



# Syntactic Planning, Informational Risk, and the Information Threshold

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(with collaborators: Rachael Bailes, Anton K. Ingason<sup>3</sup> and Christine Cuskley<sup>2</sup>)

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# “Constraints on the Adaptiveness of Information in Language” (CAIL)

- <https://cail-project.github.io/>
- Collaboration with Christine Cuskley and Rachael Bailes
- ESRC Secondary Data Analysis Initiative (SDAI), grant #ES/T005955/1

# Today's Talk

Information Uniformity and Language

What It's For: Noise Resistance

Theoretical excursus: language and ruin

What It Does: Syntactic Planning

Diachronic Study 1: Information Theoretic Constant Rate Effects:  
OV to VO

Diachronic Study 2: Adding Adjunct Fronting with V2

Theoretical Implications

Further Work: English topicalization is disappearing

Conclusions and Lots More To Do

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Effects: OV to VO

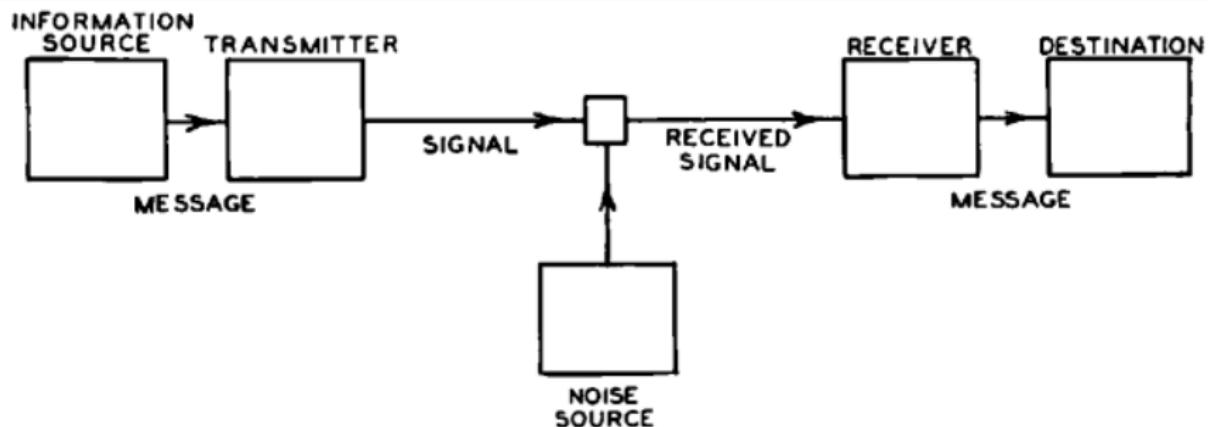
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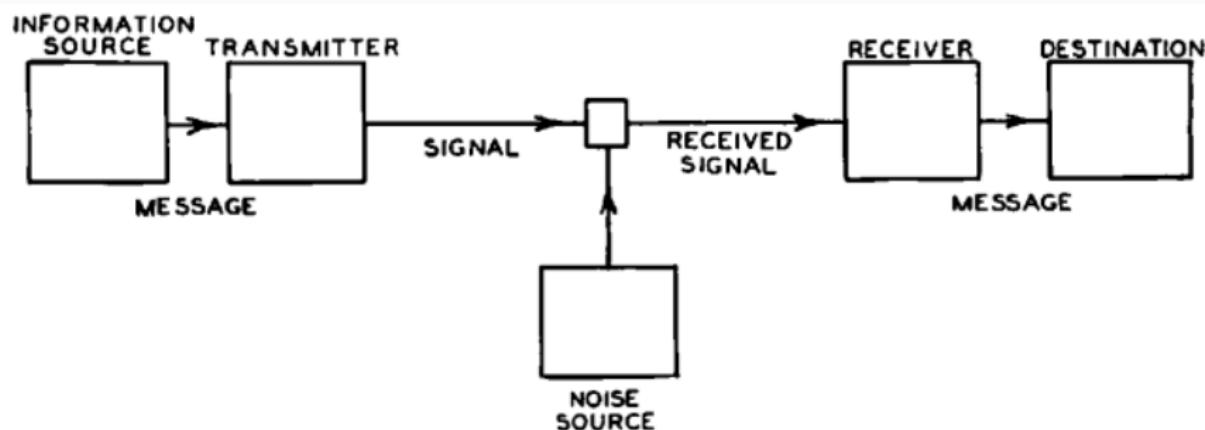
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# Information theory and language

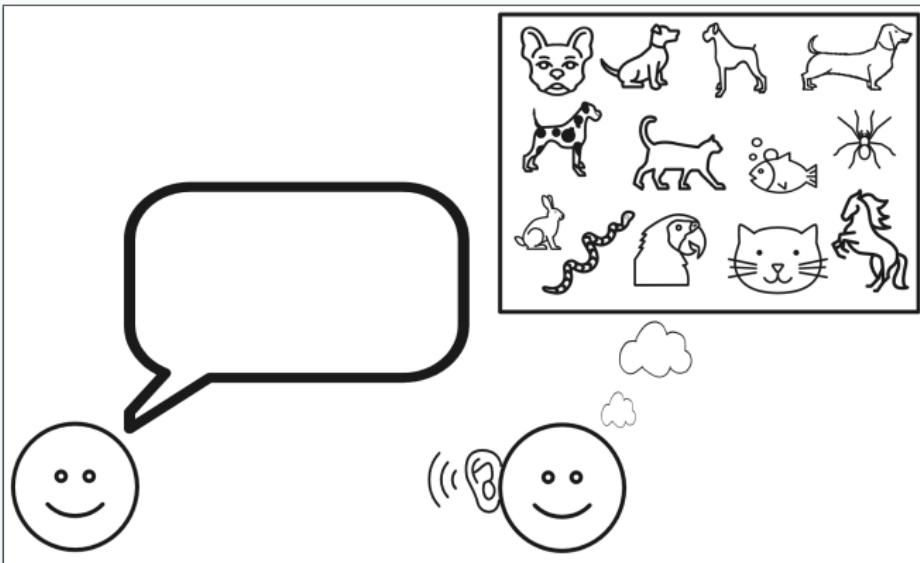


# Information theory and language



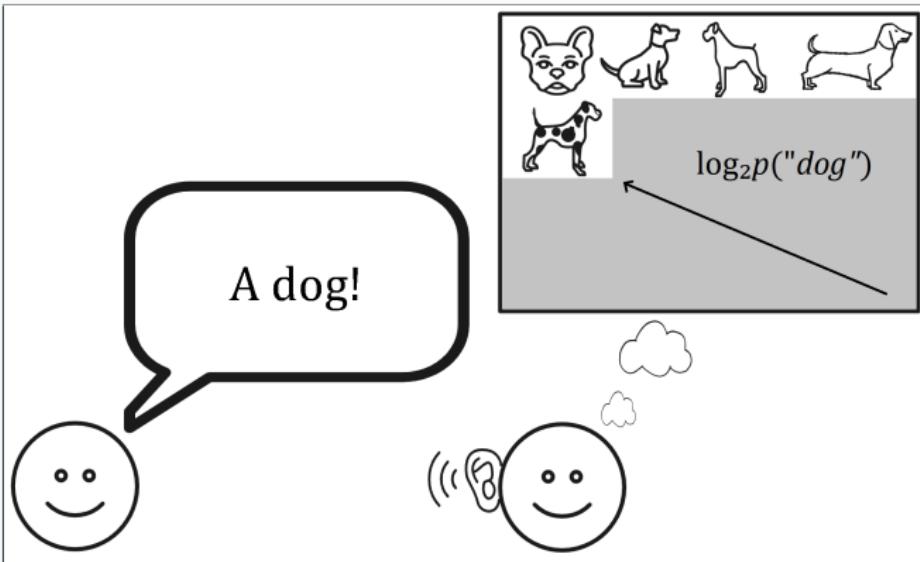
- **Key Insight:** The amount of information a sender can theoretically communicate about an event is the uncertainty ("entropy") the receiver has about the event beforehand, which may be reduced by a signal (Hartley, 1928; Shannon, 1948).

# Information content of words



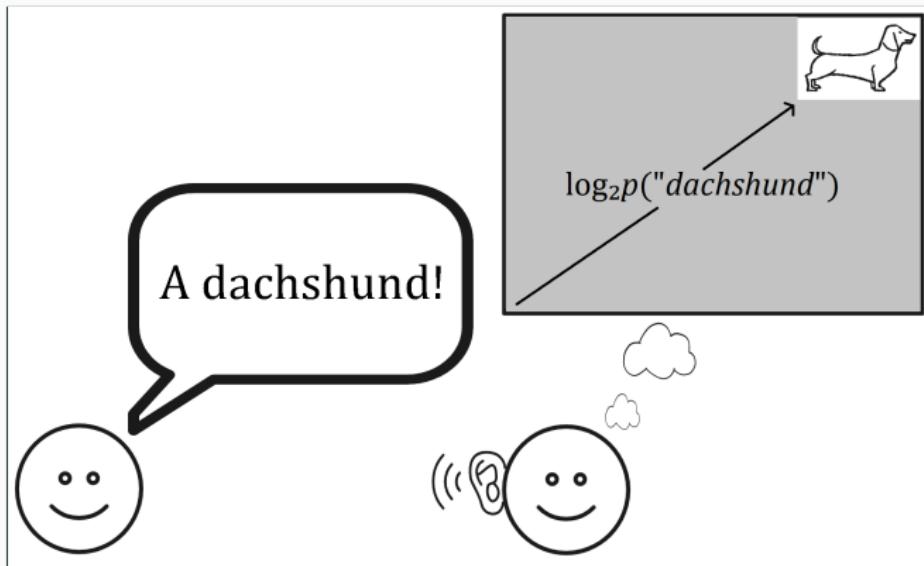
Receiver begins with a **set of expected outcomes** that could result from the message they receive. This set of expected outcomes is the amount of **uncertainty** they have about the message.

