that*, the first word does two things:
  - *How big is the family you*…
  1) It signals that a relative clause has begun
  2) It signals some information about the contents of the relative clause
- Inserting *that* separates these two things:
  - *How big is the family that you*…
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  \[\text{How big is the family you}\ldots\]

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• Hypothesis: speakers should use *that* more when the RC’s onset is informationally dense
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  How big is the family *that(1)* you(2)…

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Spreading out information in RCs (2)

How big is the family that you…

- We want to measure the quantity of information (1) and (2) literally using information theory
  
  - (1) is $P(\text{that} \mid \text{context}) \cdot P(\text{RC} \mid \text{context})$
  
  - (2) is $P(w_i \mid \text{context}, \text{RC})$  [you]
Spreading out information in RCs (2)

(1)

How big is the family *that you*...

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- (2) is $P(w_i | \text{context,RC})$ [you]
Dataset

- Corpus of spontaneous telephone conversation by speakers of American English (*Switchboard* corpus)
- Roughly 1 million words of conversation have been annotated for linguistic structure
- Contains 3,452 datapoints (relative clauses for which *that* can potentially be omitted)
A first test

[Diagram showing a graph with the x-axis labeled as log(P(W1 | W-2 W-1)) and the y-axis labeled as Likelihood of full form. The graph includes data points and a trend line.]
We use tree structures to represent natural language structure and ambiguity as a sentence unfolds…
Calculating phrasal predictability

- The use of tree structure also gives us a recurrence relation expressing the predictability of an upcoming phrase in the tree:

\[
P(RC_{n+1} \ldots | w_1 \ldots n, T_1 \ldots n) = \sum_{i=0}^{k} \left[ P(RC|N_i) \prod_{j=0}^{i-1} P(*END*|N_j) \right]
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The statistical problem

- There are two statistical questions to be addressed:
  1. How do we choose the phrasal predictability model $P(X|N_i)$?
  2. How do we assess whether phrasal predictability is associated with speakers’ behavior in *that*-use?
- These correspond to two somewhat different types of statistical question:
  1. prediction: designing an accurate model of an outcome (machine learning)
  2. hypothesis testing: assessing a particular factor’s association with an outcome (classical statistics)
The statistical problem (2)

- In both cases, there are huge numbers of features that may potentially affect the outcome
  - e.g., each English noun may have distinctive tendencies for RC modification (*way*, *apple*)
- Problem of *model selection*: which features to put into the model?
- The answer differs for each statistical question:
  1. Prediction: a very large, overparameterized model is OK, as long as it accurately predicts outcomes
  2. Hypothesis testing: test the factor of interest in a small model with carefully developed control factors
Two-step model

\[ P(\text{RC} \mid \text{context}) \rightarrow P(\text{that} \mid \text{RC}) \]

Control factors

- three outcomes (RC, *END*, other)
- regularized\(^*\) multinomial logistic regression (MaxEnt model)
- large number of surface & structural features of context (~3.3×10^6; \(n \approx 10^6\))

- binary outcome
- unregularized logistic regression (bootstrapped by speaker cluster)
- phrasal predictability is a single covariate
- a select set of controls * constitutes another 27 parameters (\(n=3,452\))
Feature space for prediction model

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- Semantically empty words tend to be elucidated relative clauses.
- Definite articles and superlative adjectives, especially together, like RCs.
- Postmodifiers of the noun tend to fill this need for elucidation.
We need to compute $P(X_{ij}|N_i)$ for $X_{ij}=$\{RC, NULL, other\}

- Using all these (overlapping, sparse) features to do so
- Regularized logit models handle this nicely
- *Featurize* each context (a node $N_i$ with its tree) as a vector $f(N_i)$; the probability is set to be

$$P(X_{ij}|N_i) = \frac{1}{Z} e^{\lambda_j \cdot f(N_i)}$$

- Learning problem is now finding parameter vector $\lambda$
- *Regularize* (=keep small) parameters by maximizing penalized likelihood:

$$\prod_{i}^{} P(X_i|N_i) - \sum_{jk} \frac{1}{\sigma^2} (\lambda_{jk})^2$$
Investigating control factors

- Separate studies (Jaeger 2006) investigated the role of many other factors in *that*-use:
  - Length of the relative clause and distance of long-distance extraction site
  - Disfluency (production difficulty)
  - Adjacent identical segments (i.e., tendency to avoid saying *that that*)...
  - Speaker gender
- These factors & others were selected from a larger set using backward AIC optimization
Putting the two models together

- Hypothesis test: enter -log P(RC|context) as covariate with the control factors in a logistic regression
- Result: phrasal predictability is associated with *that*-omission at $p<0.0001$ (Wald statistic)
- We can also run backward model selection using AIC again on the new model
- Result: several control factors drop out of the model
  - adjacent identical segments seem not to matter
  - speaker gender effect goes away
- *Phrasal predictability helps us make sense of that-use*
Production study: conclusion

