



# Syntactic Planning and the Information Threshold

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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 (a crash course)

What It's For: Noise Resistance

What It Does: Syntactic Planning

Information theoretic Effects in OV to VO

Diachronic Study 2: Adding V2

Discussion

## Information Uniformity and Language (a crash course)

What It's For: Noise Resistance

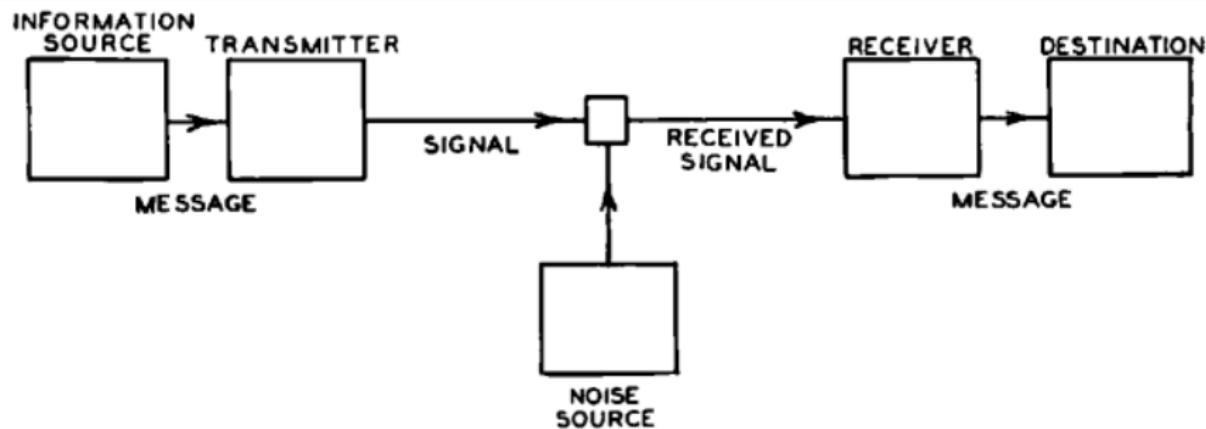
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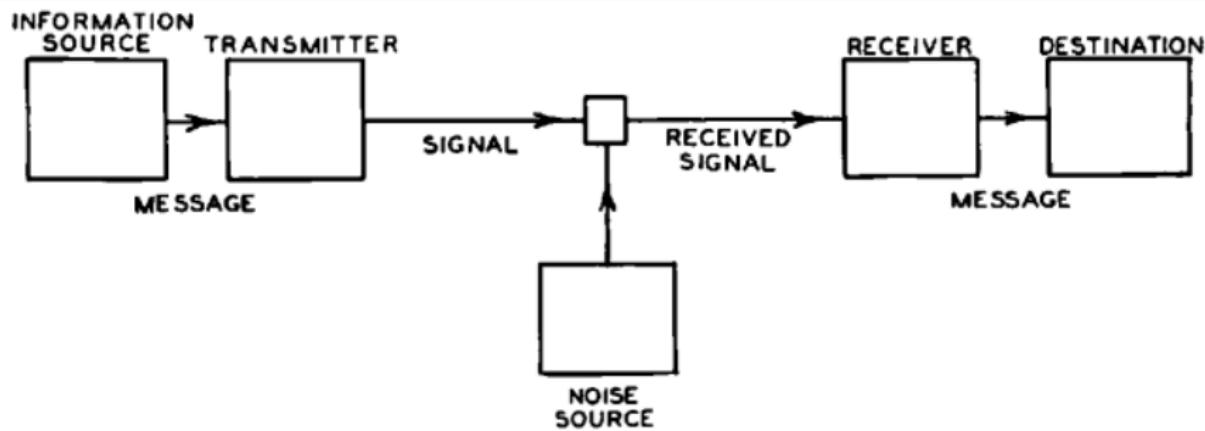
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# Crash course: Information theory and language



# Crash course: 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).

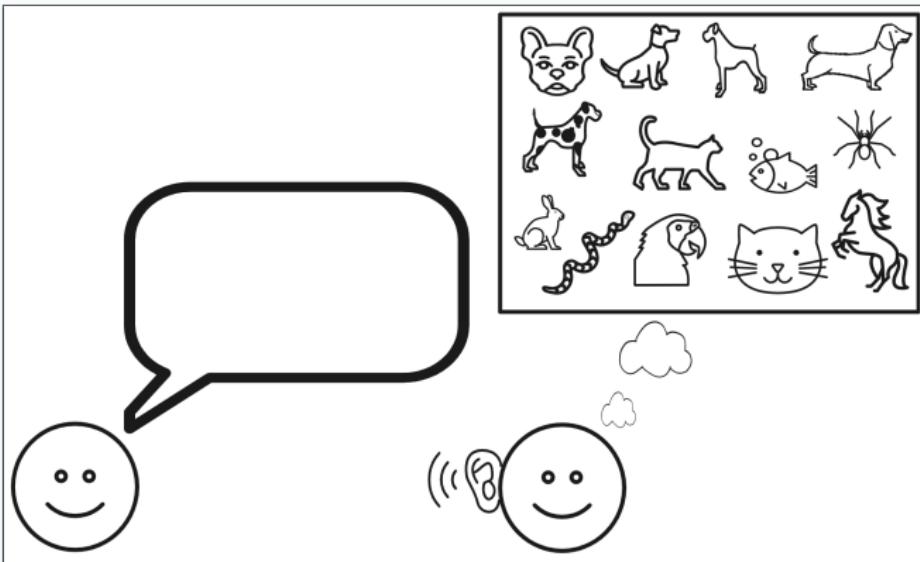
# Information content of words

Information Theory quantifies information and describes how communication systems work (Shannon, 1948).

**Key point for today:**

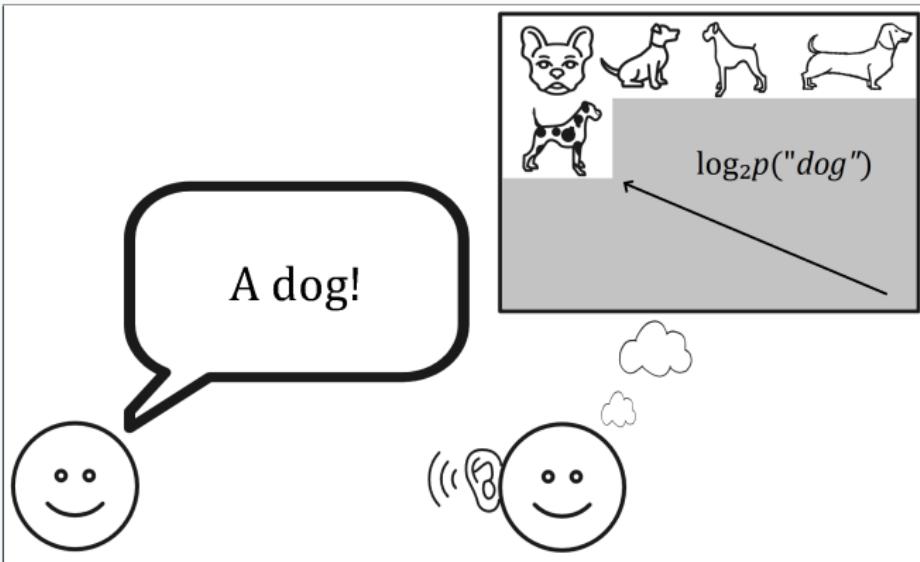
- ⇒ Low frequency words are high information,  
high frequency words are low information.

