Linguistics, mathematics and the Bible

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Introduction

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Motivations

- I come from computer science
- Why do I think linguistics is interesting?
- How do I look at languages?

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Linguistics: what and why?

- Language: a mapping, thoughts $\Longleftrightarrow$ sequences of symbols
- The world contains many such mappings, evolving through:
  - inheritance (learned from parents)
  - contact (influenced by surroundings)
  - innovations (adaptable to new situations)
- Constant pressure from cognitive, physiological and efficiency constraints

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Linguistics: why should I care?

- Language evolution is a stochastic process
- Roughly independent Markov chains
  (closer approximation on a small and remote island)
- Transitions in the process depend on:
  1. migration
  2. contact between peoples (trade, cultural influence, etc.)
  3. societal structure
  4. people being creative
  5. the human brain (and mouth, and ears)
- The world's languages make up a sample from this process
- **We can make inferences about the factors above**

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Languages today

- About 7 000 languages exist today
- A human has an *idiolect*, a personal thought–symbol mapping
- A language is a cluster of mutually intelligible idiolects
- That is, $L_i \approx L_j \equiv L_i^{-1}(L_j(x)) \approx x$
- Somewhat subjective, see Eq. (1)

$$\boxed{\text{language} = \text{dialect} + \text{army} + \text{navy}} \tag{1}$$

Fundamental theorem of language politics

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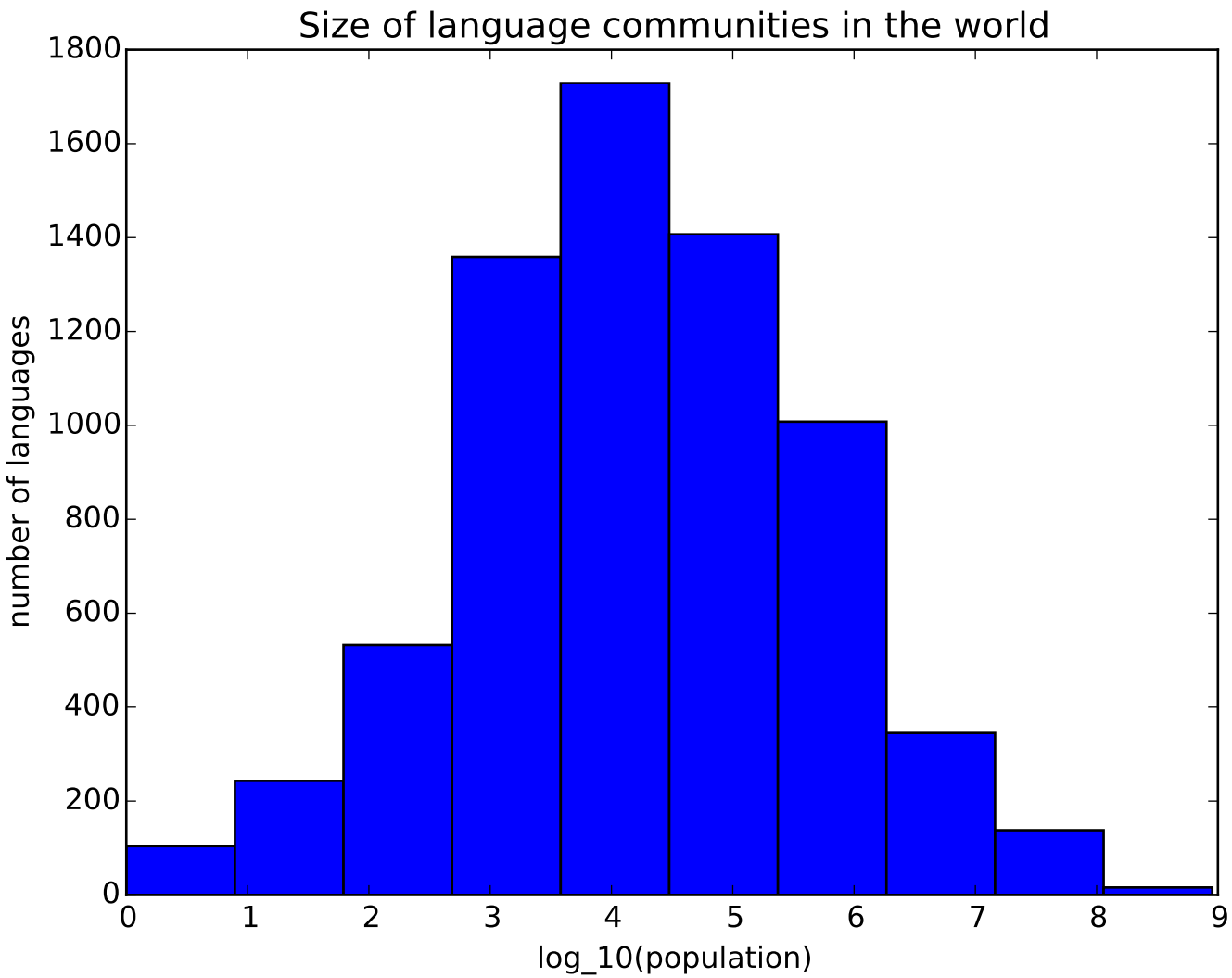
Number of speakers