- Speakers seem sensitive to information density as a principle of communicative optimality
- An optional function word like *that* acts as a “pressure valve” for speakers to regulate information flow
- Leads to a rather unconventional view of grammar
  - conventional: a set of categorical rules reflecting universal, innate principles
  - new view: a set of statistically-oriented tools to achieve communicative ends
- Are these views irreconcilable?
  - *I think this is one of the major issues facing the field*
- Methodology: combine different statistical modeling principles to gain insights about human language
Introducing the construction by examples

what the CBO does is takes Congress’s promises at face value

what we have done is taken military action in Bosnia through NATO

all he’s been doing is going over legal papers

all the government does is send out checks

the thing that I tried to do was to keep the score close

the thing I’m doing is trying to learn from my mistakes

the least we should do is make it as much fun as possible

(Wasow, Levy, et al., forthcoming)
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Post-Copular Verb (PCV)

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Some Corpus Examples

1. what we're here on earth to do is (to) celebrate humanity
2. what I would do is (to) call upon the press to police yourselves
3. the other thing that it’ll do is (to) facilitate getting Chinese troops into Tibet as well
4. the most important thing that Bretton Woods did was (to) create two institutions for international cooperation on monetary international problems
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• Can you tell which ones had to in the original?
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General utterance complexity

Uniform Information Density
Other UID-related work

- UID effects in spontaneous production at multiple levels
  - auxiliary contraction (Frank & Jaeger, 2008)
  - *that*-reduction in complement clauses (Jaeger, 2010)
  - clausal planning (Gomez Gallo & Jaeger, 2009)

- Organization of *grammar*: clausal word order typology (Maurits, Perfors, & Navarro, 2010)
Zipf’s law 1

- A word’s log-frequency and log-rank-frequency are linearly related

(Zipf, 1935)
Zipf’s law 2

- There is a (more or less) linear relationship (albeit noisy) between word log-frequency and word length

(Zipf, 1935; figure from Piantadosi et al., 2011)
Imagine that a monkey hits the keys of a typewriter at random, subject only to these constraints: (1) he must hit the space bar with a probability of $p^*$ and all the other keys with a probability of $p(L) = 1 - p^*$, and (2) he must never hit the space bar twice in a row. I wish to examine the monkey's output, not because it is interesting, but because it will have some of the statistical properties considered interesting when humans, rather than monkeys, hit the keys.

Miller (1957)
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  \]

- For the “average-frequency” word of length \( K \) there will be approximately \( M^K/2 \) higher-frequency words
Miller’s monkeys

Imagine that a monkey hits the keys of a typewriter at random, subject only to these constraints: (1) he must hit the space bar with a probability of $p^*$ and all the other keys with a probability of $p(L) = 1 - p^*$, and (2) he must never hit the space bar twice in a row. I wish to examine the monkey's output, not because it is interesting, but because it will have some of the statistical properties considered interesting when humans, rather than monkeys, hit the keys.

Miller (1957)

• With $M$ letters on the typewriter, and $q = (1 - p^*)/M$, then

\[ P(w = \text{any word of length } K) = q^K \]

\[ \log P(w) = K \log q \quad \text{Zipf’s law 2} \]

• For the “average-frequency” word of length $K$ there will be approximately $M^K/2$ higher-frequency words

\[ \log \text{rank-freq}(w) \approx K \log \frac{M}{2} \]

\[ \log \text{rank-freq}(w) \propto \log P(w) \]
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  1. If so simple and un-language-like a process as typewriter monkeys could give rise to Zipf’s law(s), then the fact that language happens to follow these laws could not be of possible scientific interest.
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  1. If so simple and un-language-like a process as typewriter monkeys could give rise to Zipf’s law(s), then the fact that language happens to follow these laws could not be of possible scientific interest.
  2. Given how thoroughly unlike monkey-typing human language is, the fact that it exhibits deeply similar statistical properties is remarkable and merits careful study.
Miller’s monkeys

- Conclusion (1) carried the day, and the issue became marginal:

Research workers in statistical linguistics have sometimes expressed amazement that people can follow Zipf's Law so accurately without any deliberate effort to do so. We see, however, that it is not really very amazing, since monkeys typing at random manage to do it about as well as we do....It seems...that Zipf's rule can be derived from simple assumptions that do not strain one's credulity (unless the random placement of spaces seems incredible), without appeal to least effort, least cost, maximal information, or any branch of the calculus of variations.

Miller (1957)
UID in the lexicon and Miller’s monkeys

- According to principles of UID, it should be expected word *surprisal*, not word *frequency*, that word length is optimized for.

- Mathematically, the expected surprisal of a word $w$ is:

\[
\sum_{Ctxt} P(Ctxt|w) \log \frac{1}{P(w|Ctxt)}
\]

- Seyfarth (2014) calls this quantity *word informativity*
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Seyfarth (2014) calls this quantity word informativity.
Informativity versus frequency

(Seyfarth, 2014)
UID in the lexicon and Miller’s monkeys

- Piantadosi, Tily, & Gibson (2011) show this is true in 11 out of 11 languages investigated!
UID in the lexicon and Miller’s monkeys

- In detail, for English:  
  
  (Piantadosi, Tily, & Gibson, 2011)

- Crucially, *monkeys on a typewriter will not give this result*
Informativity effects on acoustic duration
Informativity effects on acoustic duration

• Earlier: word predictability affects acoustic duration
Informativity effects on acoustic duration

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• Seyfarth (2014) found that word *informativity* affects duration in the same way!
Informativity effects on acoustic duration

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