# Information content of words



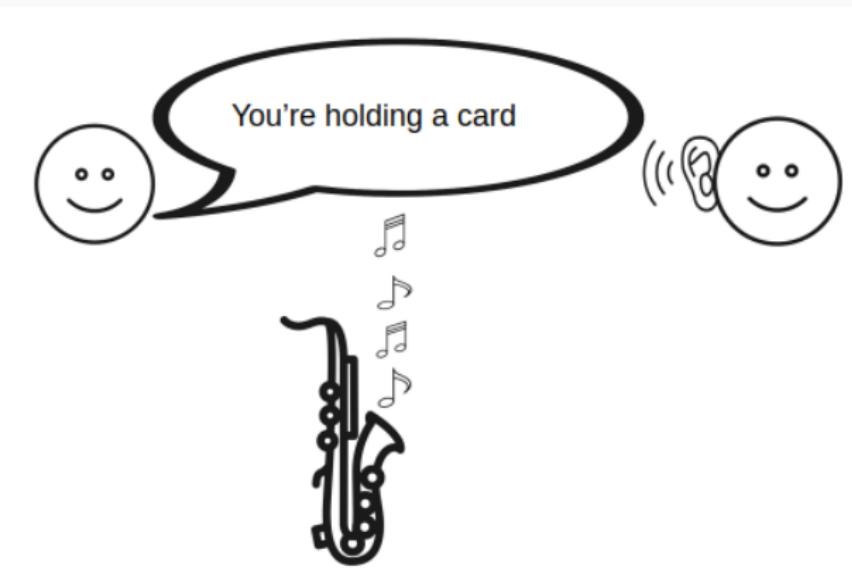
Sender uses a word that **reduces the receiver's uncertainty** by some amount proportional to the word's frequency. Here, the word is relatively frequent.

# Information content of words



The more infrequent the word, the more uncertainty is reduced.

## Redundancy mitigates against noise



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(Shannon, 1948; Fenk & Fenk, 1980; Fenk-Oczlon, 2001; Aylett & Turk, 2004; Levy & Jaeger, 2007; Frank & Jaeger, 2008; Jaeger, 2010; Turk, 2010; Chingacham et al., 2023)

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## Reordering for uniformity: functional for noise resistance?

- Signalling error reduced arbitrarily given sufficient redundancy (Shannon, 1948).
- Does reordering confer noise resistance?

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Cognition

Volume 214, September 2021, 104754



## Noise resistance in communication: Quantifying uniformity and optimality

Christine Cuskley, Rachael Bailes, Joel Wallenberg

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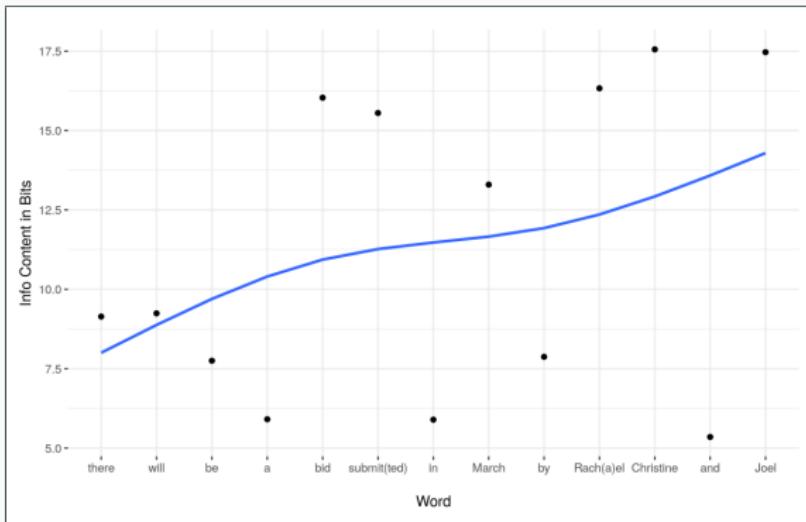
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<https://doi.org/10.1016/j.cognition.2021.104754>

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# Information distributions of sentences

Deriving the information content of each word means we can derive a **distribution of information content values** for a given sentence.

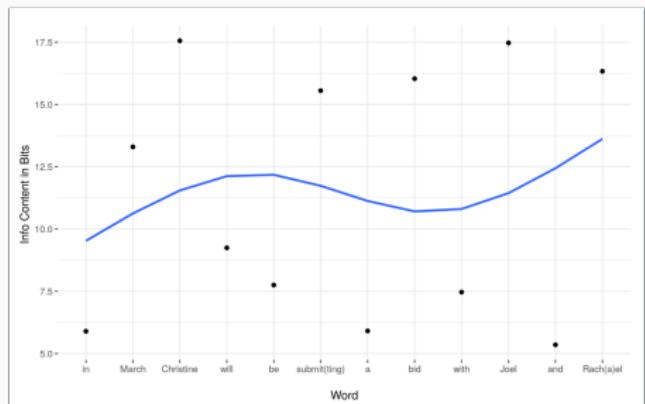
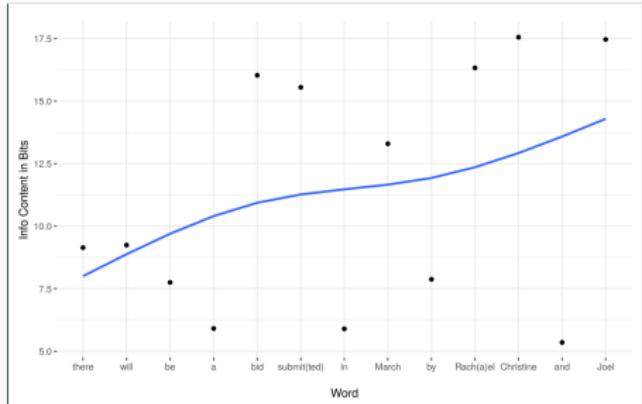


## Uniformity of information distributions

These distributions can vary in terms of how the information is spread or clustered. The **order of elements** in a sentence derives **more uniform** or **more asymmetric** distributions of information (Cuskley, Bailes, & Wallenberg, 2021).

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We can measure how uniform an information distribution is with Deviation of the Rolling Mean (DORM) (Cuskley et al., 2021).

## DORM: Deviation of the Rolling Mean

en	eg	skal	sjá	yður	aftur
6.79	6.15	10.1	9.25	6.15	10.4

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Sample variance of rolling means = 1.33 bits<sup>2</sup>

**low DORM → more uniform**

**high DORM → more lopsided**

## UIDO: Uniform information density optimisation

- An algorithm that finds the most uniform/dispersed/smooth distribution of a given set of values (Cuskley et al., 2021).
- Not absolute lowest DORM possible; but robust enough and computationally tractable.
- Useful **calibration** for utterance DORMs & establishing a baseline.

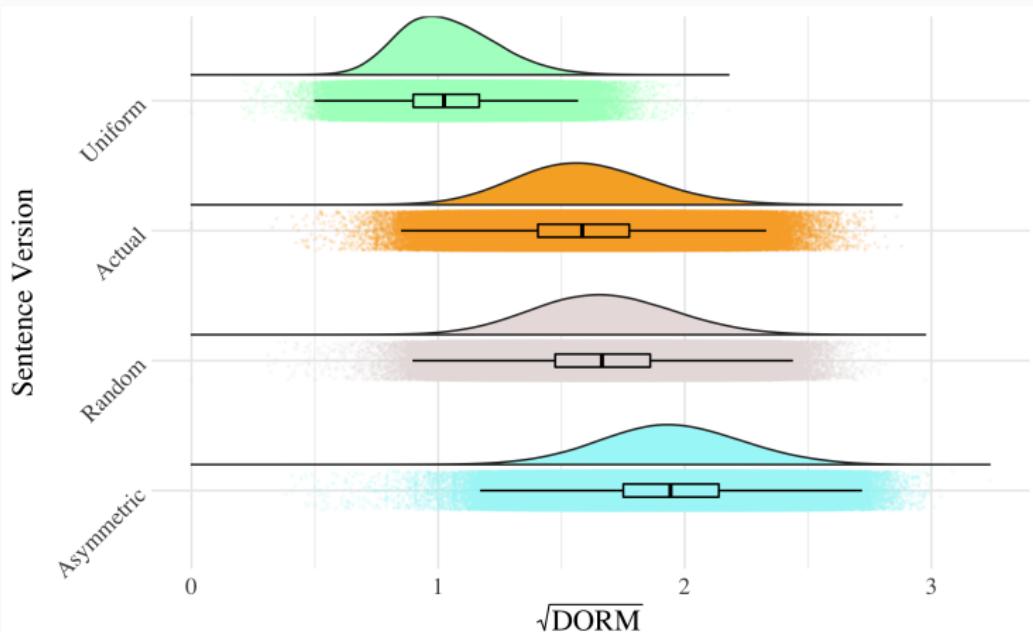
## UIDO: Uniform information density optimization

- For a given array of values (e.g. information values of words in a sentence):
  - The array of information content values is ordered greatest to least.
  - Starting with the second and penultimate value in the array and moving inward, every other number is swapped, mixing up the large and small values.
  - DORM is calculated for the resulting array.
  - If this is lower than the original DORM, the array is kept.
  - Otherwise, the algorithm proceeds with the original array.
- Useful calibration for interpreting utterance DORMs & establishing a baseline, as well as current study use.

## Corpus-Based Simulation

- The Penn-York Computer-annotated Corpus of a Large amount of English (PYCCLE; Ecay, 2015).
- 628,083 sentences exactly 10 words in length.
- DORMs for 4 versions: maximally uniform/dispersed, original, random, maximally asymmetric.

# Uniformity of distributions



**Figure 1:** Distributions of the square root of DORM values for 628,083 sentences prior to noise simulation.

## Single-unit and clustered noise

- Single-unit noise: three random single units “knocked out” per distribution per trial.