# Information content of words



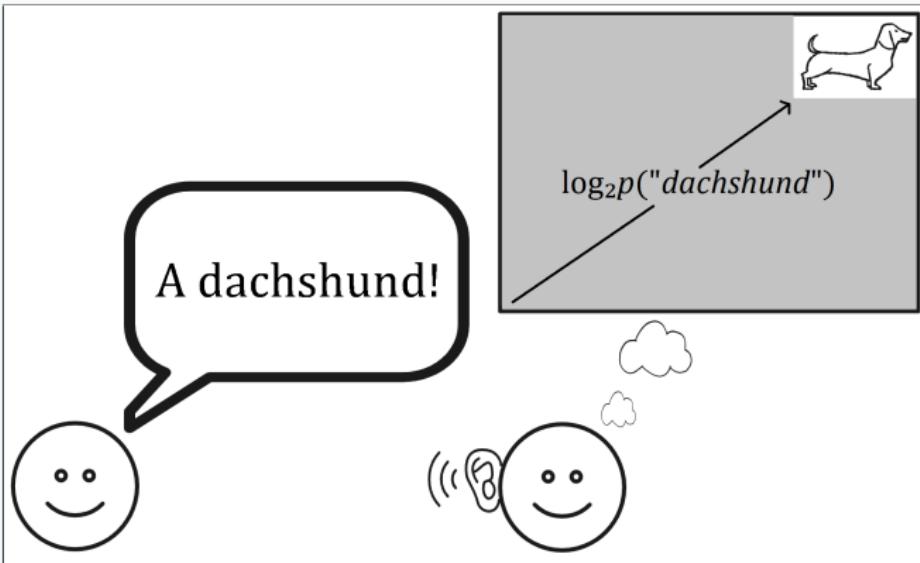
Receiver begins with a **set of expected outcomes** that could result from the message they receive. This set of expected outcomes is the amount of **uncertainty** they have about the message.

# Information content of words



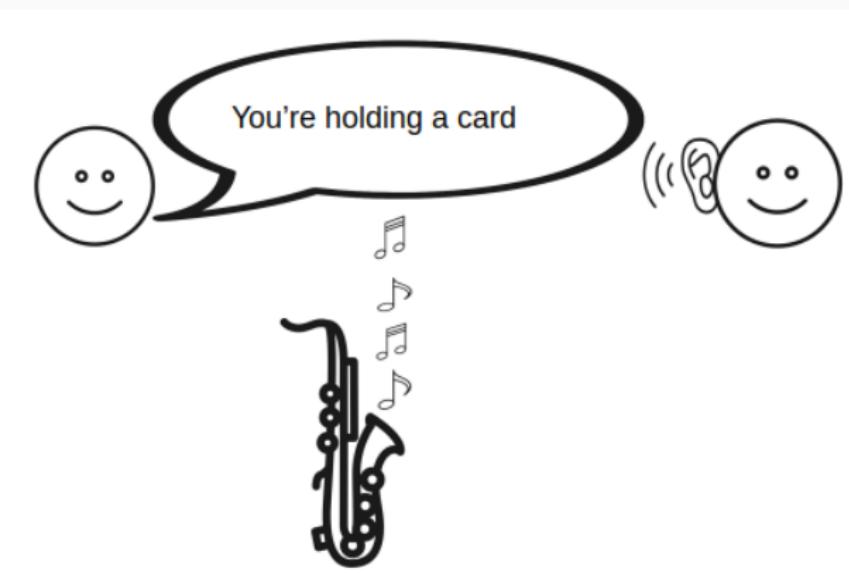
Sender uses a word that **reduces the receiver's uncertainty** by some amount proportional to the word's frequency. Here, the word is relatively frequent.

# Information content of words

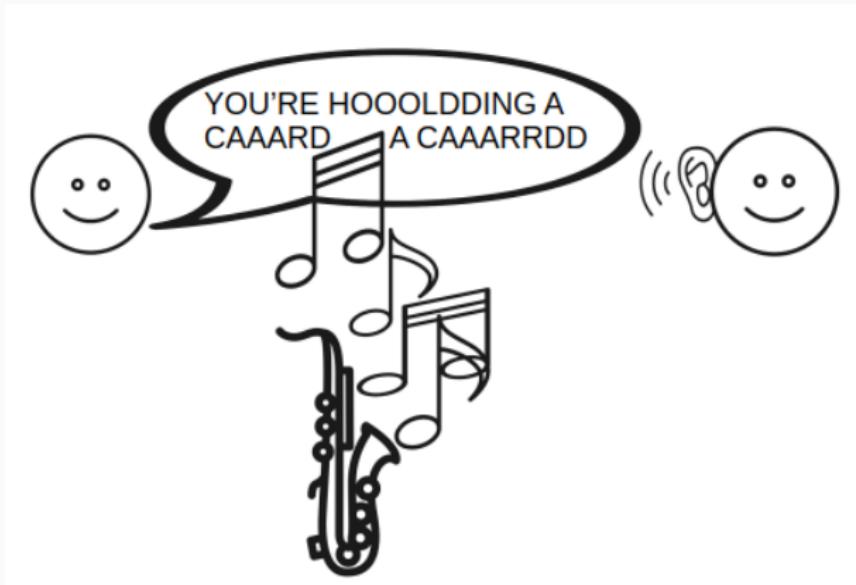


The more infrequent the word, the more uncertainty is reduced. This is the same thing as saying **the more infrequent the word, the more information it has.**

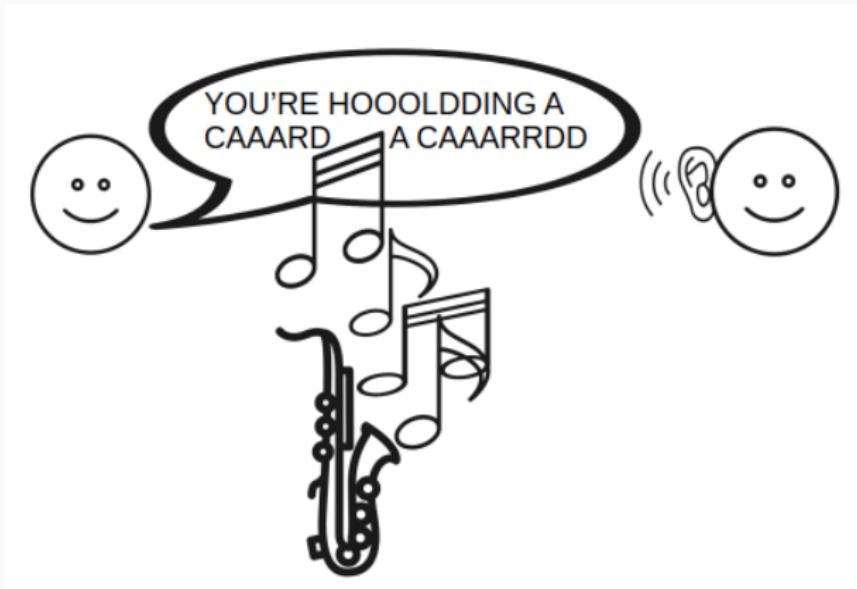
## Noise and redundancy



## Noise and redundancy



## Noise and redundancy



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

# Information Uniformity and Language (a crash course)

**What It's For: Noise Resistance**

What It Does: Syntactic Planning

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## Reordering for uniformity: functional for noise resistance?

- It has been established that redundancy confers noise resistance (Shannon, 1948)
- Does reordering elements also confer noise resistance?

# Reordering for uniformity: functional for noise resistance?

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- Does reordering elements also confer noise resistance?



Cognition  
Volume 214, September 2021, 104754



## Noise resistance in communication: Quantifying uniformity and optimality

Christine Cuskley, Rachael Bailes, Joel Wallenberg

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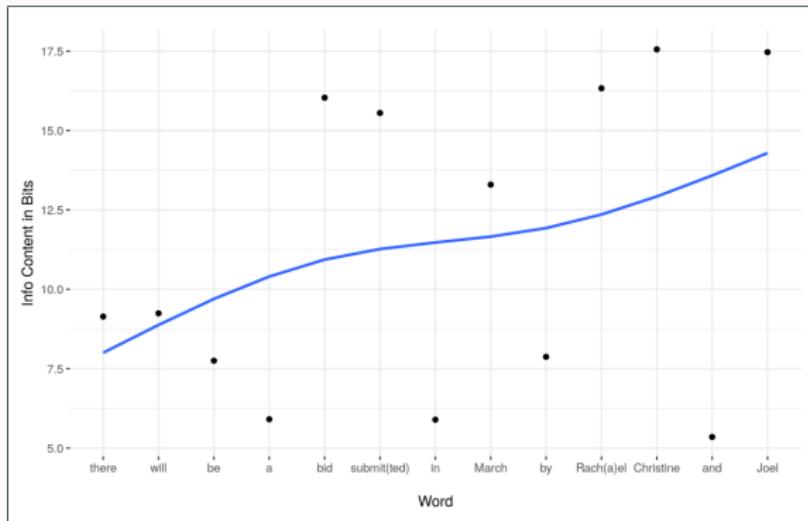
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<https://doi.org/10.1016/j.cognition.2021.104754>

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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.



