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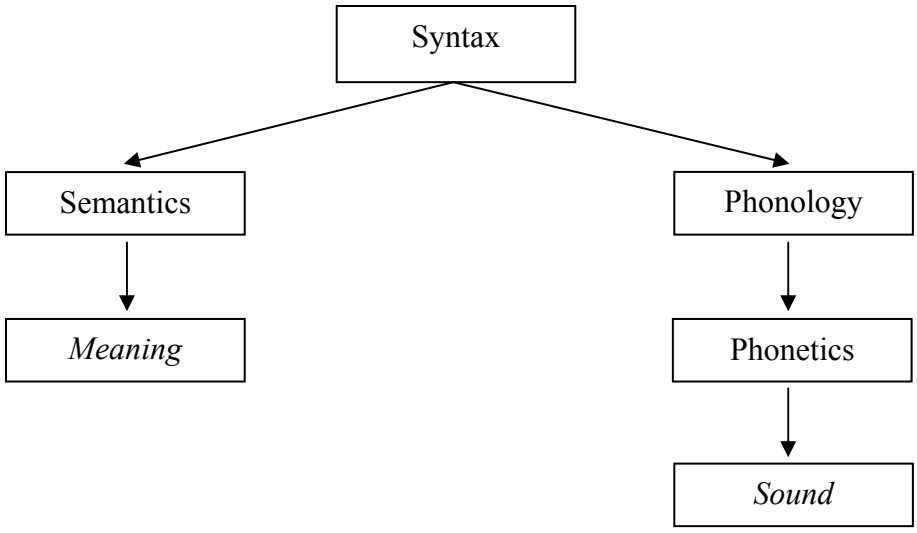
More on leaking grammars: Sentence construction respects phonological markedness constraints

I. CONTEXT

1. Research question

- How do the domains of human linguistic knowledge ("components") interact in the creation of sentences?

2. The classical feed-forward model (e.g. Chomsky 1965)



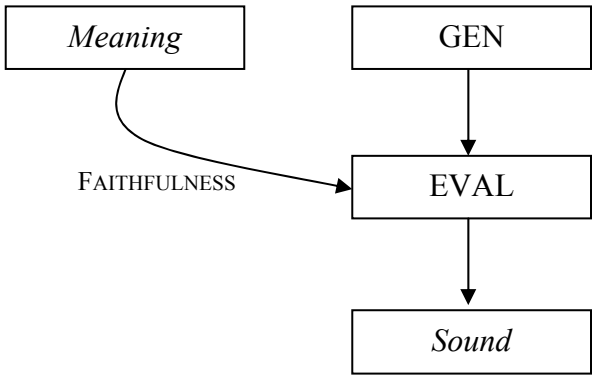
- Key prediction: the construction of sentences is blind to any phonological consequences of word-concatenation.

3. Challenges to the feed-forward model arrive from multiple directions

- Recent work:
  - Shih and Zuraw (in press): Tagalog speakers use the twin syntactic constructions Adj. $\begin{Bmatrix} ŋ \\ na \end{Bmatrix}$ Noun vs. Noun $\begin{Bmatrix} ŋ \\ na \end{Bmatrix}$ Adj. in ways that statistically avoid violating these constraints:
    - — *[+nasal][+nasal]
    - — *HIATUS
    - — *NÇ

- Much other work, e.g. Inkelas and Zec (1990), book, Zuraw (2015), Shih et al. (2015), Shih (2012, 2017), Anttila (2016), Ryan (2017)

4. A pure-parallelist alternative to (2)



- … where candidates are deeply structured objects with semantic, syntactic, phonological, morphological, and phonetic structure.
- This is just one conception of a parallelist architecture; for established research programs see e.g. Jackendoff (2002, 2010), Bresnan et al. (2015).

5. Goal

- Earlier work employs scalpel-like precision on specific domains like Tagalog adjective-noun word order.
- We seek to learn how general these effects are from an **across-the-board, brute force** approach:
  - Look at whole sentences — *all* word concatenation.
  - Since we are indiscriminate in our choice of sequences, we can look at a wide variety of phonological constraints.