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Language structure

- Abstract mappings are not too useful
- Linguistics is about peeking into these mappings
- Multiple levels are used:
  - Morphology (word formation rules, $\approx$ linear)
    morphemes, smallest meaning-bearing unit
  - Syntax (sentence formation rules, $\approx$ hierarchical)
    words, largest non-hierarchical unit
    phrases, non-leaf nodes in the tree
  - Semantics (the "thoughts" link)

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Syntax and morphology

- Linguistic symbols (morphemes/words) form categories
- nouns (cat, rat, hat), number markers (cat**s**), etc.
- Syntax/morphology rules how categories are combined
- That is, they constrain the *range* of L_i
- Described formally e.g. as rewriting rules
- A language is associated with a set of such rules

English	Mandarin
$\mathrm{VP} \rightarrow \mathrm{V\ NP}$	$\mathrm{VP} \rightarrow \mathrm{V\ NP} \mid \mathrm{ba\ NP\ V}$
$\mathrm{V} \rightarrow \mathrm{drink}$	$\mathrm{V} \rightarrow \mathrm{he}$
$\mathrm{N_{plu}} \rightarrow \mathrm{N\ s}$	$\mathrm{N_{plu}} \rightarrow \mathrm{N}$
...	...

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Semantics

- Symbols (and their combination) map to "thoughts"
- Thoughts are fluid, English *cat* captures lots of variation
- A symbol maps to a volume in a semantic space
- *Kitten* maps to a subset of the *cat* space
- *Abyssinian* to another (partially overlapping) subset
  ... and also to other things from Ethiopia
- The structure of this mapping differs across languages
  (e.g., not all languages have kittens)

Source: Wikipedia

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Form

- The forms of linguistic symbols (morphemes) also evolve
- No coincidence *cat*, *Katze*, *katt* etc. sound similar
- In spoken languages, near-arbitrary
- Not so in signed languages!
- Still subject to physiological constraints
- Good source of evolutionary evidence

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Linguistic typology

- The study of linguistic variation
- Examples of interesting differences:
  - Does L use the rule $\mathrm{N}_{\mathrm{plu}} \to$ N x or $\mathrm{N}_{\mathrm{plu}} \to$ x N?
  - Does L use the rule NP $\to$ Adj N and/or NP $\to$ N Adj?
  - Is there any symbol used by L that maps to the semantic spaces of both *tree* and *fire*?

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Lexical typology

- How do the symbols of a language partition the semantic space?