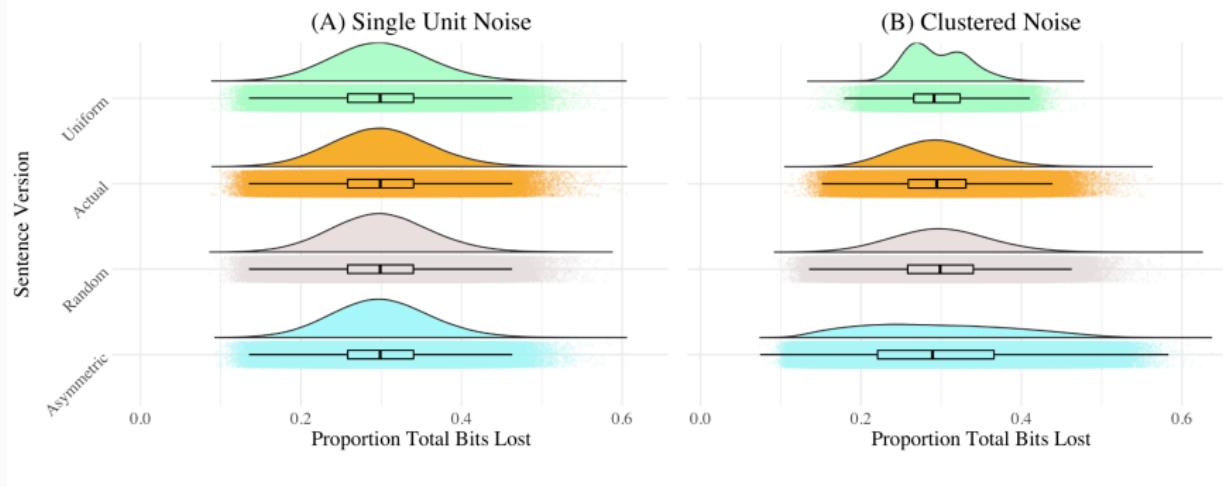
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- Single-unit noise: three random single units “knocked out” per distribution per trial.
- Clustered noise: three sequential units “knocked out” per distribution per trial.
  - More similar to naturally occurring noise events that span multiple linguistic units.

## Single-unit and clustered noise

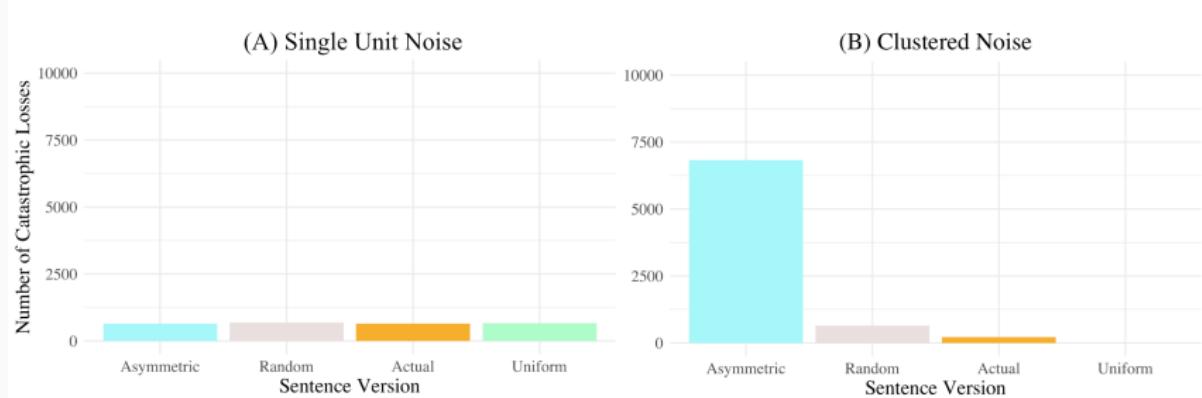
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- Clustered noise: three sequential units “knocked out” per distribution per trial.
  - More similar to naturally occurring noise events that span multiple linguistic units.
- Knocked out item positions matched across all 4 versions of all sentences in each trial.

# Information loss in conditions of noise



**Figure 2:** Distributions of the proportion of information lost in 628,083 trials in each condition under 3 single-word noises (A) and clustered noise (B)

# Catastrophic Failures



**Figure 3:** The number of sentences with “catastrophic” information failure in each condition (a noise event knocking out  $\geq 50\%$  of the total information content) under 3 single-word noises (a) and clustered noise (b)

## Interim Conclusions: What It's For

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- ...particularly where continuous noise spans multiple categorical linguistic units.
- More uniform orders may decrease overall info loss, probably because of Zipfian vocabularies (but so do asymmetric).

## Theoretical Excursus: Language and “Ruin”

- Signalling happens between every linguistic level, as does noise (Aylett & Turk, 2004).

**acoustic → segmental/allophonic → phonemic → morphemic  
→ morphosyntactic → propositional/utterance-function**

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  - We can fill in gaps with left- and right-context (Alcántara et al., 2004).

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  - “Asymmetric” had a single-sentence 98.9% VaR of 50%, or a 100% VaR of 63%.
  - “Uniform” had a single-sentence 100% VaR of 50%, or a 99.9% VaR of 42%.

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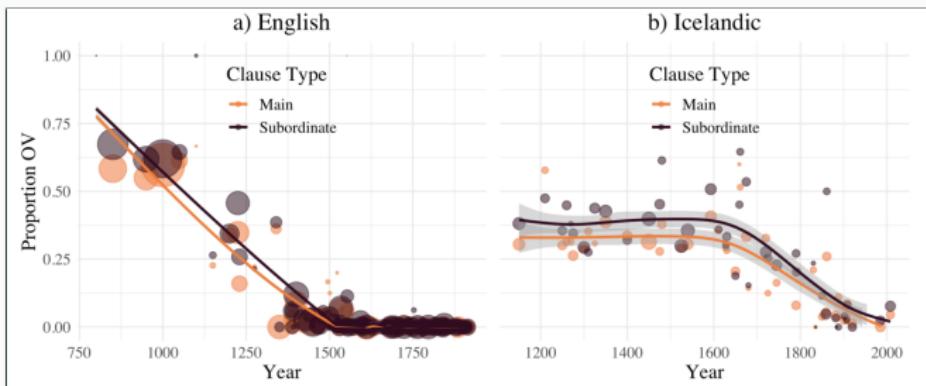
## Diachronic Study 1: Constant Rate Effects

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- When a change is in progress for a given linguistic variable, some contexts favour one of its variants over another **without affecting the change** (Kroch, 1989).



e.g. In the change from OV to VO in English & Icelandic, OV is consistently favoured in subordinate clauses throughout the steady decrease in its overall proportion (see also Pintzuk & Taylor 2006).

# CRE in English and Icelandic OV to VO



*languages*



*Article*

## Smooth Signals and Syntactic Change

Joel C. Wallenberg <sup>1,\*</sup>, Rachael Bailes <sup>1</sup>, Christine Cuskley <sup>1</sup> and Anton Karl Ingason <sup>2,\*</sup>

- Based on this account of information uniformity, (Wallenberg, Bailes, Cuskley, & Ingason, 2021) predicted a previously undetected argument-type effect in the English and Icelandic OV to VO changes.

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Article

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- Based on this account of information uniformity, (Wallenberg et al., 2021) predicted a previously undetected argument-type effect in the English and Icelandic OV to VO changes.
- During the change, speakers had access to both constituent orders, making this an ideal case for testing whether language users choose more informationally uniform constructions.

# OV-to-VO in English

## Middle English:

- (1) Mi feader & Mi moder for-þi þt ich nule      be  
My father and my mother because that I not+would you  
forsaken; habbe forsake me.  
forsake have forsaken me

“Because I would not forsake you, my father and mother have  
forsaken me”

(*St. Juliana*, northern Herefordshire/southern Shropshire, date: c1225;  
ID CMJULIA-M1,106.172 from the *Penn Parsed Corpus of Middle  
English* 2 PPCME2, 2000)

# OV-to-VO in Icelandic

## Historical Icelandic:

- (2) a. ... og sannleikurinn mun yður frelsa  
and the truth will you free  
“... and the truth will free you.”

(*Oddur Gottskálksson's New Testament*, date: 1540; ID 1540.NTJOHN.REL-BIB, 204.662 from *Icelandic Parsed Historical Corpus* (*IcePaHC*, 2009))

- b. ... en eg skal sjá yður aftur.  
but I shall see you-pl again  
“... but I shall see you again”

(*Oddur Gottskálksson's New Testament*, date: 1540; ID 1540.NTJOHN.REL-BIB, 223.1305 from *IcePaHC*)

## English and Icelandic OV to VO

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Constituent Type	Average Information Content (PPCMBE; A. S. Kroch et al., 2016)
Pronominal DP	low ( $\approx 11.7$ bits)
Nominal DP	high ( $> 13.7$ bits)
Lexical Verb	mid ( $\approx 13.5$ bits)

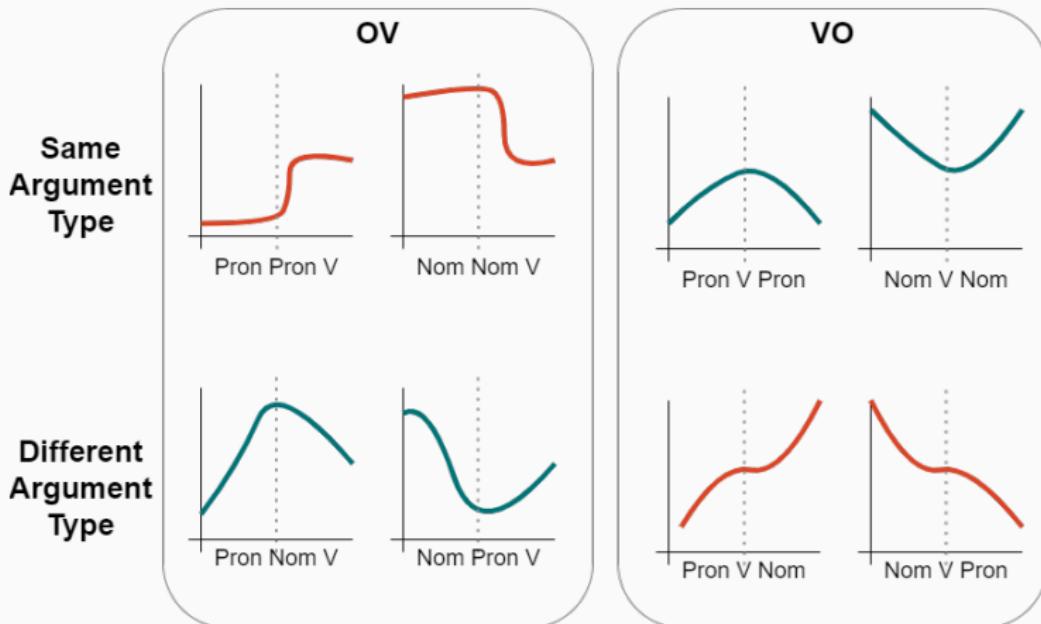
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- We can therefore make predictions about the ordering of elements that speakers will prefer, when they have a choice - i.e., constituent orders that yield more uniform information distributions.