II. METHOD

6. A precedent: Martin (2011) on *GEMINATE in English compounds

- Key finding: compounds that violate *GEMINATE, such as *bookkeeper* [ˈbʊkkipɚ], are *statistically underrepresented* relative to those that don't.
- He uses a Monte Carlo method (Good 2005) to demonstrate this; we follow this method here.
- Martin thinks that the statistical extension of *GEMINATE beyond the word level arises from "leaking grammars" — overbroad learning of word-internal constraints — hence our title.

7. Step 1: Form a list of *bigrams* (consecutive two-word sequences)

- Example: if the text is Jane Austen's novel *Emma* (first sentence given below) …

> Emma Woodhouse, handsome, clever, and rich, with a comfortable home and happy disposition, seemed to unite some of the best blessings of existence.

- … then the bigram sequence begins:

  [Emma Woodhouse], [Woodhouse, handsome], [handsome, clever], …

- Look up words in our augmented version of the CMU Pronouncing Dictionary:

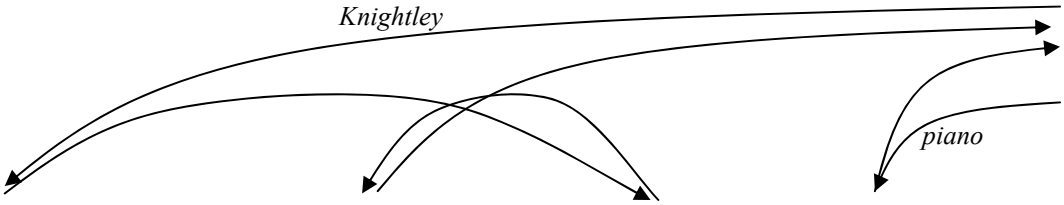
  [ɛmə, wʊdhaʊs][wʊdhaʊs, hændsəm][hænsəm, klɛvɚ] …

8. Step 2: Count how many times the constraints are violated in the bigrams

- In the bigrams of *Emma*, *GEMINATE is violated 590 times.

9. Step 3: Randomly shuffle the bigrams of the corpus

- For each bigram in the list, replace its Word2 with the Word2 of a randomly-selected bigram.



[Emma *Woodhouse*], [Woodhouse, *handsome*], [handsome, *clever*], [clever, *and*], …

[Emma *Knightley*], [Woodhouse, *clever*], [handsome, *Woodhouse*], [clever, *piano*], …

- Purpose: estimate the number of violations that might occur under the null hypothesis that word concatenation is phonologically free.

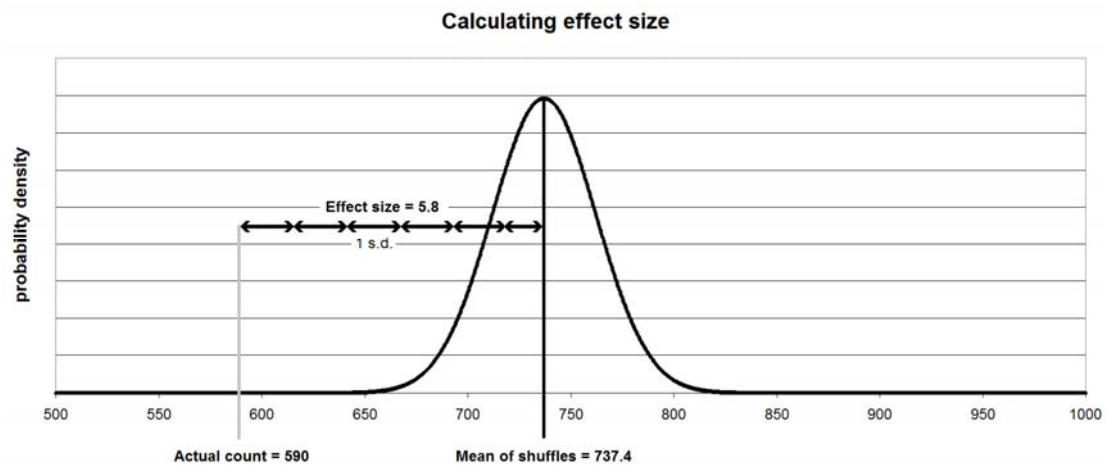
10. Step 4: Shuffle repeatedly, obtaining means and standard deviations of violation counts

- Shuffling *Emma* 1000 times (our standard), we find that *GEMINATE is violated an average of 737.4 times. Standard deviation is 25.2.