Concept	English	Swedish	Mandarin
Father's older brother	uncle	farbror	daye
Father's younger brother	uncle	farbror	shu
Mother's older brother	uncle	morbror	jiu
Mother's younger brother	uncle	morbror	jiu

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Automated linguistics

- Define lots of features where languages do differ
- Describe each language in terms of its feature values
- Data $\rightarrow$ math $\rightarrow$???

Existing attempts

- Automated Similarity Judgement Program (ASJP)
  - words for 40 concepts in nearly all languages
  - mostly useful for studying evolution of form
  - and for checking which semantic concepts overlap in form
  - and for investigating cognitive/physiological constraints
- World Atlas of Language Structures (WALS), GramBank
  - syntax/morphology in lots of (up to a thousand) languages
  - evolution of syntax/morphology

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Data... from where?

- Just one problem, how to get this data?
  1. Lots and lots of manual work
  2. Automation

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Parallel texts

- Translated text, e.g. the Bible has 2000+ translations
- The text contains multiple sentences x_j
- Each sentence is encoded by multiple languages L_i
- $n \approx 8\ 000$, $m \approx 1500$

$$\begin{bmatrix} L_1(x_1) & L_1(x_2) & \dots & L_1(x_n) \\ L_2(x_1) & L_2(x_2) & \dots & L_2(x_n) \\ \vdots & \vdots & \ddots & \vdots \\ L_m(x_1) & L_m(x_2) & \dots & L_m(x_n) \end{bmatrix}$$

There must be a good way to use this structure...

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Extracting data

- Let $\mathbf{x}_{\text{house}}$ be the sentences about houses
- Which symbols are most overrepresented in $\{L_i(x_j) | x_j \in \mathbf{x}_{\text{house}}\}$?
  Now we know the symbol for house in each language!
- What about $\mathbf{x}_{\text{small}}$ (referring to houses)?
  ...and for small!
- What is the order of these symbols?
  ...now we know if NP $\rightarrow$ N Adj or NP $\rightarrow$ Adj N
- Is something appended or prepended to the *house* symbol when multiple houses are referred to?
  ..now we know if $\text{N}_{\text{plu}} \rightarrow$ N x or $\text{N}_{\text{plu}} \rightarrow$ x N