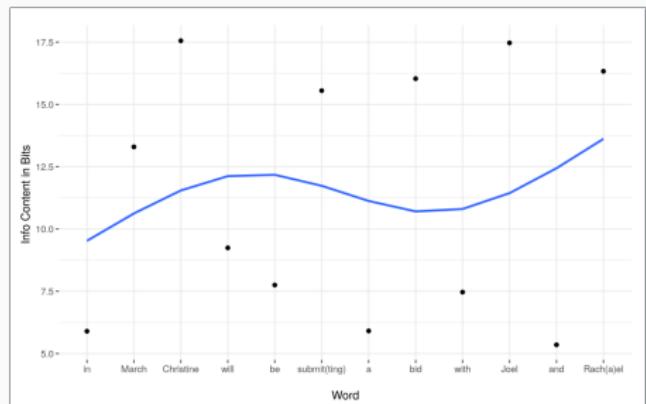
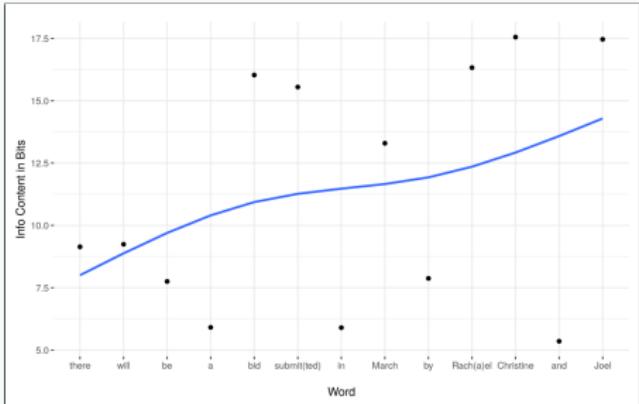
## Uniformity of information distributions

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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).

# 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 et al., 2021).



We can measure how uniform an information distribution is (Cuskley et al., 2021) - details available in the Q&A upon request!

## 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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	<b>6.47</b>				

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Sample variance of rolling means = 1.33 bits

**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.

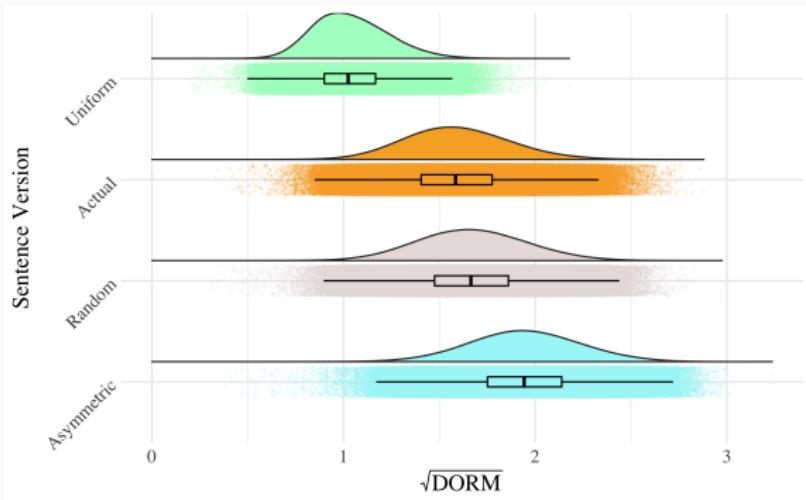
# UIDO: Uniform information density optimization

- 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

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

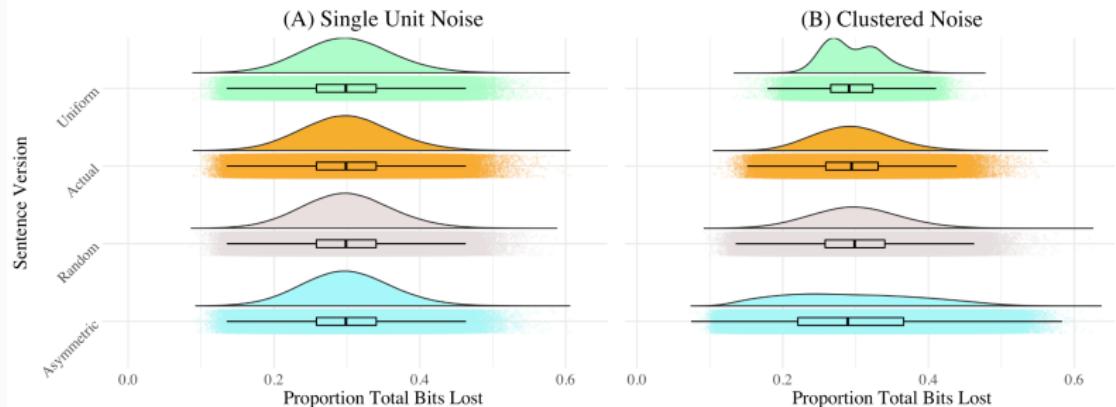
## Single-unit and clustered noise

- 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

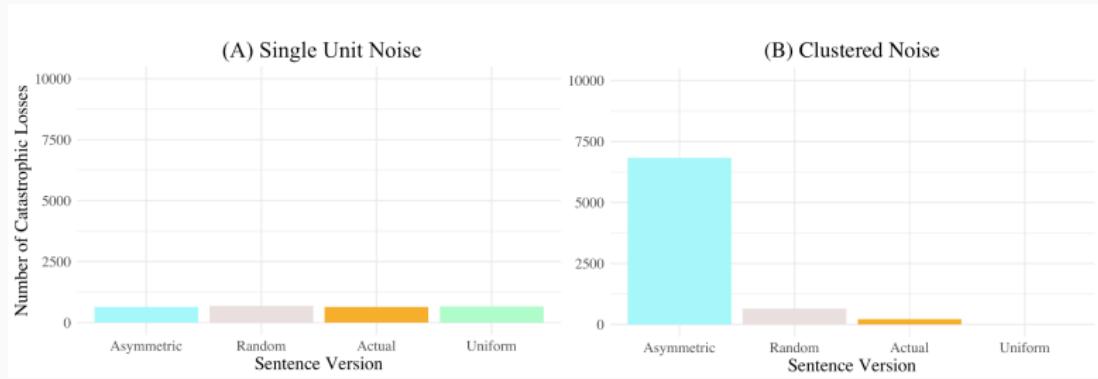
- Single-unit noise: three random single units “knocked out” per distribution per trial.
- Clustered noise: three sequential units “knocked out” per distribution per trial.
  - More similar to naturally occurring noise events that span multiple linguistic units.
- Knocked out item positions matched across 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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- Hyperdispersing information prevents catastrophic losses,
- ...particularly where continuous noise spans multiple categorical linguistic units.
- More uniform orders may decrease overall info loss compared, probably because of Zipfian vocabularies.

## Interim Speculations: Language and “Ruin”

- Thresholds: metaphor of insurance reserving and underwriting.
- Signalling happens between every linguistic level, as does noise.  
**acoustic → segmental/allophonic → phonemic → morphemic  
→ morphosyntactic → propositional/utterance-function**
- Humans make use of inference at every level, so do not need perfect mutual information, but do need some.

## Information Uniformity and Language (a crash course)

What It's For: Noise Resistance

**What It Does: Syntactic Planning**

**Information theoretic Effects in OV to VO**

Diachronic Study 2: Adding V2

Discussion

# 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 CRE in the English and Icelandic OV to VO changes

# CRE in English and Icelandic OV to VO



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 et al., 2021) predicted a previously undetected CRE 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

- Syntactic constituents (and their lexical content) occur at different frequencies, which means they have different information content values.