11. Step 5: Assessing underrepresentation in the real count

- We use a standard metric (Coe 2002): **effect size**
  - = number of standard deviations that the observed value falls below the mean of the shuffles

12. Computing effect size for *GEMINATE in *Emma*



- Mean violations of *GEMINATE in the shuffles = 737.4
- Standard deviation = 25.2
- Number of violations of *GEMINATE in corpus = 590
- Effect size = (737.2 − 590) / 25.2 = **5.8**

13. Interpreting effect size

- Rule of thumb: an effect size of magnitude 2.4 corresponds to a *p*-value of 0.01.
- 5.8 is a very substantial effect; we think Jane Austen was almost certainly avoiding geminates when she composed *Emma*.

III. REFINEMENTS

14. Refinement 1: taking into account phonological phrasing

- Across languages, phrasal phonology tends to be blocked at large prosodic breaks.
- So we might get cleaner results if we only consider bigrams falling within the same large prosodic phrase.
- To operationalize, we select the bigrams that are not separated in text by punctuation:

[Emma Woodhouse],	[Woodhouse, handsome],	[handsome, clever],	[clever, and], …
↓	↓	↓	↓
[Emma Woodhouse]	∅	∅	∅

- And the complement set can serve as a control case.

[Emma Woodhouse],	[Woodhouse, handsome],	[handsome, clever],	[clever, and], …
↓	↓	↓	↓
∅	[Woodhouse, handsome],	[handsome, clever],	[clever, and], …

  - ➢ We expect such violations to be more freely tolerated.

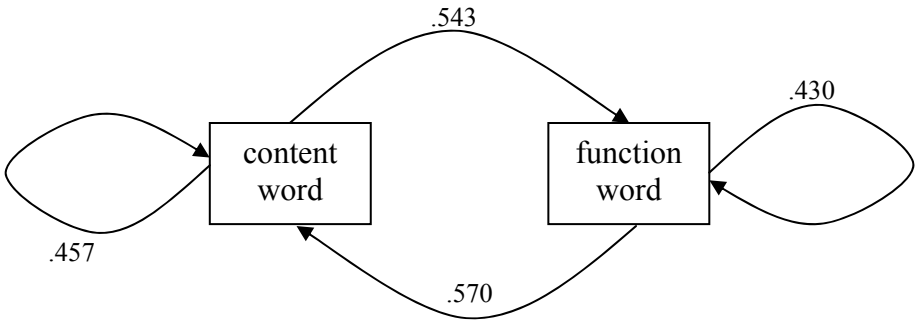
15. Refinement 2: dealing with frequent bigrams

- Frequent bigrams have three origins:
  - Common syntactic patterns, e.g. *subject pronoun + copula* (*I am*).
  - Frequent phrases (*a great deal*, *very good*, *a few minutes*)
  - Items frequent in a particular text: e.g. *Mr. Knightley* in *Emma.*
- If our interest is in studying *productive word concatenation*, it would be worthwhile to remove these phrases, which are likely to be lexicalized.
- To do this: discard all but the **hapax** bigrams (unique in corpus).

16. Refinement 3: controlling for syntax

- Even sticking just to hapaxes, it remains a fact that syntax has major effects on word order (!).
- We would like to control for this statistically.
- Ideally, we would implement model (4) but we need a lot of help …
- So until this is feasible, we use …

17. The poor man's syntax: a grammar for *Emma*



- Function words tend to be followed by content words and vice versa.
- The simplest control procedure, adopted for this talk, is just to *throw away all but content + content bigrams*.
  - Reduces the *Emma* bigram set like this:

[with a] [a comfortable] [comfortable home] [home and] [and happy] [happy disposition]
↓ ↓ ↓ ↓ ↓ ↓
∅ ∅ [comfortable home] ∅ ∅ [happy disposition]

- This procedure proves to be conservative (yields smaller effect sizes).