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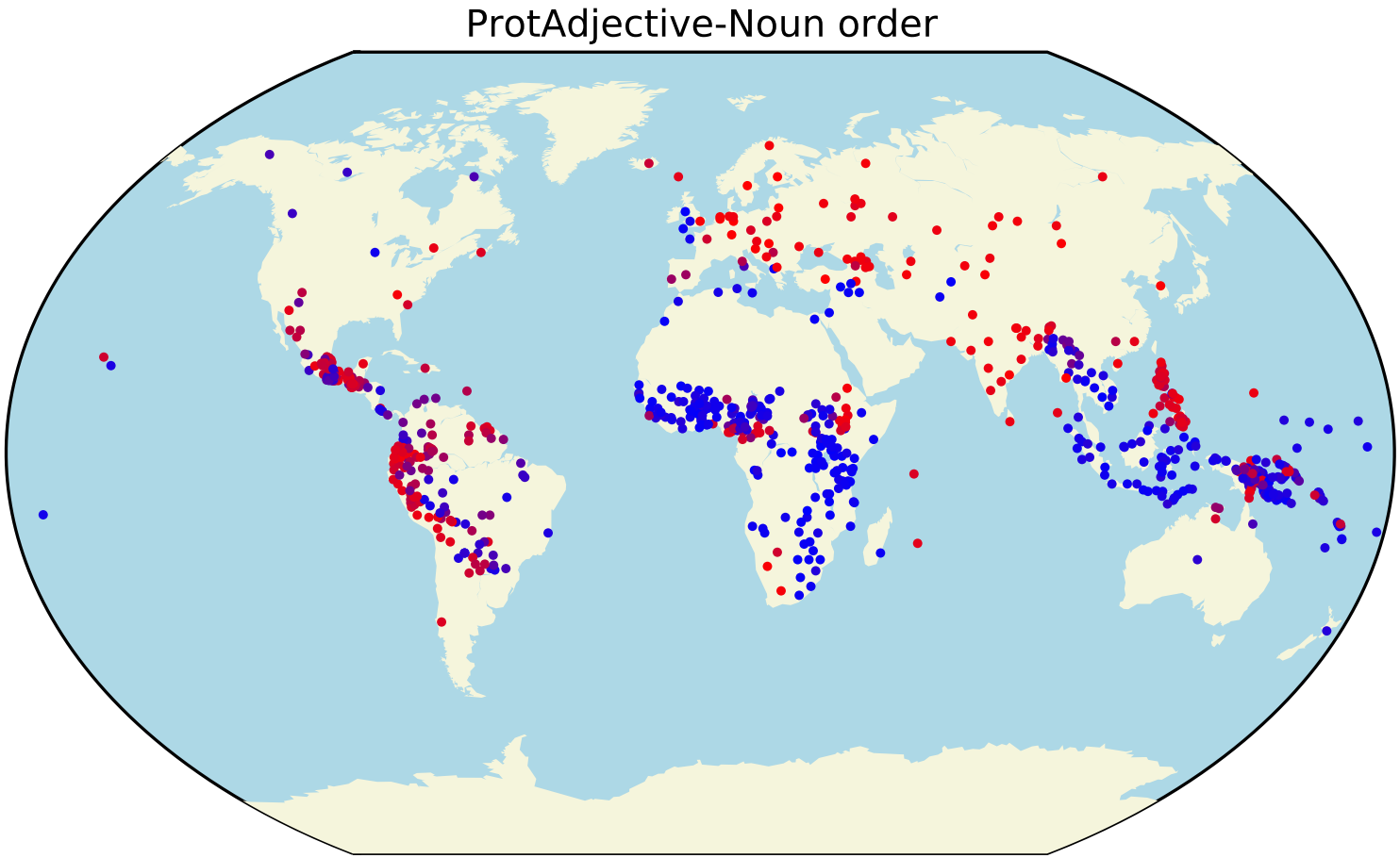
NP → Adj N or NP → N Adj?