# English and Icelandic OV to VO

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

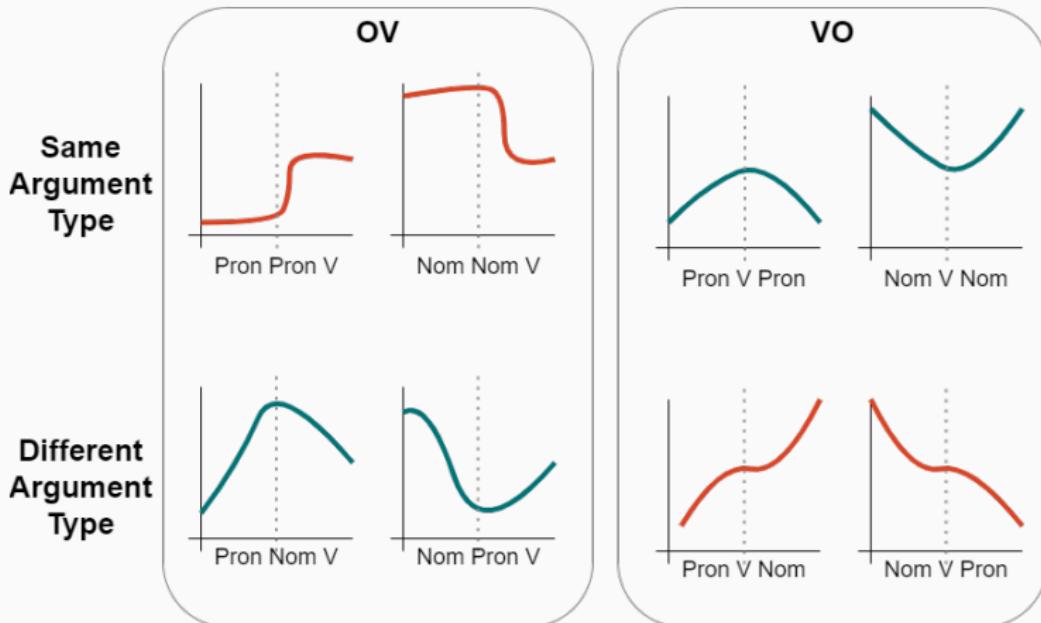
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- We can therefore make predictions about the ordering of elements that speakers will prefer, when they have a choice - i.e., constituent orders that yield more uniform information distributions.

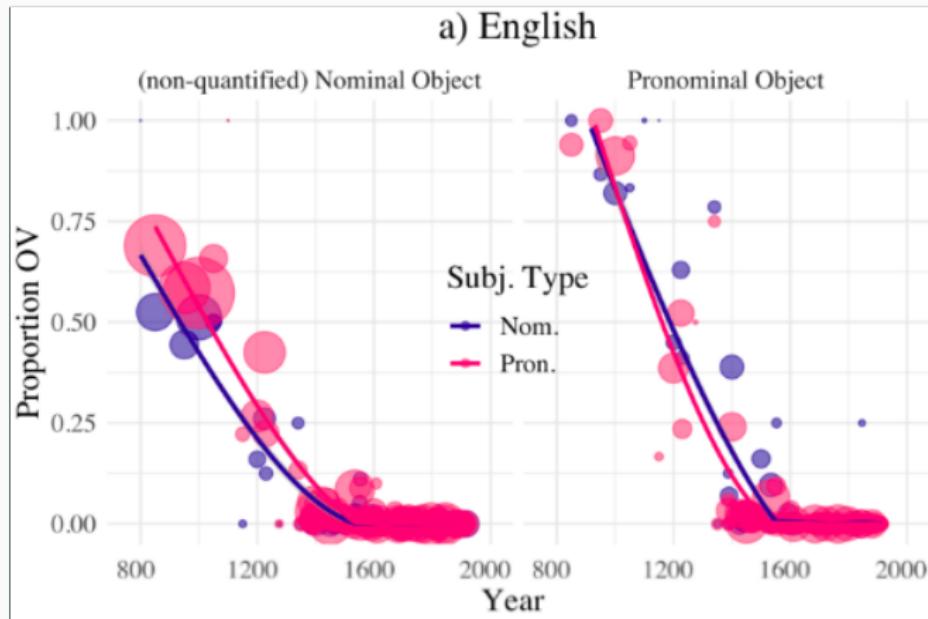
# Predictions



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

## Results:

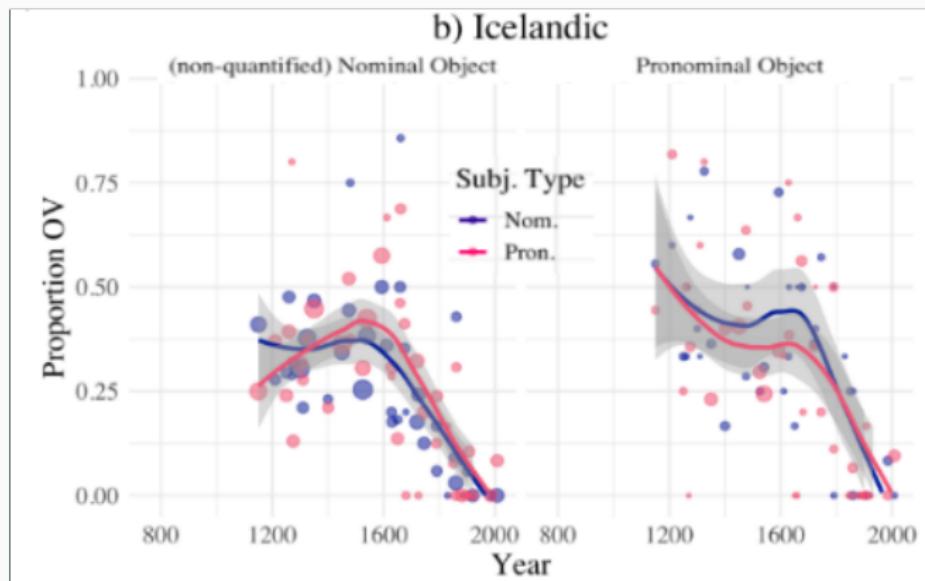
OV is favoured when Subject and Object are different types