IV. PHONOLOGICAL CONSTRAINTS EXAMINED

18. Constraints examined

a.	*CLASH	Stressed syllables flanking #: *táll trées*
b.	*IAMBIC CLASH	Iambic word before stress, like **seréne lúte*
c.	*C#C	Simple ban on CC cluster across word boundary
d.	*3+ CONSONANTS	*C#CC or *CC#C
e.	*3+ OBSTRUENTS	ditto for obstruents only
f.	*4+ CONSONANTS	
g.	*4+ OBSTRUENTS	
h.	*GEMINATE	
i.	*BAD SONORITY	Violate Syllable Contact Law (Vennemann 1988)
j.	*HIATUS	*V#V
k.	*NÇ	voiceless consonant after nasal (Pater 1999)
l.	*SIBILANT CLUSTER	Sibilants are: {s, ʃ, z, ʒ, tʃ, dʒ}

19. We also studied "virtues"

- We made up a group of configurations that struck us as phonologically completely ordinary, calling them "Virtues".

a.	VOWEL # ALVEOLAR STOP	
b.	r # t	
c.	V # r	
d.	NAS # VCED HOMORG. STOP	Obeys *NÇ, place and voice assimilation
e.	V#CV	
f.	GOOD SONORITY	opposite of BAD SONORITY
g.	UNSTRESSED # STRESS	part of the complement set of *CLASH

- We expect no underrepresentation for classically unmarked configurations, so they serve as a check on the method.