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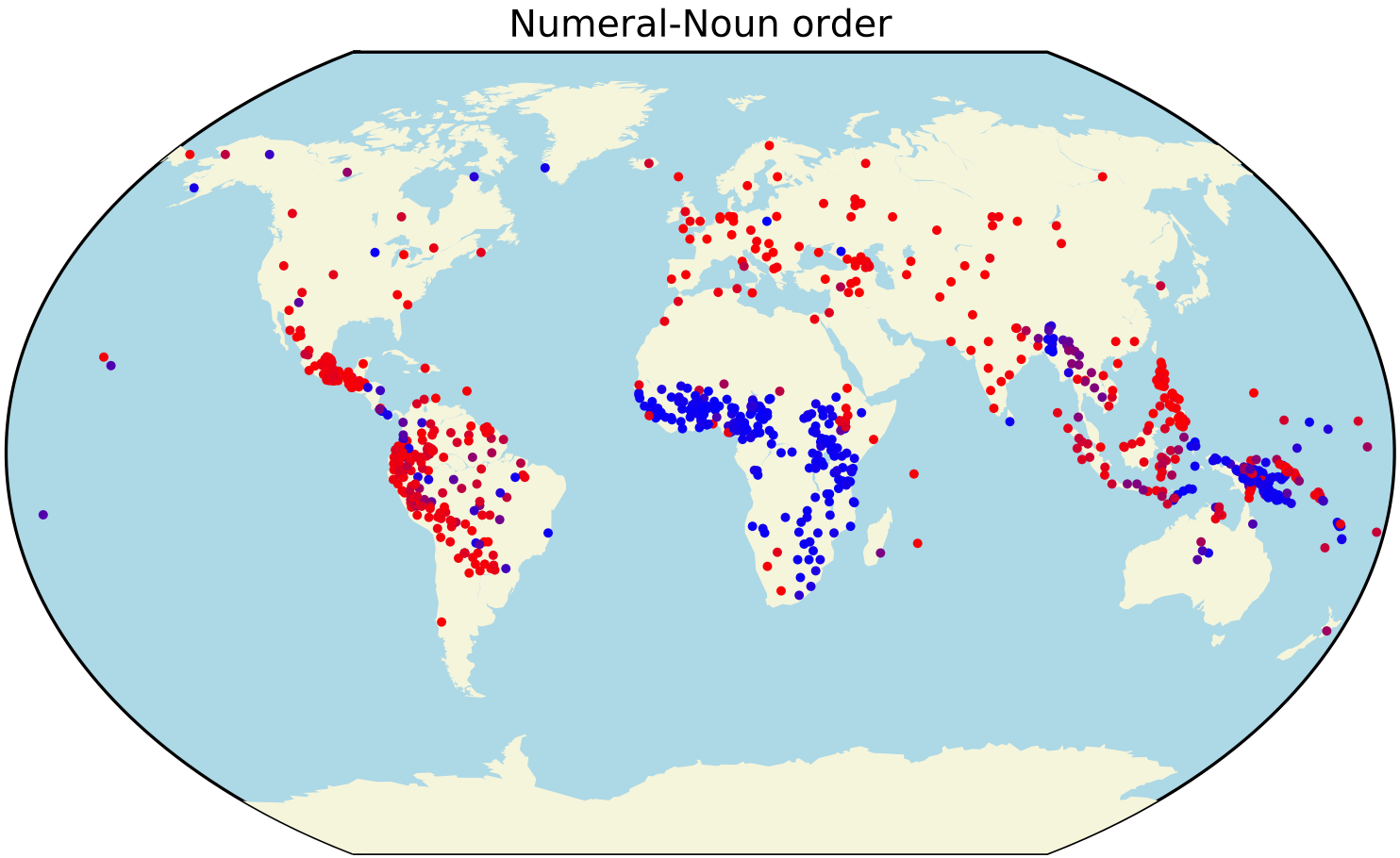
NP → Num N or NP → N Num?