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

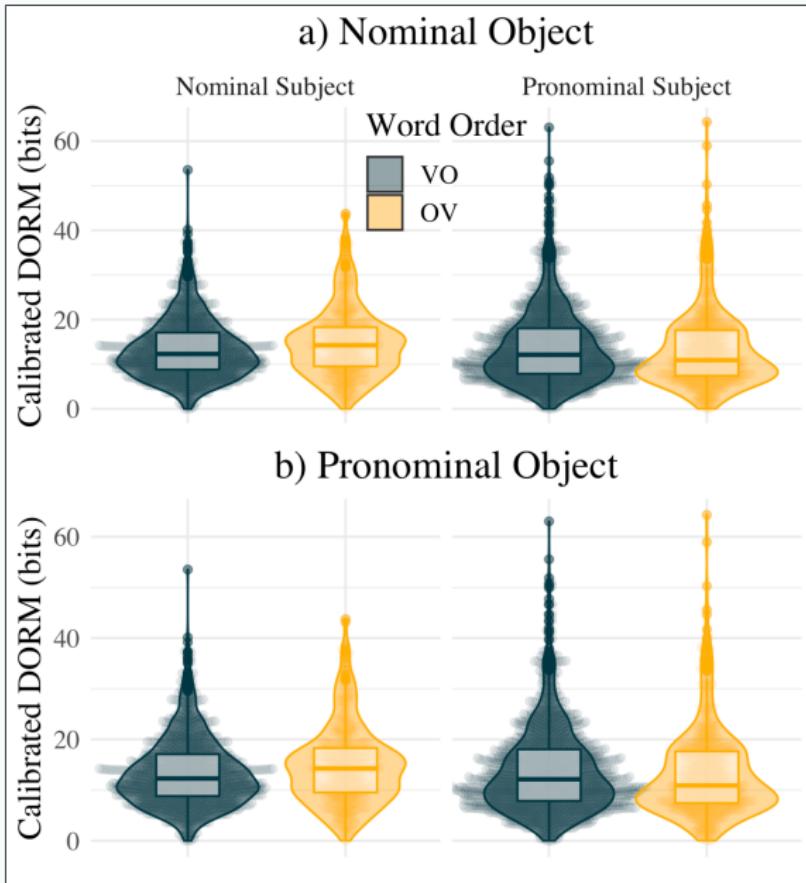
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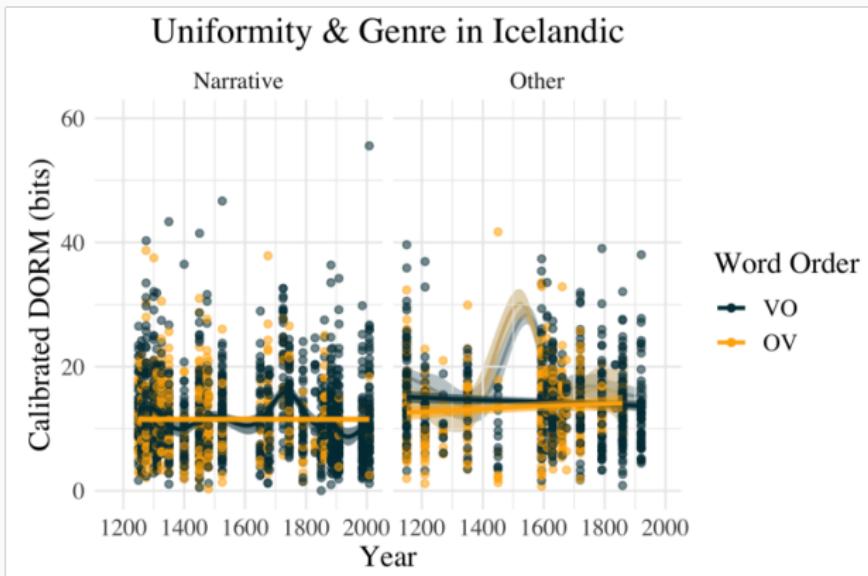
*IcePaHC (Wallenberg, Ingason, Sigurðsson, & Rögnvaldsson, 2011)*

## Results: DORMs by Obj, Sbj Type



## Results: A threshold?

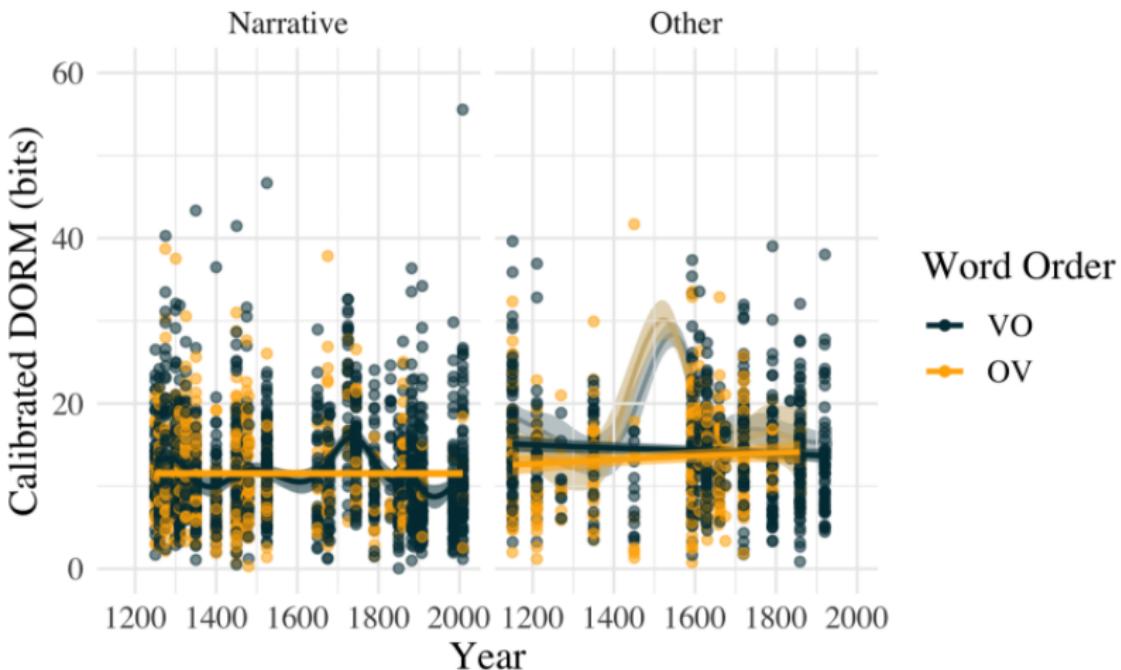
Information density remains constant



- The average uniformity of sentences is constant across the history of Icelandic.

...but the outlier indicates a complex planning problem

## Uniformity & Genre in Icelandic



## Information Uniformity and Language (a crash course)

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### Diachronic Study 2: Adding V2

Discussion

## Study 2: Adding V2

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- 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” (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; 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**

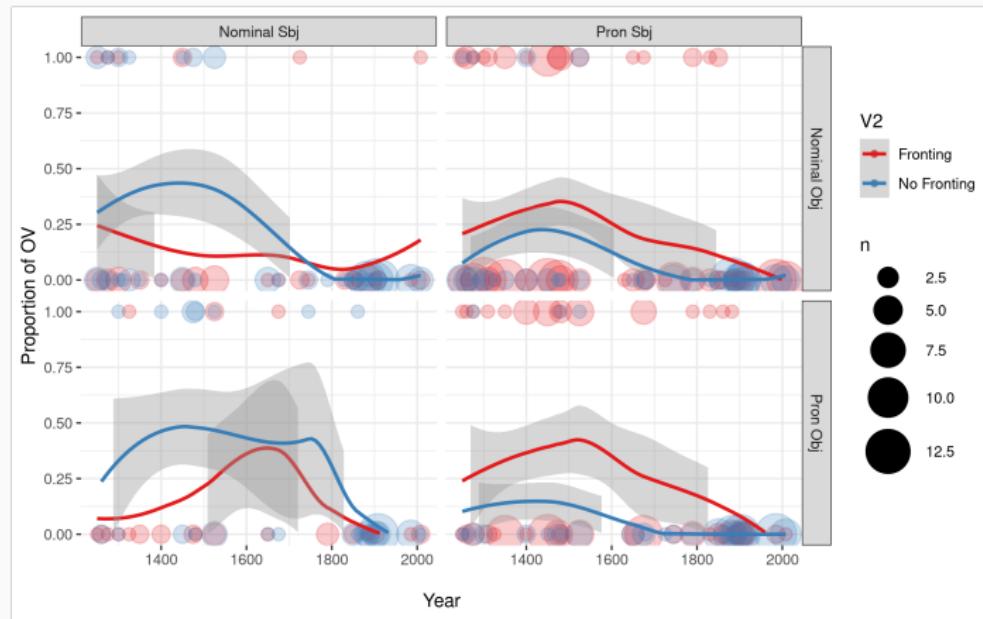
## Study 2: Adding V2

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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:

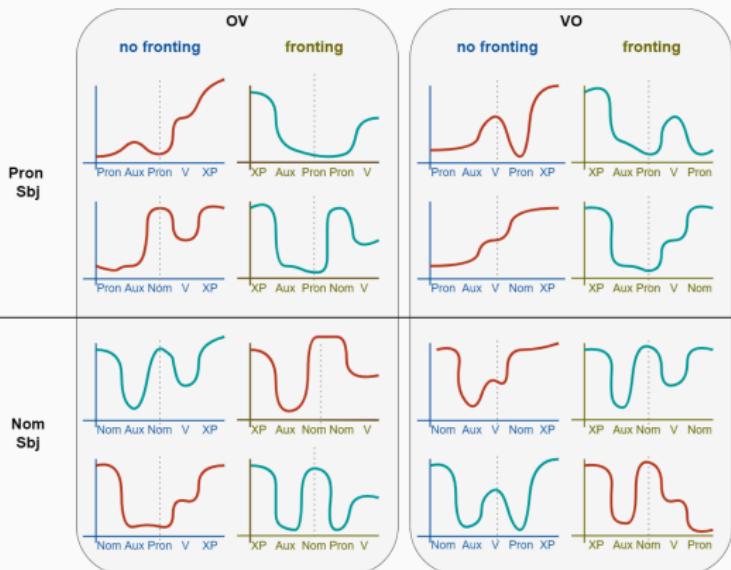
# Is V2 a “context” for OV/VO (in the CRE sense)?