V. CORPORA EXAMINED

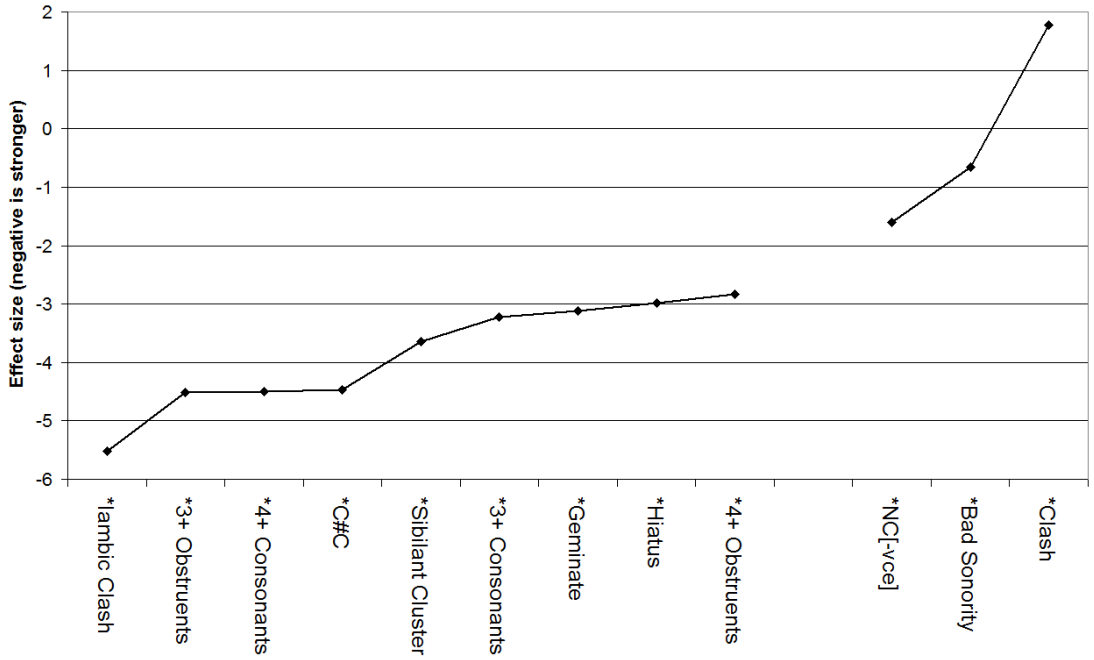
20. List

- Six novels by Jane Austen (722,000 words)
- Six novels by Mark Twain (568,000 words)
- Six novels by Nathaniel Hawthorne (592,000 words)
- Six non-fiction works by Charles Darwin (935,000 words)
- A mélange of conversations from six corpora of spoken English (~ 1,000,000 words)
  - 2016 Primary Debates corpus, Buckeye Corpus, Beatles corpus (Stanton 2016), Michigan Corpus of Academic English, British Academic Spoken English corpus, Human Communications Research Center Map Task corpus.

VI. RESULTS

21. Results I

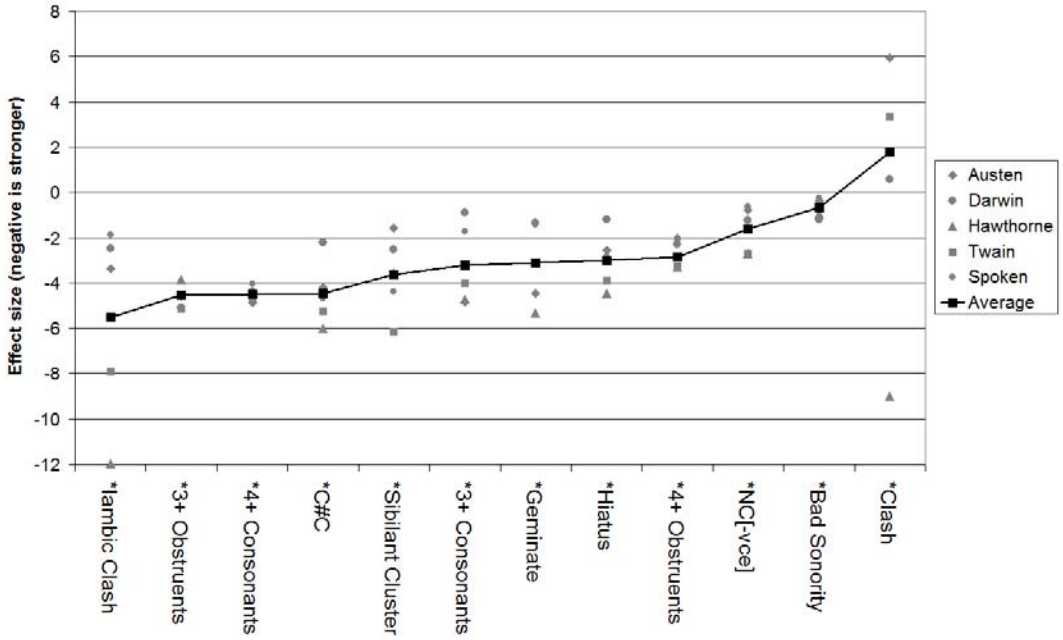
- We plot effect size, averaged across all five corpora.
- Mostly, there is underrepresentation.
- Effect sizes of magnitude > 2.4 are significant at the $p < .01$ level.
  - Gap separates out those that were found to be significantly underrepresented from those that were not.
- For detailed results see Appendix.



22. Our sore thumb — *CLASH

- Unlike most of the others, this constraint did not show any underrepresentation.
- Yet:
  - It has an impeccable typological pedigree.
  - It is active in English phrasal phonology (Liberman and Prince 1977, Hayes 1984, etc. etc.)
- We discuss it further below.