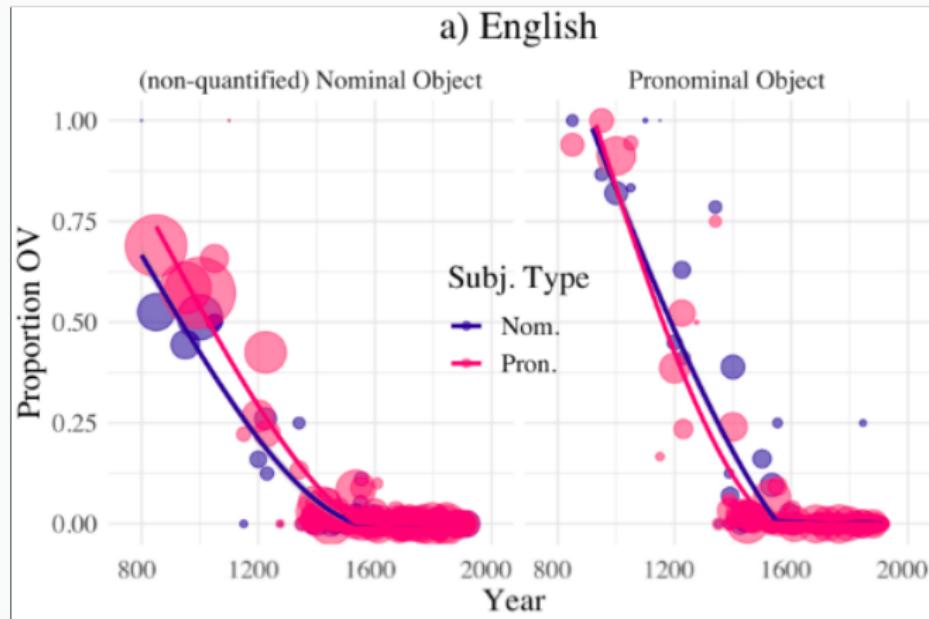
# Predictions



- OV is disfavoured when Sbj and Obj are the **same type**
- OV is favoured when Sbj and Obj are **different types**

## Results:

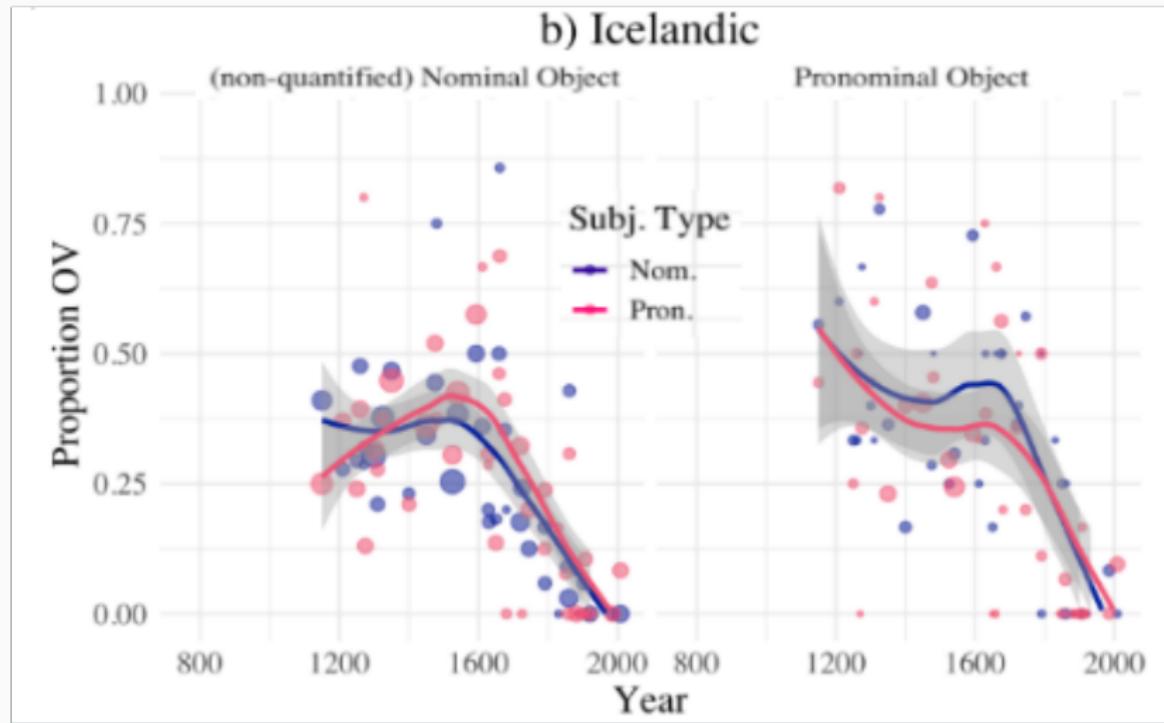
OV is favoured when Subject and Object are different types



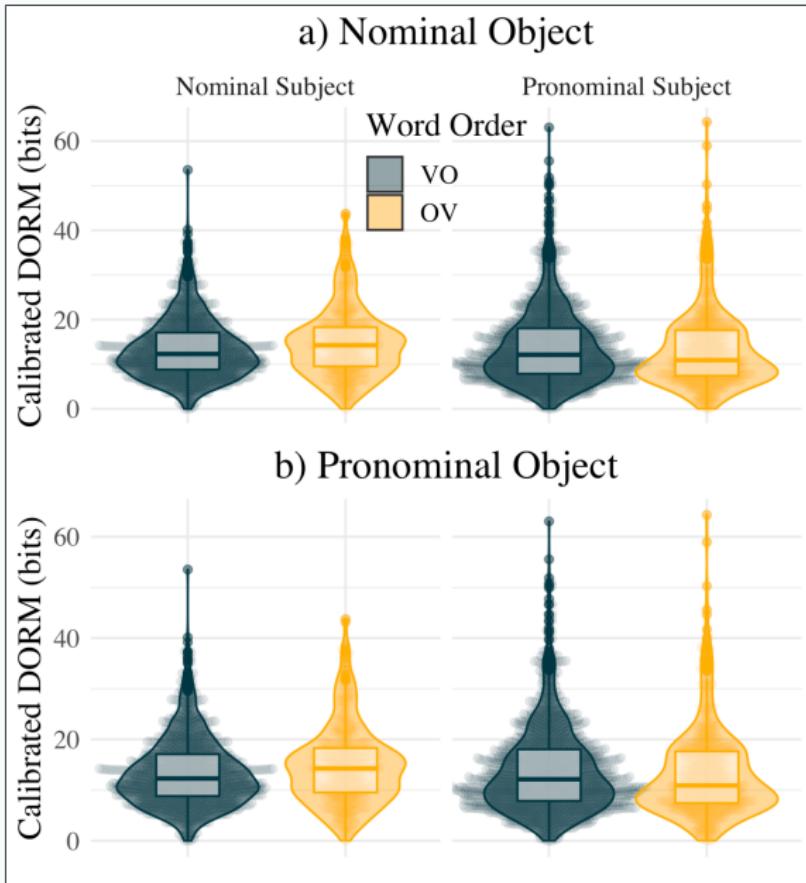
*YCOE and Penn Parsed Corpora of Historical English* (Taylor, Warner, Pintzuk, & Beths, 2003; A. S. Kroch & Taylor, 2000; A. Kroch, Santorini, & Delfs, 2004; A. S. Kroch et al., 2016)

## Results:

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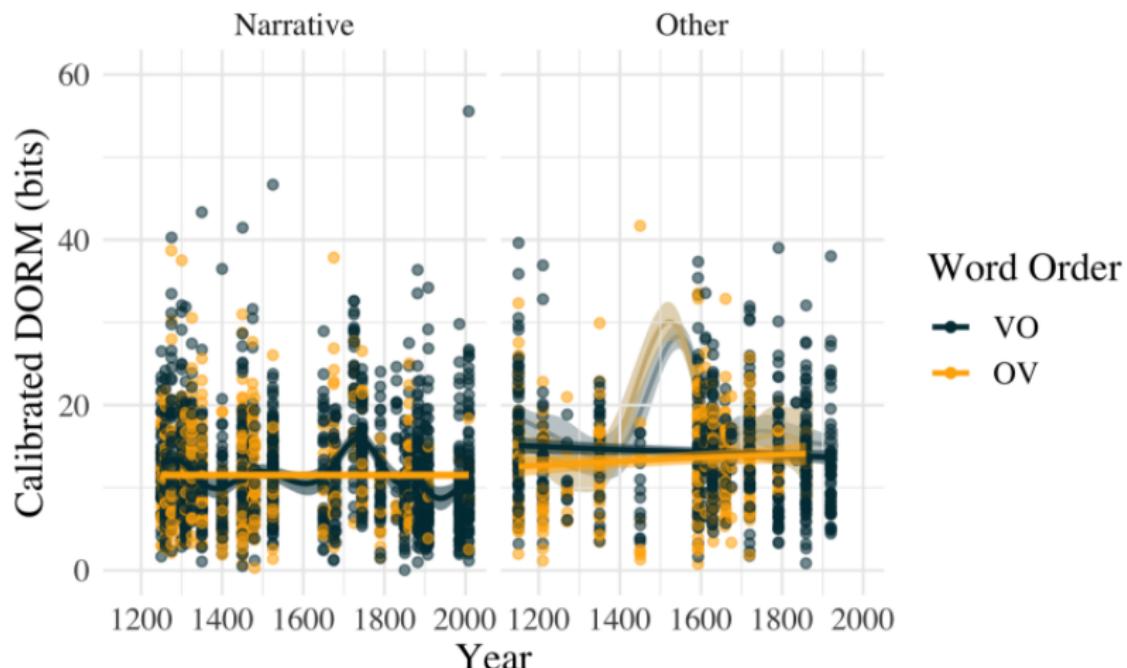
# Results: DORMs by Obj, Sbj Type