- If V2 were a conditioning context for OV/VO, we'd expect a CRE.
- This *may* apply to Pron Sbj + Nom Obj, but not in other cases.
- Predictions not borne out if V2-fronting conditions choice of OV/VO.

# Study 2 Predictions

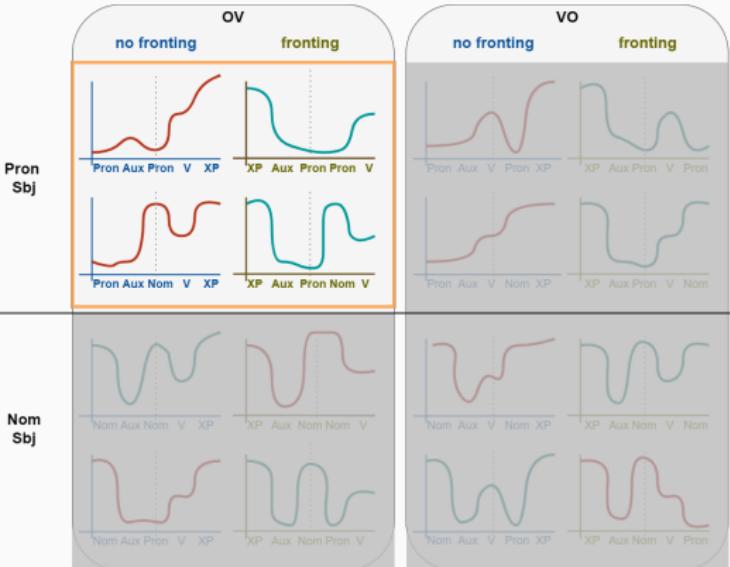
Speakers deploy fronting when it yields more uniformity



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:

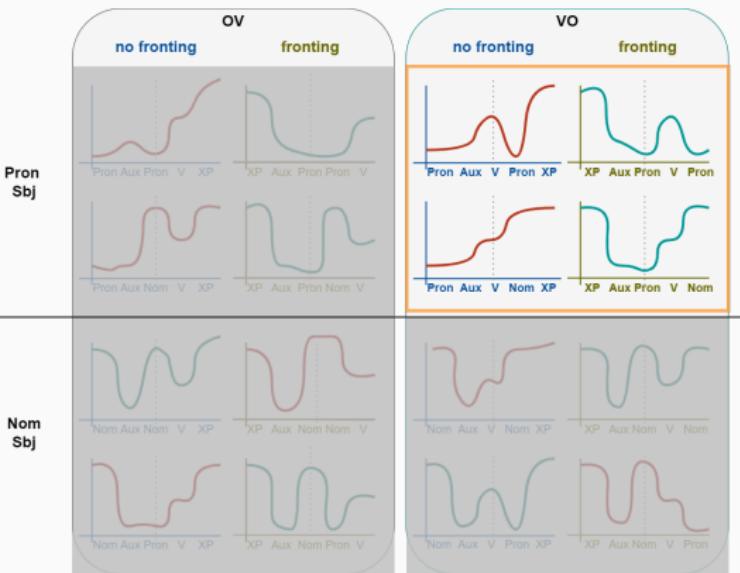
- Fronting helps balance out the unavoidable 3-unit informational troughs (Pron-Aux-Pron & Aux-Pron-Pron)

+ Nom Obj:

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

# Study 2 Predictions

## Given VO and Pron Sbj:



+ Pron Obj:

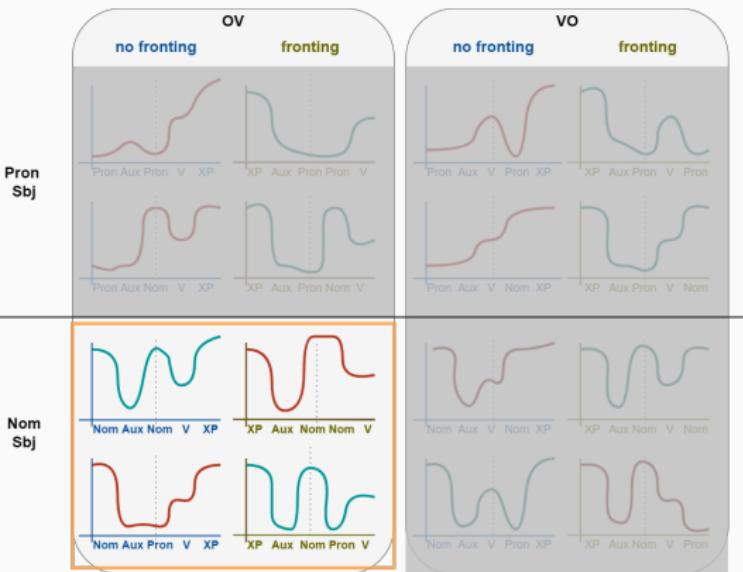
- Fronting may yield a bit more uniformity

+ 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:

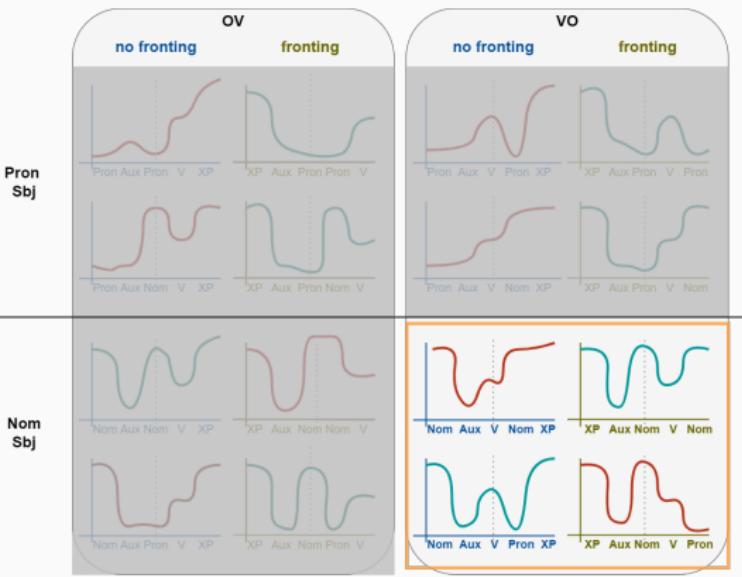
- Fronting yields 2-unit informational peak (Nom-Nom), so *may* be disfavoured

+ 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:

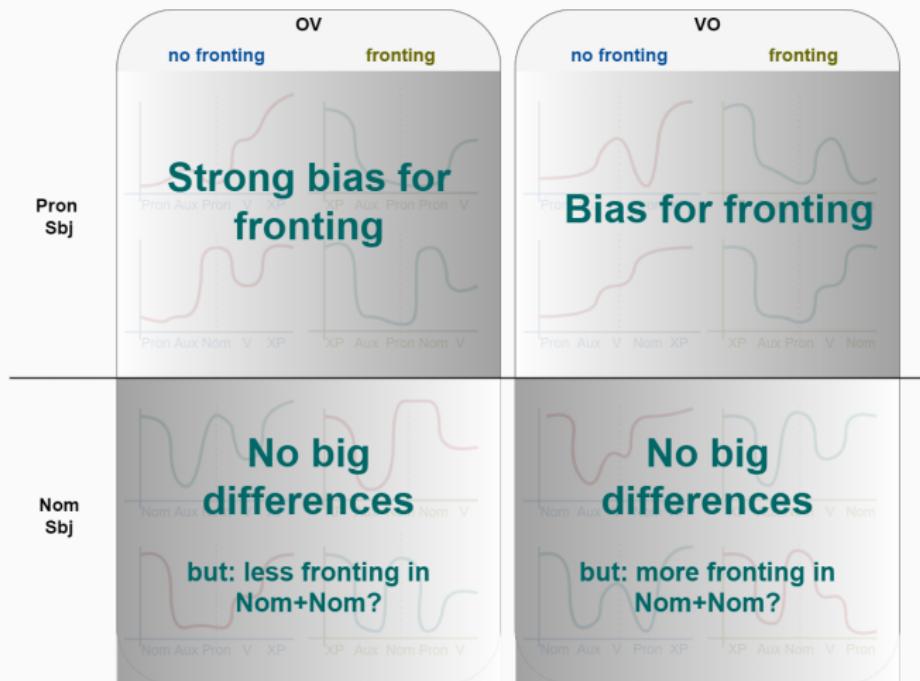
- Fronting *may* yield slightly more uniform distribution (by avoiding clustered peak of Nom+XP)