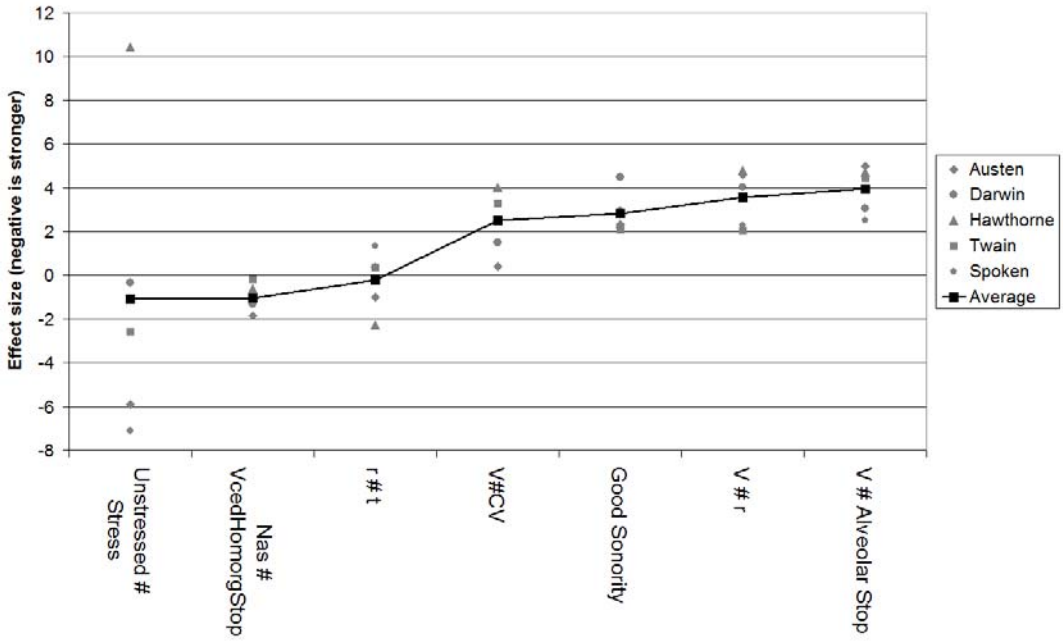
23. Results II: breaking the results down by the five individual corpora



- Underepresentation is found for all cases except *CLASH.
- Note massive difference between clash-avoiding Hawthorne and clash-seeking Austen; others in between.

VII. CONTROL PROCEDURES

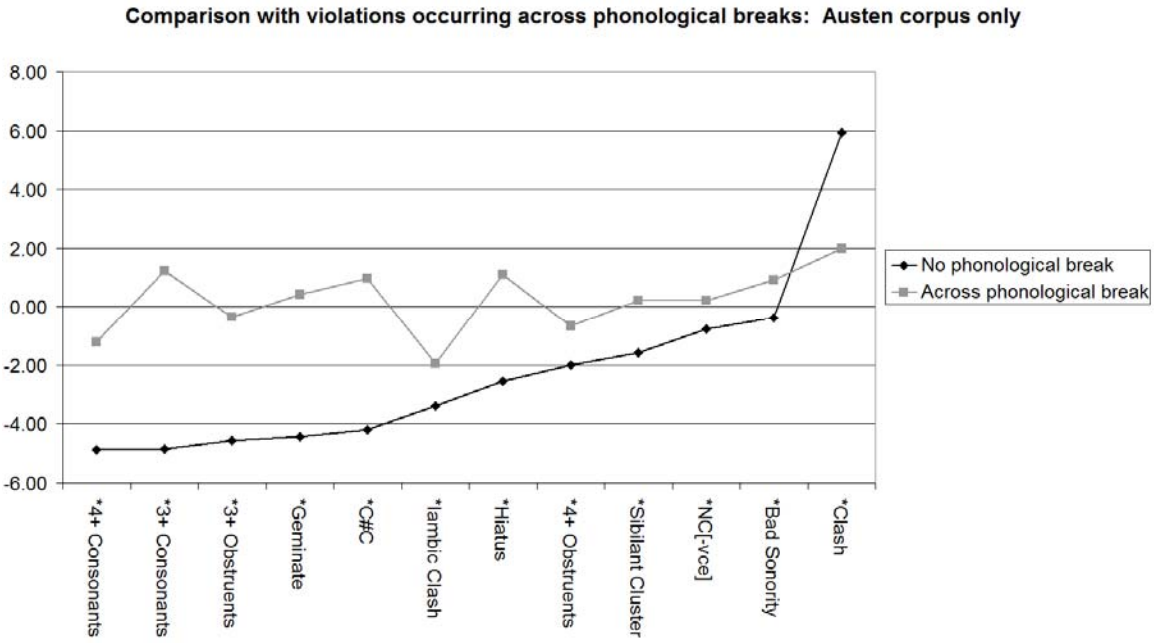
24. Our "virtues" (19) do not yield significant effect sizes



- None test out with significant average underrepresentation.