## Results: A threshold?

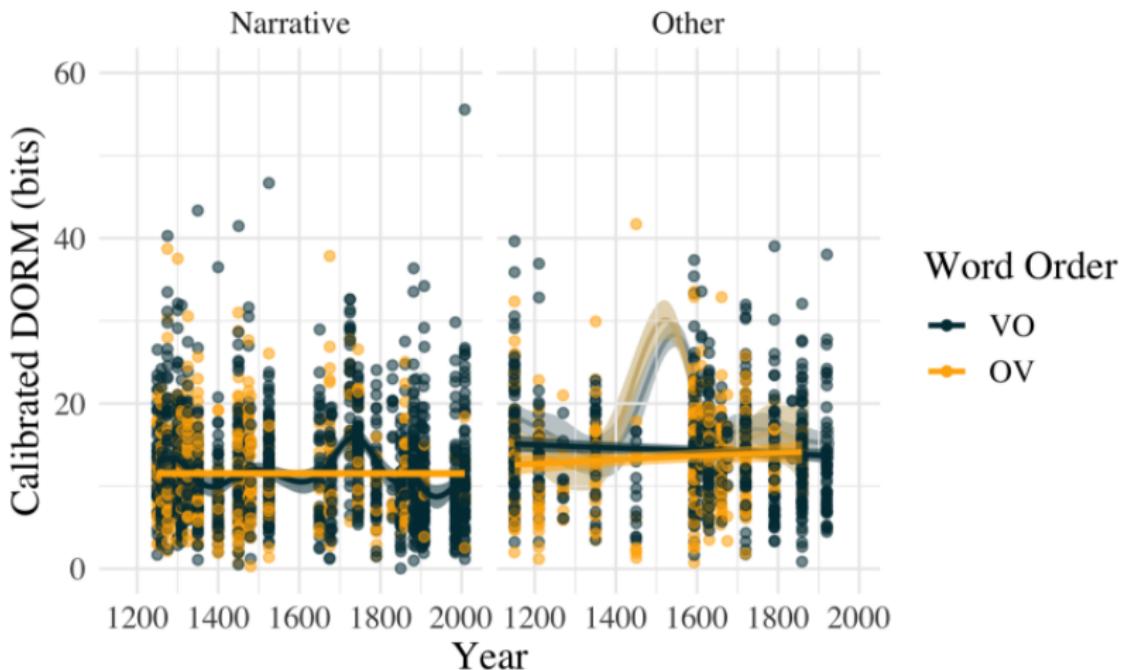
Information density remains constant

### Uniformity & Genre in Icelandic



...but the outlier indicates a complex planning problem

## Uniformity & Genre in Icelandic



## Diachronic Study 2: Adding V2

- Wallenberg et al. (2021) showed that a pressure for information uniformity creates contextual effects in the OV-to-VO change.
- OV-to-VO progresses across the argument-type contexts at the same rate (“Constant Rate Effect” (A. S. Kroch, 1989) and subs).
- But we did not account for how Subject-Aux inversion under V2 interacts informationally with OV/VO.
- We now consider Icelandic main clauses with adjunct XPs...

# Examples: adjunct fronting under V2

## VO – no fronting

- (3) Jón hefur **keypt** bók  
Jón has bought a.book  
í dag.  
in today  
'Jón has bought a book  
today.'

## OV – no fronting

- (4) Pessi sami riddari vildi  
This same knight wanted  
eigi **gaum** **gefa**  
not attention give  
'This same knight didn't  
want to pay attention  
[to...].'  
(1475.AEVINTYRI.NAR-REL.,.933)

## VO – adjunct fronting

- (5) Í dag hefur **Jón**  
in today has **Jón**  
**keypt** bók.  
**bought** a.book  
'Today, Jón has bought a  
book.'

## OV – adjunct fronting

- (6) Aldrei hafði **kóngsson**  
never has a prince  
slíkan grip séð.  
such a.thing seen  
'Never has a prince seen  
such a thing'  
(1450.VILHJALMUR.NAR-  
SAG,21.327)

## Diachronic Study 2: Adding V2

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- From earlier study, constituent order affects distribution uniformity.

## Diachronic Study 2: Adding V2

- From earlier study, constituent order affects distribution uniformity.
- Remember: syntactic constituents occur at different frequencies, which means they have different information content values.

Constituent Type	Average Information Content (PPCMBE; A. S. Kroch et al., 2016)
Pronominal DP	low ( $\approx 11.7$ bits)
Aux	low-ish ( $\approx 12.4$ bits)
Lexical Verb	mid ( $\approx 13.5$ bits)
Nominal DP	high ( $> 13.7$ bits)

Finally, Adjunct XPs are comparable to (not least because in many cases they include) Nominal DPs, and are therefore treated here as **high**

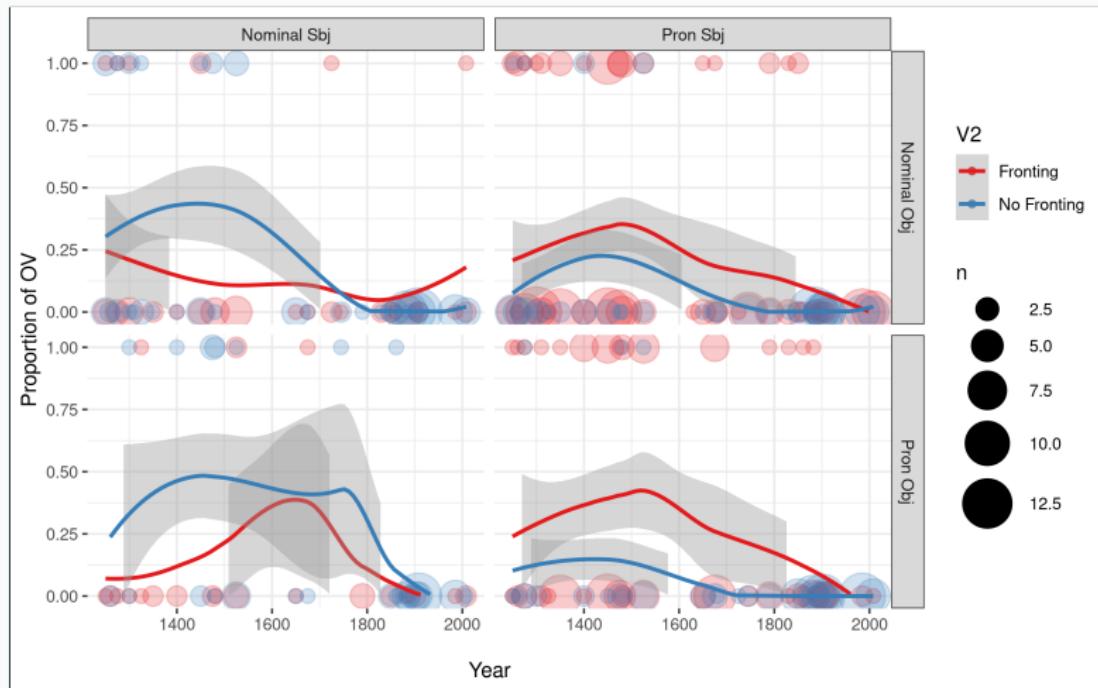
## Study 2: Adding V2

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- We might also expect that V2 will also give rise to information theoretic effects that interact with OV/VO, as argument type did in previous study.
- So that's what we looked for...

## Preliminary:

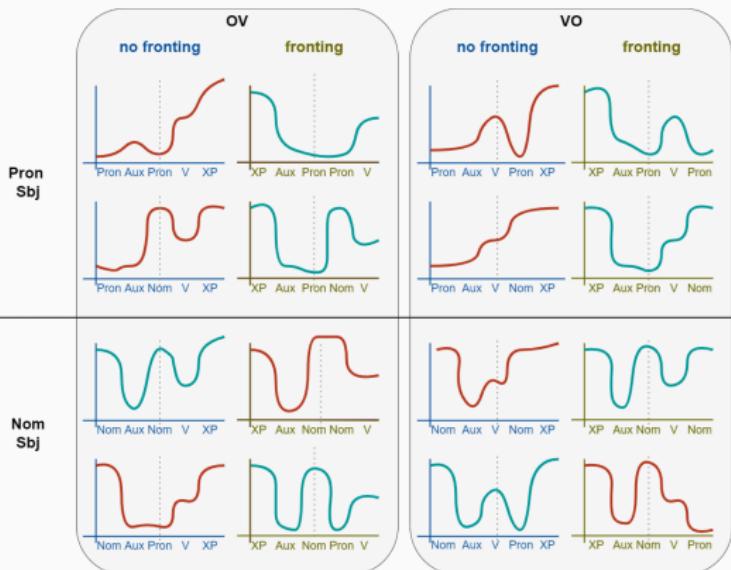
Is V2 a “context” for OV/VO (in the CRE sense)?



- Predictions not borne out if V2-fronting conditions choice of OV/VO.