+ Pron Obj:

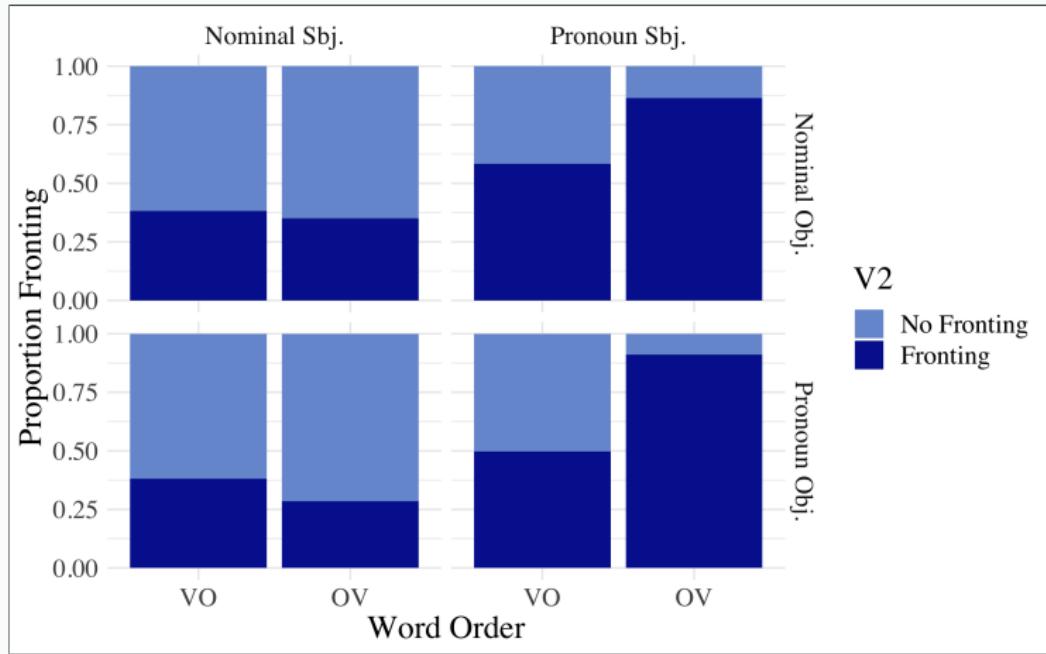
- Non-fronting might be more symmetrical