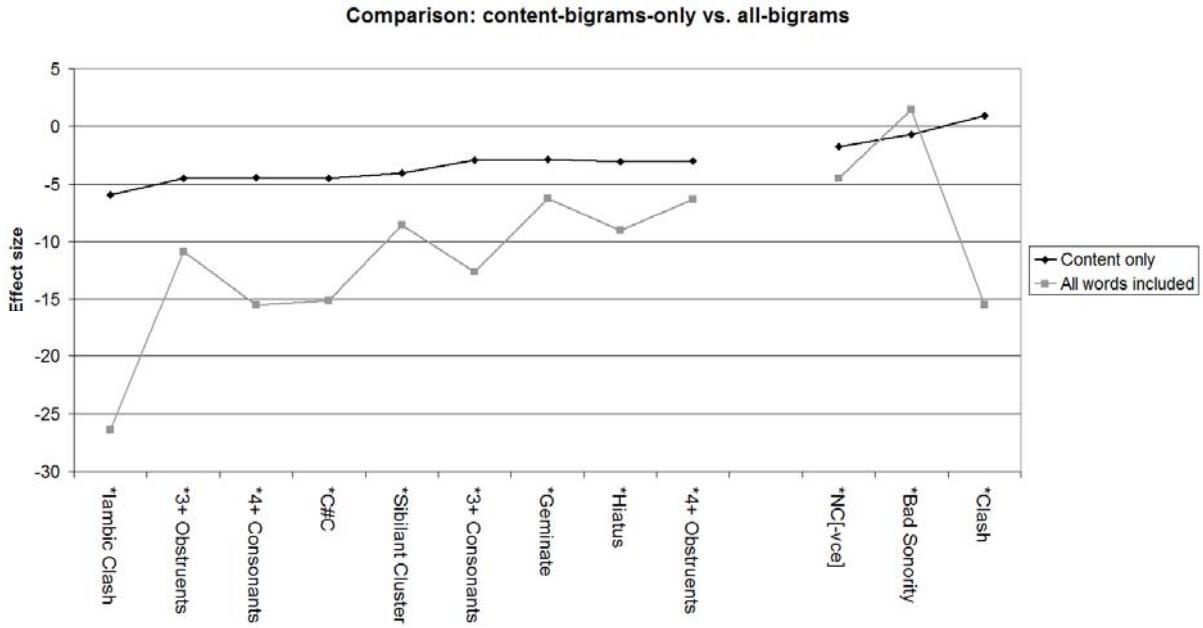
- Often, they instead involve overrepresentation, as expected.
- The aberrant Virtue UNSTRESSED # STRESS is partly the complement of *CLASH, so is in a sense the same mystery.

25. Per (14), significant effects are *not* found for bigrams formed across phonological breaks



- Basically, no effect — large breaks inhibit phonology.

26. What happens when you leave all the function words in?



- Key:
  - Black line = main results of (21), repeated but rescaled
  - Grey line = results obtained by including function words — far more dramatic
- We see that culling to just content words is indeed a conservative procedure.
- Note that *CLASH is strongly underrepresented when function words are included.

VIII. SOME THOUGHTS ON *CLASH

27. Burstiness?

- In texts, *CLASH violations have a **bursty** distribution (Altmann et al. 2009) — concentrated in clumps.
- Shuffling suppresses the bursts, eliminating sequences locally rich in *CLASH violations.
- Result: an artifact — text looks clash-seeking, but is merely bursty.

28. This explanation is tentative

- We've tried short-distance shuffling, attempting to preserve burstiness.
- It helps a bit, but even so Austen still looks like a (modest) clash-seeker!