# Study 2 Predictions

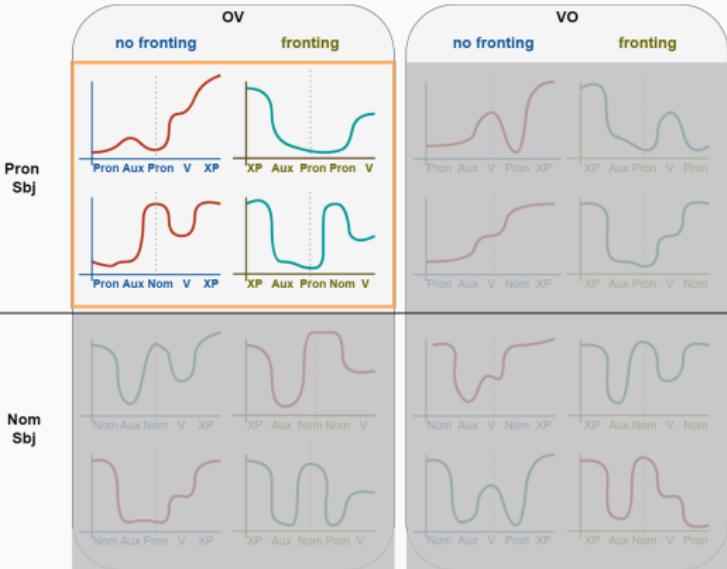
Speakers deploy fronting when it yields more uniformity



If speakers *deployed* adjunct-fronting to maximise information uniformity (given other parameters), they would conform to this pattern

# Study 2 Predictions

## Given OV and Pron Sbj:



+ Pron Obj:

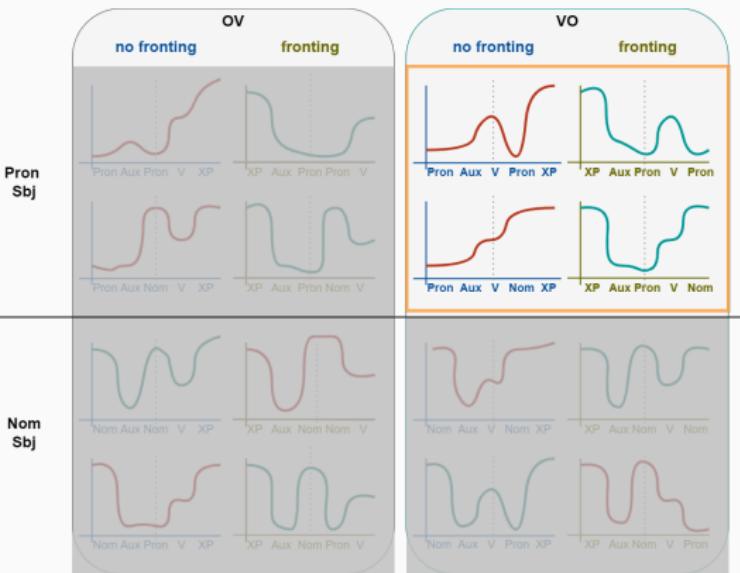
- Fronting helps balance out the unavoidable 3-unit informational troughs (Pron-Aux-Pron & Aux-Pron-Pron)

+ Nom Obj:

- Fronting means avoidance of clustered information peak (Nom-V-XP)

# Study 2 Predictions

## Given VO and Pron Sbj:



+ Pron Obj:

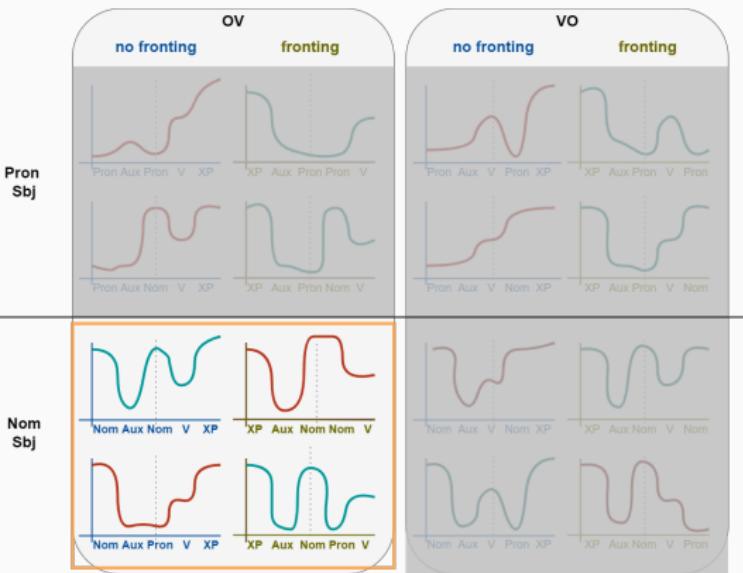
- Fronting may yield a bit more uniformity

+ Nom Obj

- Pressure from 2-unit informational troughs and peaks (Pron-Aux & Nom-XP)
- Maximally asymmetric distribution can be avoided by fronting

# Study 2 Predictions

## Given OV and Nom Sbj:



Distribution symmetries aren't so obviously different, so pressures probably aren't strong. But:

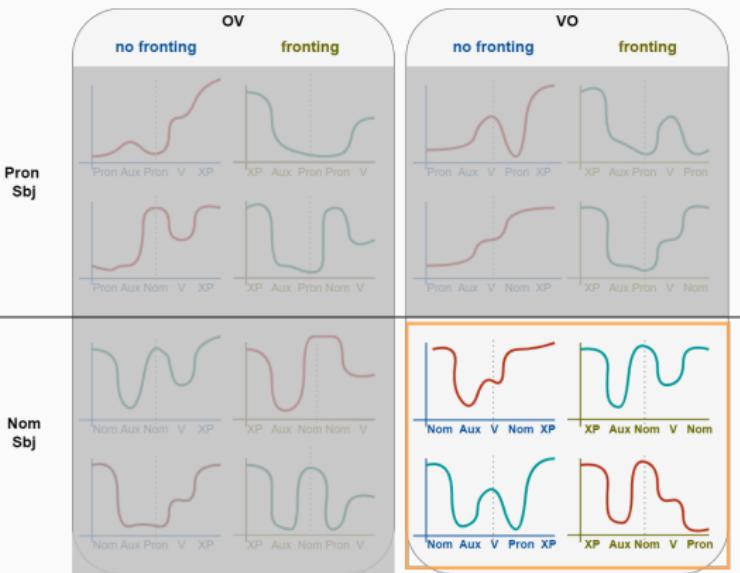
+ Nom Obj:

- Fronting yields 2-unit informational peak (Nom-Nom), so *may* be disfavoured

+ Pron Obj:

- Fronting *might* be more uniform (if not more symmetrical)

# Study 2 Predictions Given VO and Nom Sbj:



Distribution symmetries not obviously different, so pressures probably aren't strong. But:

+ Nom Obj:

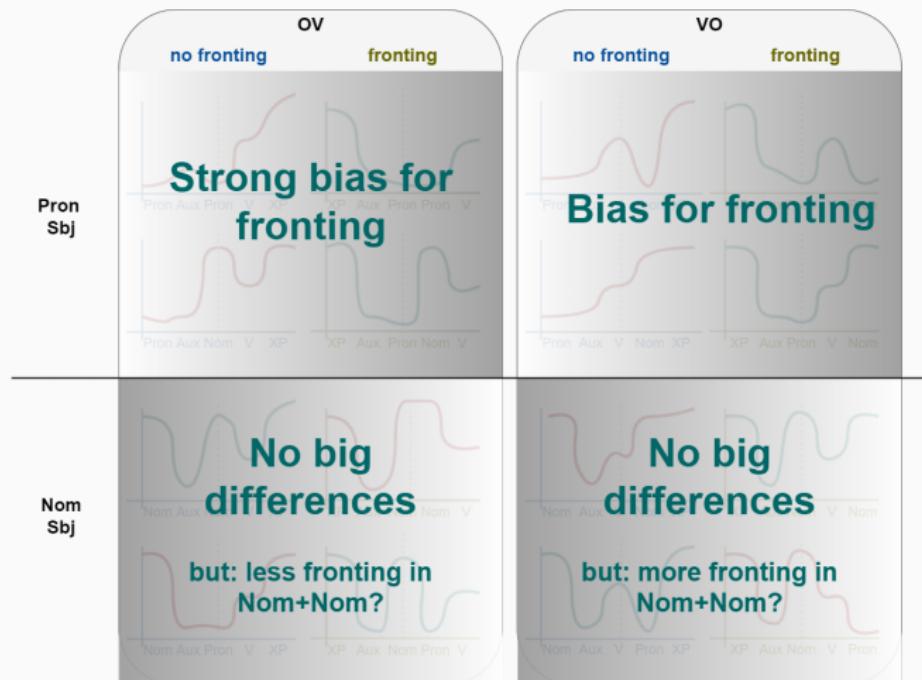
- Fronting *may* yield slightly more uniform distribution (by avoiding clustered peak of Nom+XP)

+ Pron Obj:

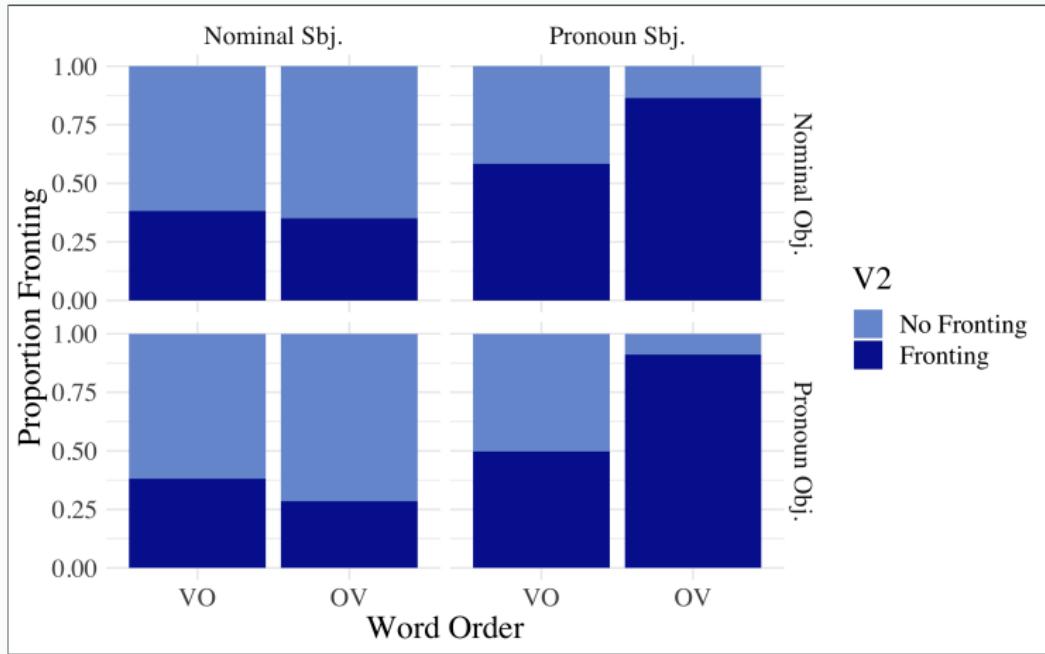
- Non-fronting might be more symmetrical