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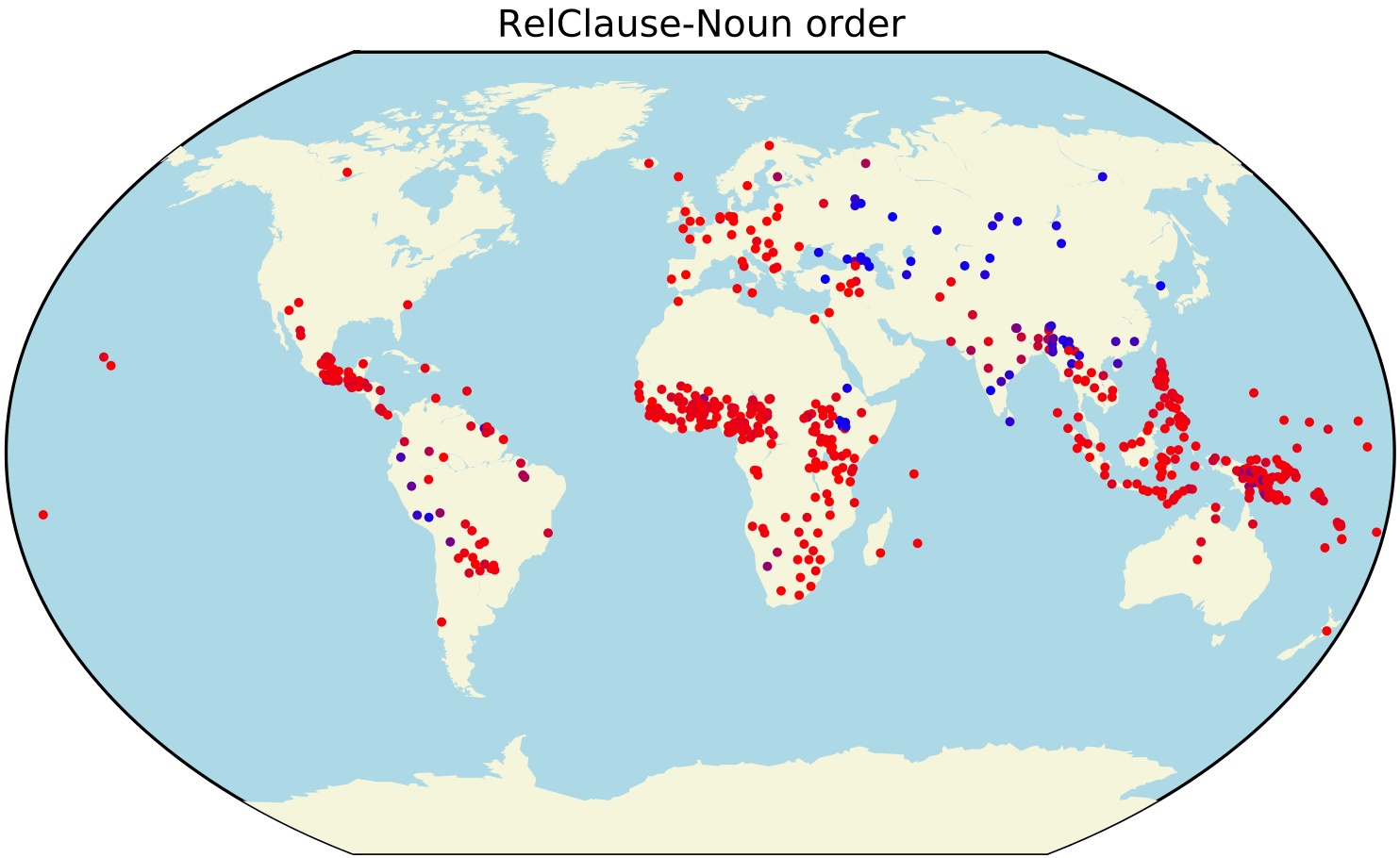
NP → RelCl N or NP → N RelCl?