IX. SUMMING UP

29. Our results in context

- Our results build on earlier work that detected effects of specific constraints in specific constructions (per (3) and (6) above).
- Our "brute force" approach suggests that such effects are *pervasive*, found in essentially any text and for most of the constraints examined.
- Our results offer encouragement to the pursuit of parallelist (non-feed-forward) models of grammatical organization.

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Appendix

Effect sizes and p-values for constraints (all five corpora)

Constraint	Austen		Darwin		Hawthorne		Twain		Spoken		Average
	Effect size	*p*	Effect size	*p*	Effect size	*p*	Effect size	*p*	Effect size	*p*	Effect size
*IAMBIC CLASH	-3.38	*0.000*	-2.47	*0.007*	-11.98	*< .001*	-7.91	*< .001*	-1.88	*0.030*	-5.52
*3+ OBSTRUENTS	-4.57	*< .001*	-5.10	*< .001*	-3.84	*0.000*	-5.14	*< .001*	-3.95	*< .001*	-4.52
*4+ CONSONANTS	-4.86	*< .001*	-4.39	*< .001*	-4.40	*< .001*	-4.74	*< .001*	-4.06	*< .001*	-4.49
*C#C	-4.19	*< .001*	-2.21	*0.014*	-5.99	*< .001*	-5.25	*< .001*	-4.70	*< .001*	-4.47
*SIBILANT CLUSTER	-1.58	*0.057*	-2.51	*0.006*	-3.57	*0.000*	-6.15	*< .001*	-4.37	*< .001*	-3.64
*3+ CONSONANTS	-4.85	*< .001*	-0.87	*0.191*	-4.72	*< .001*	-4.00	*< .001*	-1.71	*0.044*	-3.23
*GEMINATE	-4.45	*< .001*	-1.34	*0.089*	-5.30	*< .001*	-3.07	*0.001*	-1.40	*0.080*	-3.11
*HIATUS	-2.56	*0.005*	-1.19	*0.117*	-4.44	*< .001*	-3.90	*< .001*	-2.80	*0.003*	-2.98
4Obs+ Clusters:	-2.00	*0.023*	-2.29	*0.011*	-3.29	*0.000*	-3.27	*0.001*	-3.33	*0.000*	-2.84
*NC̬	-0.78	*0.216*	-1.21	*0.112*	-2.70	*0.003*	-2.71	*0.003*	-0.63	*0.266*	-1.61
*BAD SONORITY	-0.38	*0.351*	-1.18	*0.119*	-0.94	*0.174*	-0.54	*0.295*	-0.25	*0.403*	-0.66
*CLASH	5.95	*< .001*	0.58	*0.282*	-9.01	*< .001*	3.35	*0.000*	8.02	*< .001*	1.78

Effect sizes and p-values for virtues (all five corpora)

Virtue	Austen		Darwin		Hawthorne		Twain		Spoken		Average
	Effect size	*p*	Effect size	*p*	Effect size	*p*	Effect size	*p*	Effect size	*p*	Effect size
UNSTRESSED # STRESS	-5.89	*< .001*	-0.32	*0.373*	10.45	*< .001*	-2.61	*0.005*	-7.09	*< .001*	-1.09
ND CLUSTER	-1.86	*0.031*	-1.31	*0.095*	-0.60	*0.273*	-0.18	*0.429*	-1.30	*0.096*	-1.05
r # t	-0.98	*0.163*	0.35	*0.364*	-2.27	*0.012*	0.38	*0.351*	1.36	*0.087*	-0.23
V#CV	0.41	*0.341*	1.49	*0.068*	4.01	*< .001*	3.29	*0.001*	3.30	*0.000*	2.50
GOOD SONORITY	2.29	*0.011*	4.50	*< .001*	2.34	*0.010*	2.07	*0.019*	2.98	*0.001*	2.84
V# r	4.63	*< .001*	4.01	*< .001*	4.79	*< .001*	2.02	*0.022*	2.29	*0.011*	3.55
V # ALV STOP	4.99	*< .001*	3.05	*0.001*	4.72	*< .001*	4.46	*< .001*	2.52	*0.006*	3.95