# Study 2 Predictions

Speakers deploy fronting when it yields more uniformity



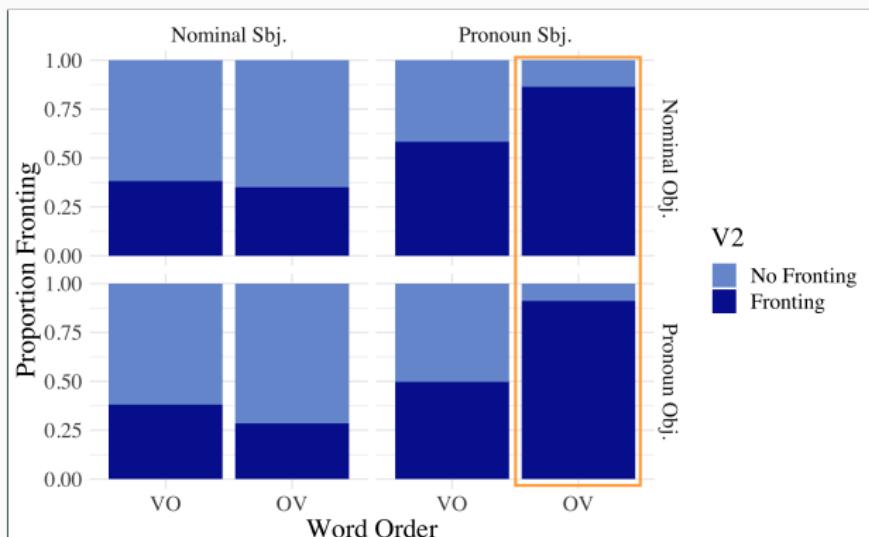
## Study 2 Results



- 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

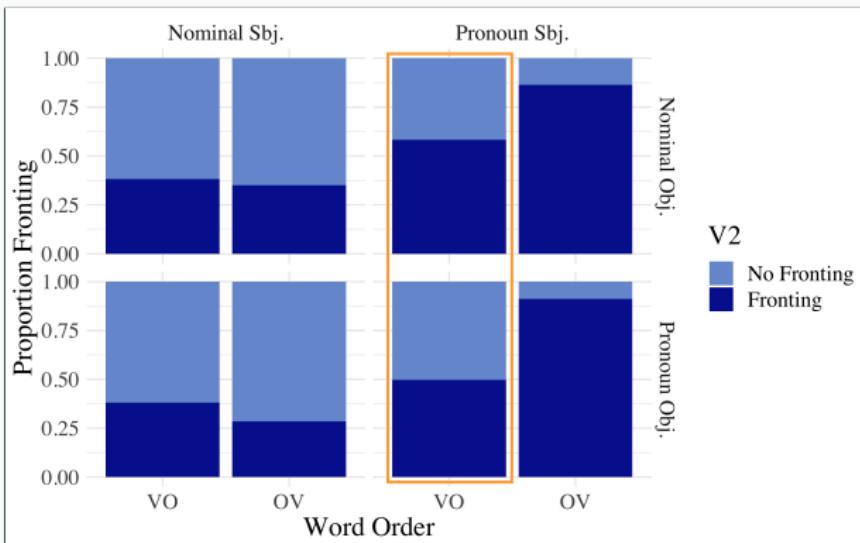
Two pressures for fronting



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

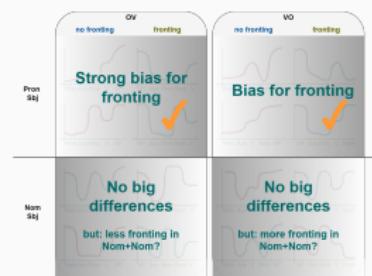


# Study 2 Results: Given VO and Pron Sbj

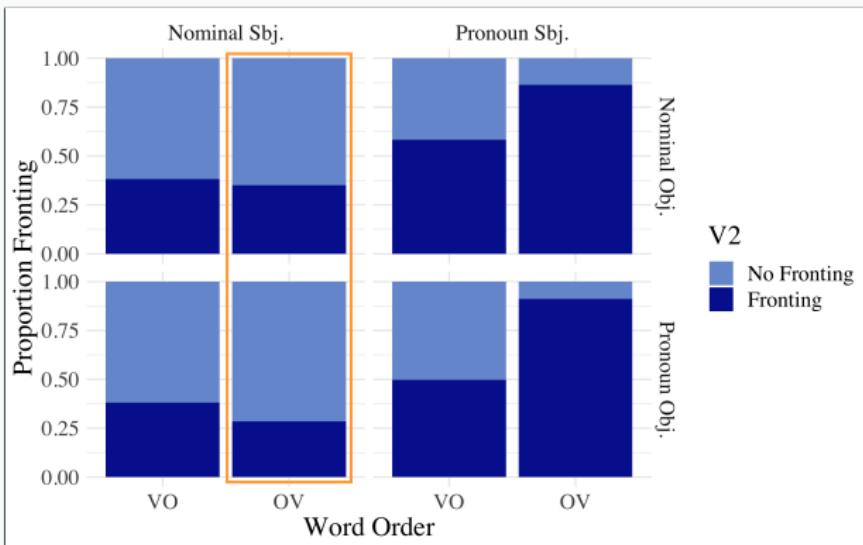


## Bias for fronting

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



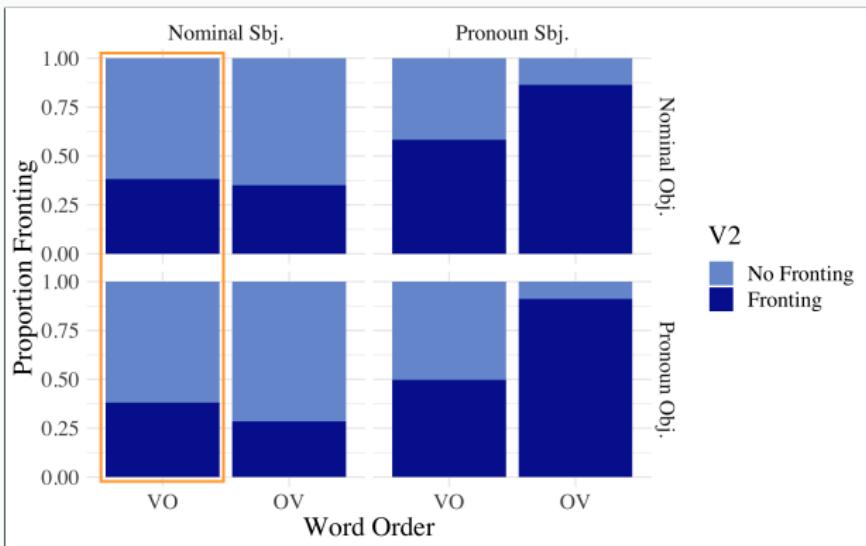
# Study 2 Results: Given OV and Nom Sbj



- 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



## Information Uniformity and Language (a crash course)

What It's For: Noise Resistance

What It Does: Syntactic Planning

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### Discussion

## Theoretical Implications

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- As in Study 1, Study 2 shows speakers use the syntactic resources available to optimize for information uniformity in planning.

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- The way they do so suggests:
  1. Speakers select lexical array first (incl. Obj, Sbj types).
  2. Speakers then select right- or left-headed vP/VP.
  3. Then, movement  
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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.

## Conclusions: uniformity and thresholds

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- **What It's For:** prevents catastrophic losses, which could lead to loss of proposition/utterance-level meaning.

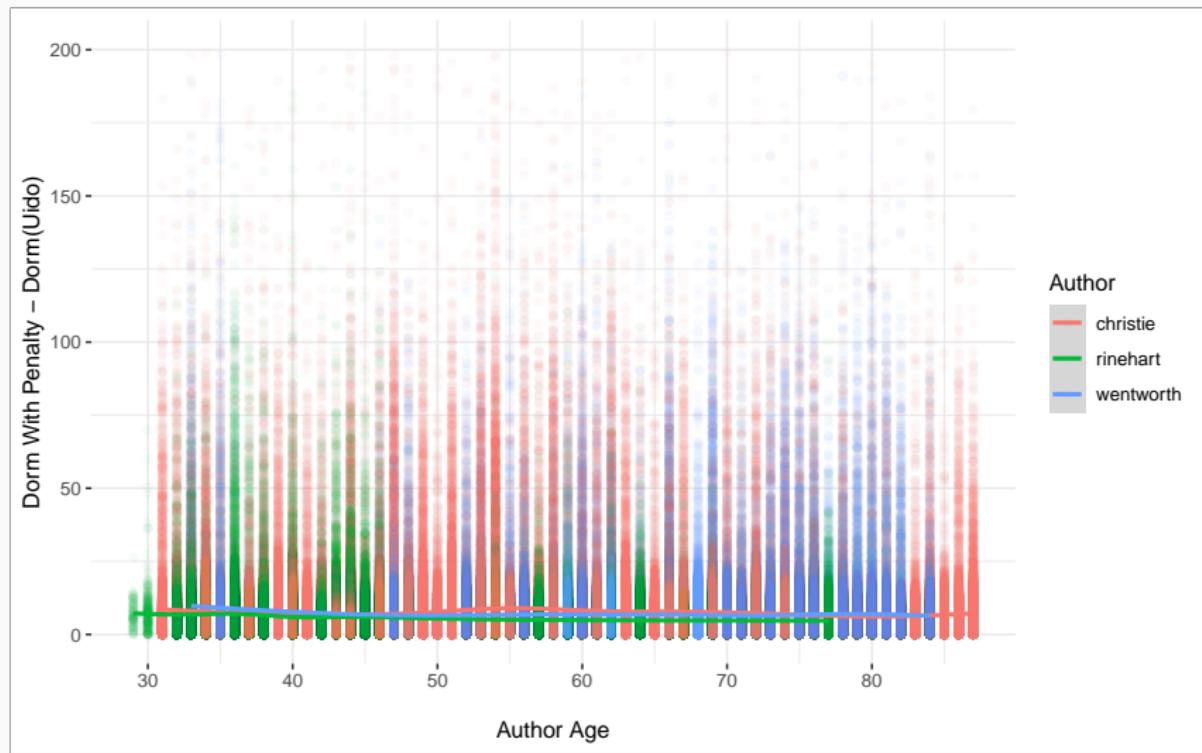
## Conclusions: uniformity and thresholds

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- **What It's For:** prevents catastrophic losses, which could lead to loss of proposition/utterance-level meaning.
- **What It Does:** causes speakers to use their syntactic resources to disperse information as uniformly as possible across a sentence.
- Presumably there is a threshold for allowable losses, and so a threshold for sentence DORM.
- **Other Implications:** derivational ordering effects, where sbj/obj type and perhaps headedness precede movement.
- **Exploratory Work:** syntactic planning and ageing...

# Very Rough Work on 3 Writers

200,000-500,000 sentences each



# Acknowledgements, and thanks for listening!

Questions?



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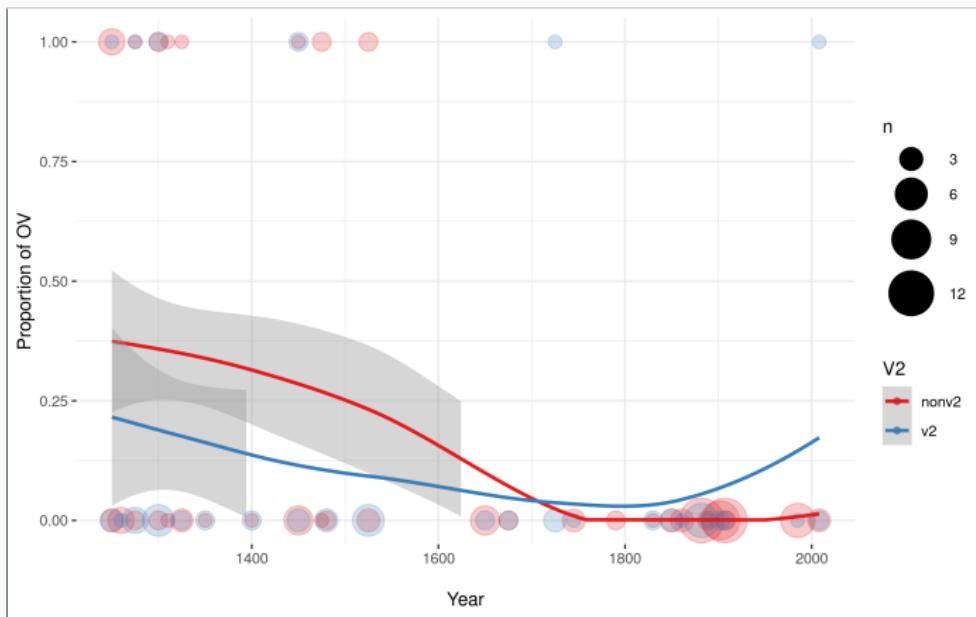
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[http://www.linguist.is/icelandic\\_treebank](http://www.linguist.is/icelandic_treebank))

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



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