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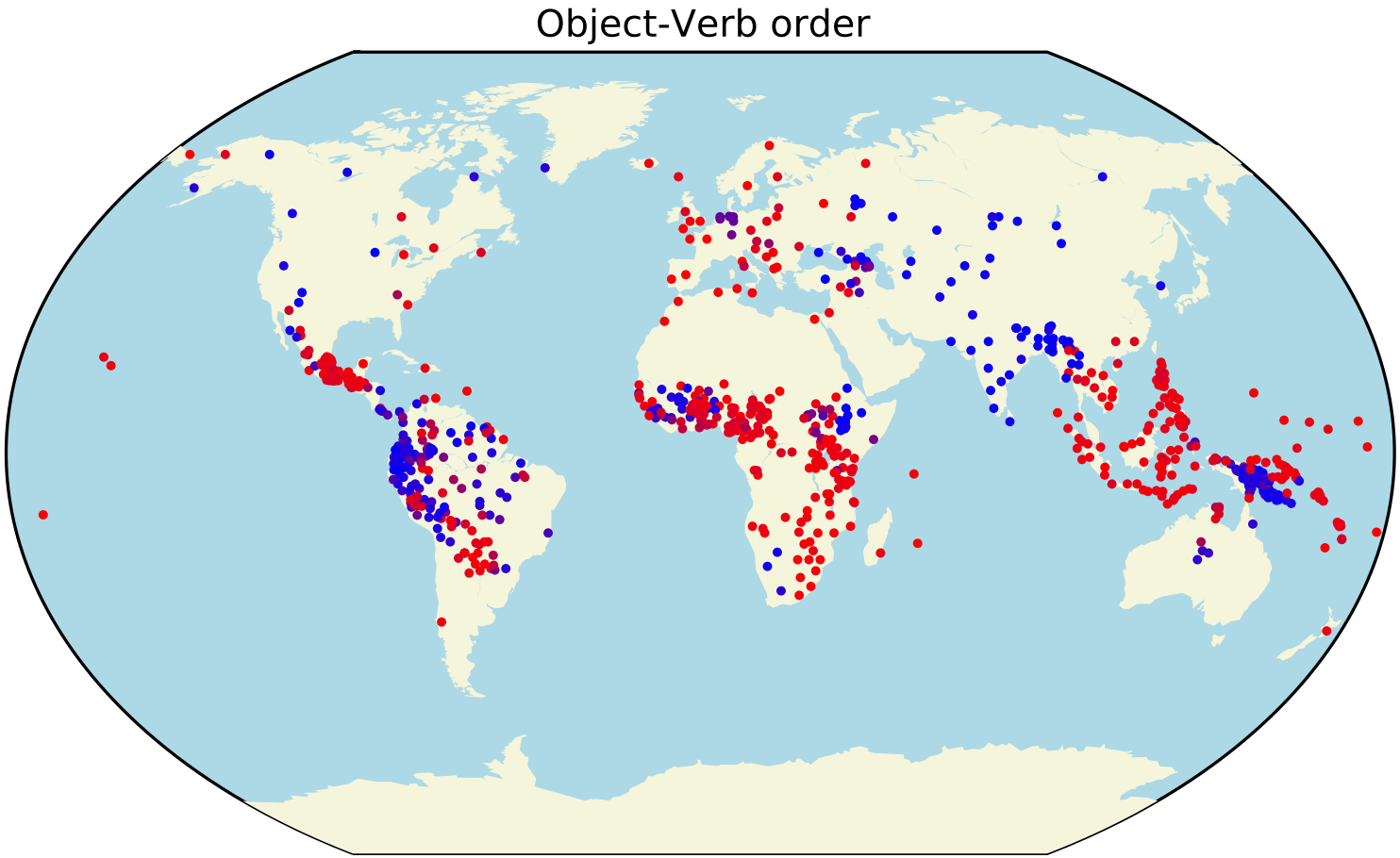
VP → NP V or VP → V NP?



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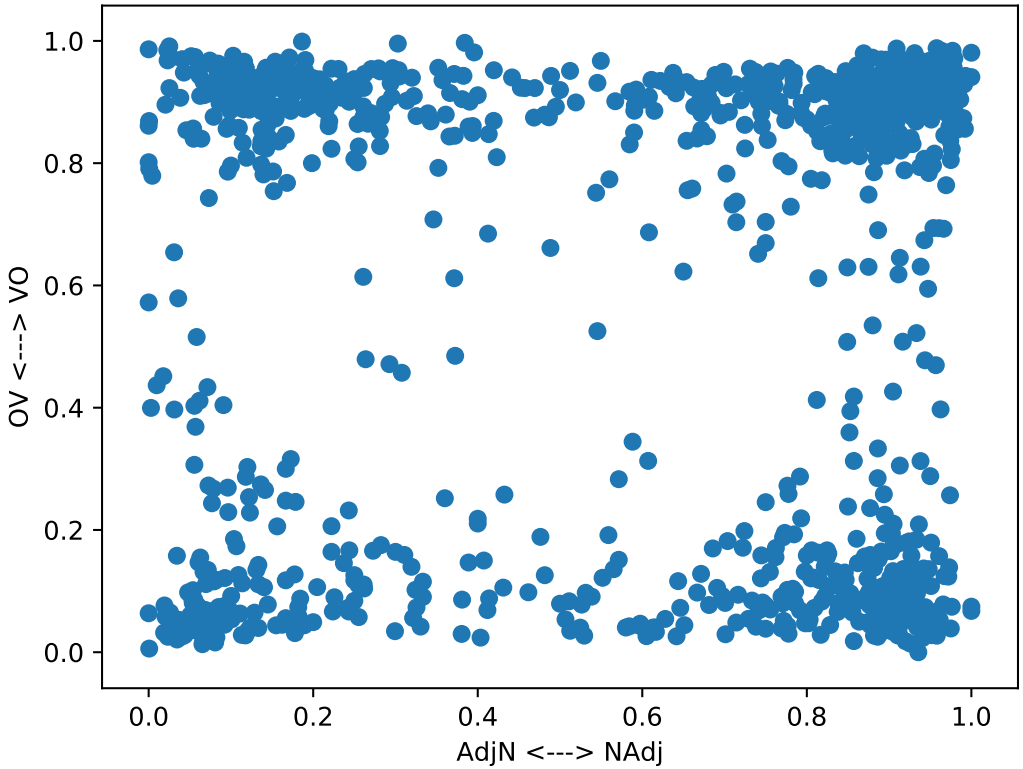
Testing theories