# Study 2 Predictions

Speakers deploy fronting when it yields more uniformity



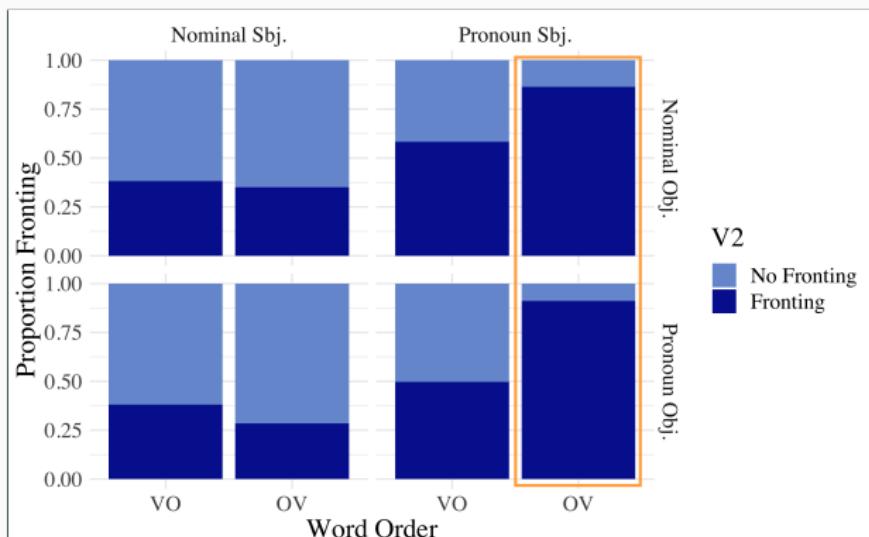
## Study 2 Results



- Overall, fronting appears where we'd expect if speakers are trying to maximise the uniformity of information distributions with the order of constituents.

# Study 2 Results: Given OV and Pron Sbj

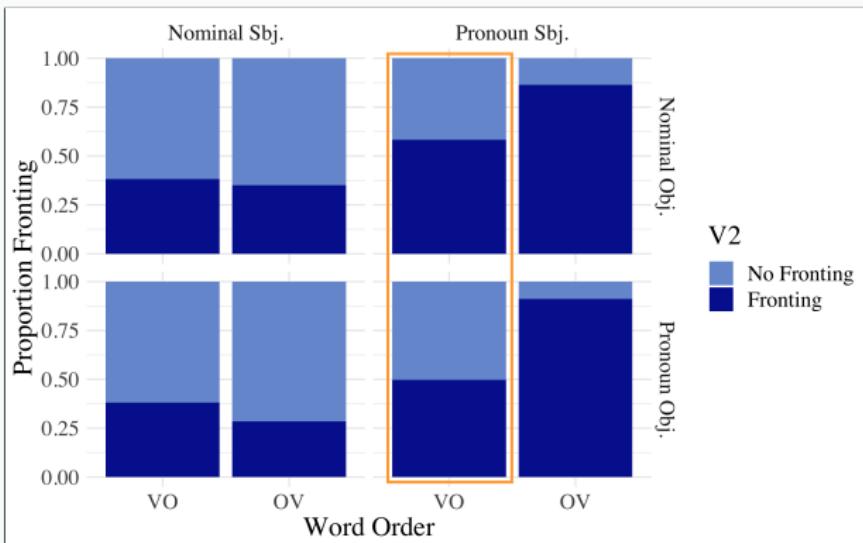
Two pressures for fronting



- Pron Sbj + Nom Obj:  
Avoid long peak  
(Nom-V-XP)
- Pron Sbj + Pron Obj:  
Avoid maximal  
asymmetry

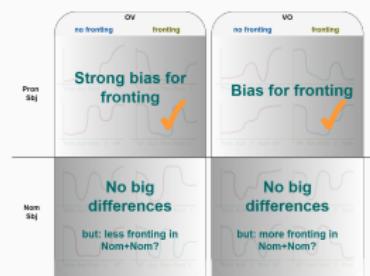


# Study 2 Results: Given VO and Pron Sbj

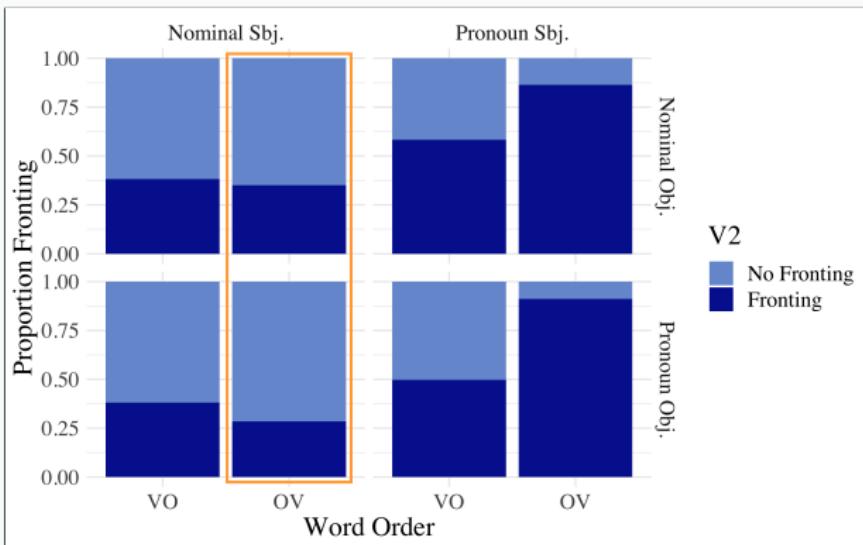


## Bias for fronting

- Stronger (>50%) for Pron Sbj + Nom Obj
- Avoidance of maximal asymmetry



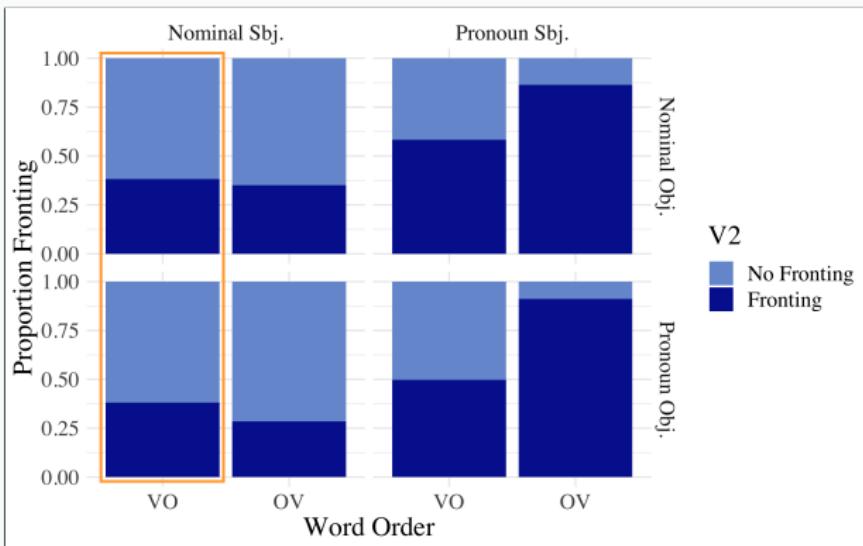
# Study 2 Results: Given OV and Nom Sbj



- Less fronting than in VO overall
- No big difference between Pron/Nom Obs, but not the direction we'd expected (less fronting to avoid Nom+Nom)



# Study 2 Results: Given VO and Nom Sbj



- No big difference between Pron/Nom Obs



## Theoretical Implications

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    - (i.e. fronting modulates information uniformity under the constraint of OV or VO, rather than vice versa).
    - (cf. Speyer, 2010 where Sbj type conditions topicalization in English)
- **The Kauhanen-Walkden Theorem** (aka Time Separation Theorem) (Kauhanen & Walkden, 2018): time separation is strictly bounded.
- Maximum/minimum uniformity is strictly bounded.

## Information Uniformity and Language

What It's For: Noise Resistance

Theoretical excursion: language and ruin

What It Does: Syntactic Planning

Diachronic Study 1: Information Theoretic Constant Rate

Effects: OV to VO

Diachronic Study 2: Adding Adjunct Fronting with V2

Theoretical Implications

**Further Work: English topicalization is disappearing**

Conclusions and Lots More To Do

## Further Work: Non-V2 Object Topicalization

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(11) Joel she likes (but Bill she doesn't).

(12) Joel the cat likes.

(13) Joel Viola likes.

(14) Joel, Viola likes.

From PPCMBE, nominal objects ( $\chi^2 = 260$ ,  $p < 2 \times 10^{-16}$ ):

	Fronted	In Situ	Prop. Fronted
Pron Sbj	631	20,071	0.031
Nom Sbj	119	16,808	0.0071

## Further Work: Non-V2 Object Topicalization

- Speyer also showed that as V2 options are lost in English, direct object topicalization declines.
- Potential improvement in informational uniformity is a continuous variable, predicting slow change over time:

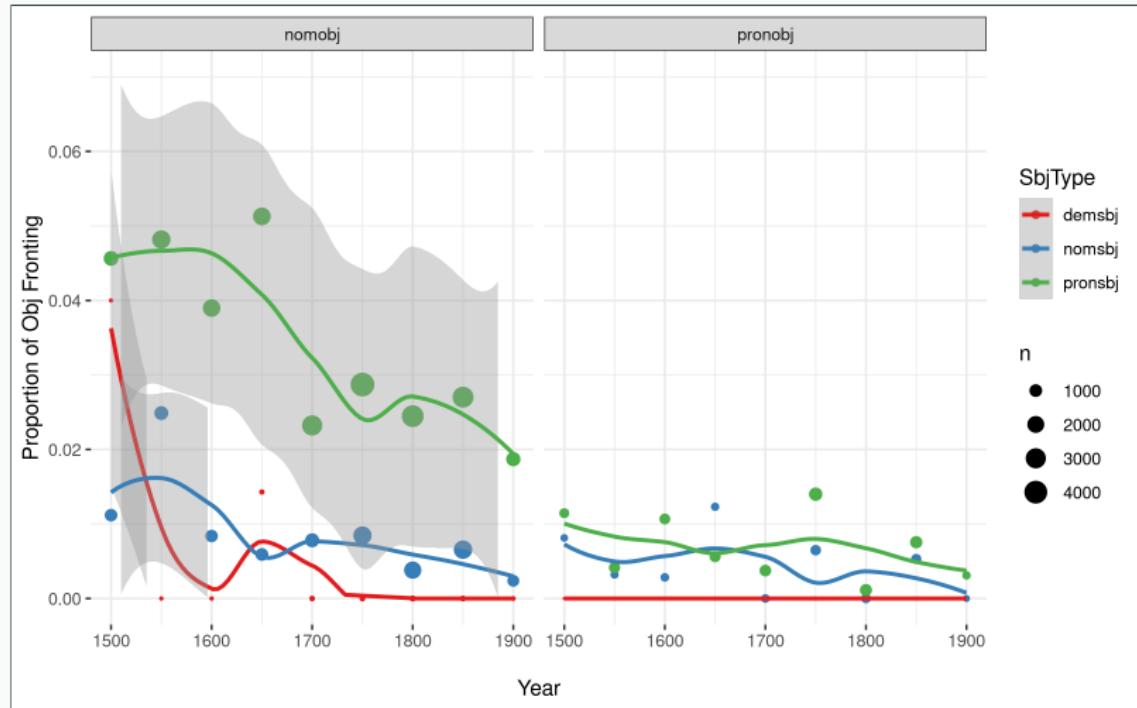
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  - The two syntactic forms overlap in function (Prince, 1998), and therefore compete in use (A. S. Kroch, 1994).
  - The competition is mitigated by specialization, but along a continuous dimension, and so total specialization is impossible and slow change results (Wallenberg, 2016).

## Further Work: Non-V2 Object Topicalization



Note: significant effects of **Year**, **Obj**, **Sbj**, sig **Obj:Sbj** interaction, but no sig **Obj**, **Sbj** interactions with **Year** (Constant Rate Effect).

## Further Work: Non-V2 Object Topicalization

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- Is accent clash continuous or categorical?
- Speyer suggested two levels of accent clash, but not more.
- Both dimensions are likely in operation, but can they be distinguished?
  - (15) Joel, Bob likes.
  - (16) Joel, the cats like.
- Calibrated DORM and accent clash are both bounded dimensions.

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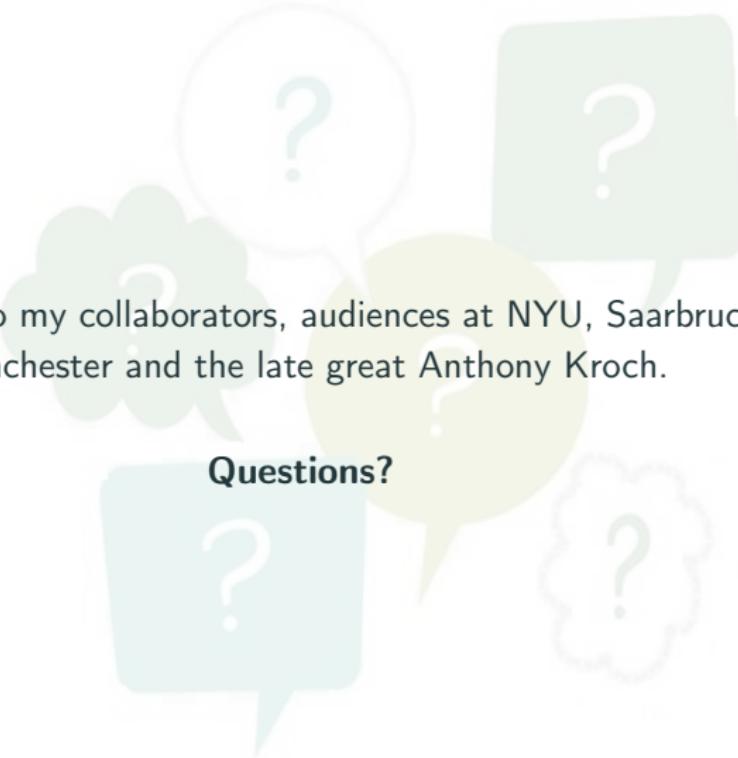
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- **Other Implications:** derivational ordering effects, where sbj/obj type and perhaps headedness precede movement.
- Minimizing DORM is a tough planning problem, making it hard to do with other constraints.
- **Exploratory Work:** information uniformity can be a continuous dimension of specialization, slowing change in non-V2 topicalization.

## Future Work

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- Estimate the threshold for information loss?
- Nail down Icelandic results with the Gigaword Icelandic Corpus.
- Nail down English results with lemmatized PPCHE.
- Experiment with Calibrated DORM and conditional entropies.
- Experiment with contextual probabilities derived from word-embeddings (LLMs, e.g. ROBERTA embeddings), to allow for left- and right-context.
- DORM and individual differences: ageing, Parkinsons.

# Acknowledgements, and thanks for listening!

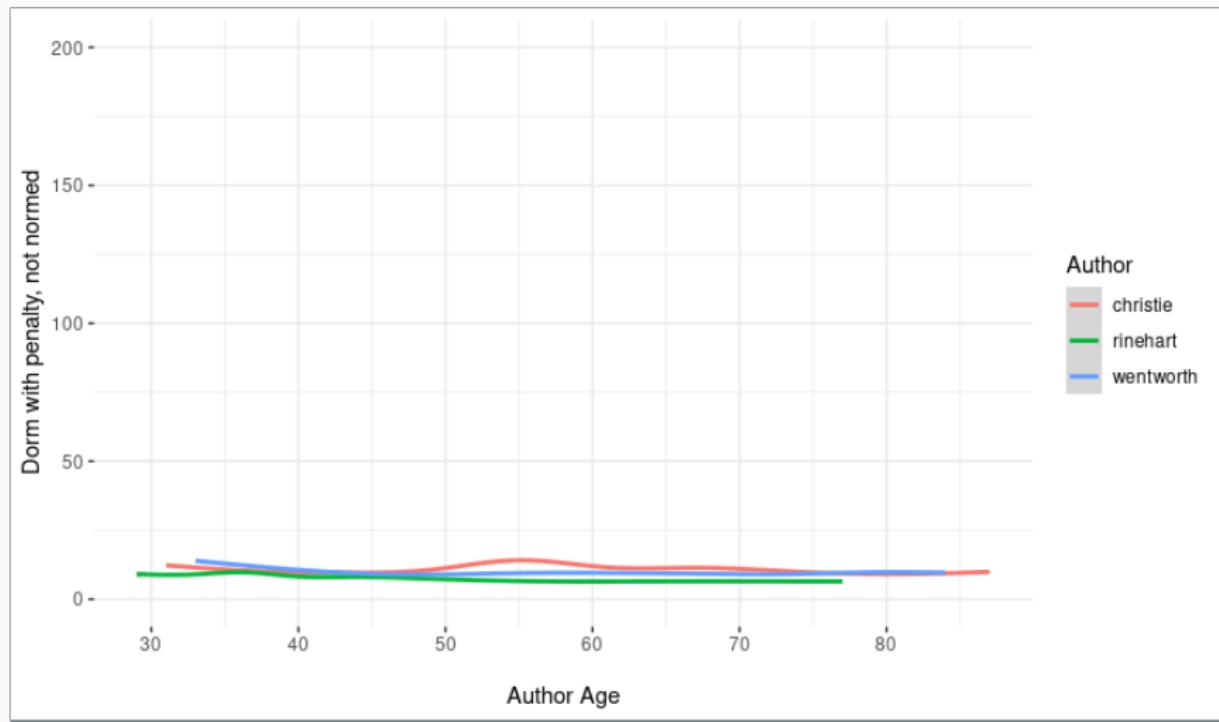


Thank you to my collaborators, audiences at NYU, Saarbrucken,  
Manchester and the late great Anthony Kroch.

**Questions?**

## More Exploratory Work: Anything to See Here?

3 Writers; 200,000-500,000 sentences each



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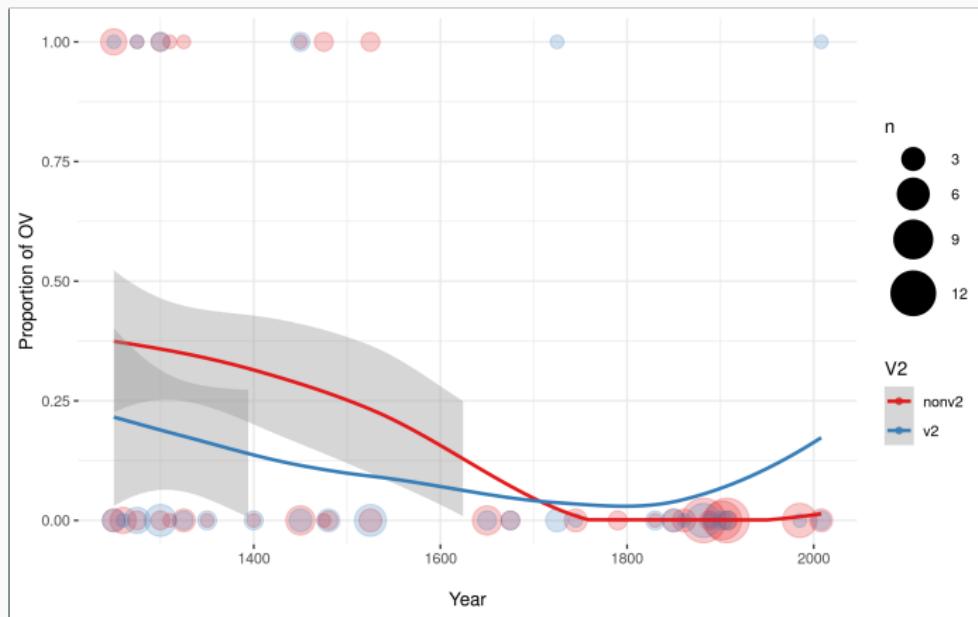
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[http://www.linguist.is/icelandic\\_treebank](http://www.linguist.is/icelandic_treebank))

## Study 2 Results: OV disfavoured by adjunct-fronting through OV-to-VO



## Study 2 Results: Count data for V2 in Icelandic