- If languages can be divided into left- and right-branching, these should be strongly correlated



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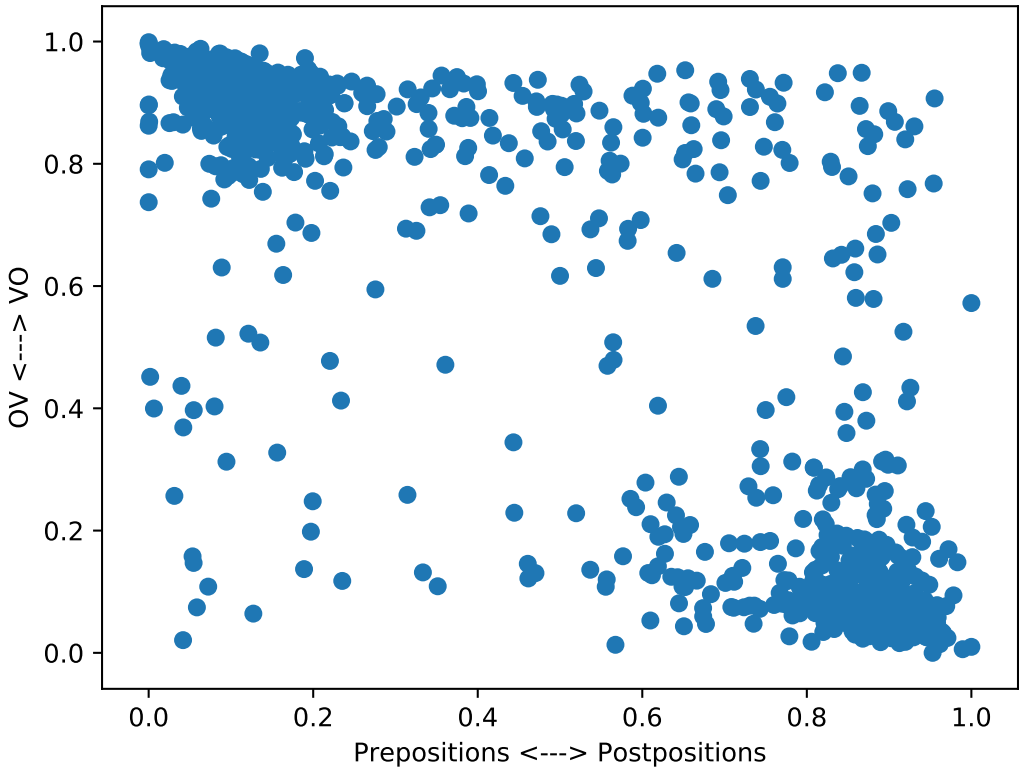
Testing theories

- YES: eating bread at home, bread home at eating
- NO: eating bread home at, bread at home eating
- Cognitive constraint, or historical accident?



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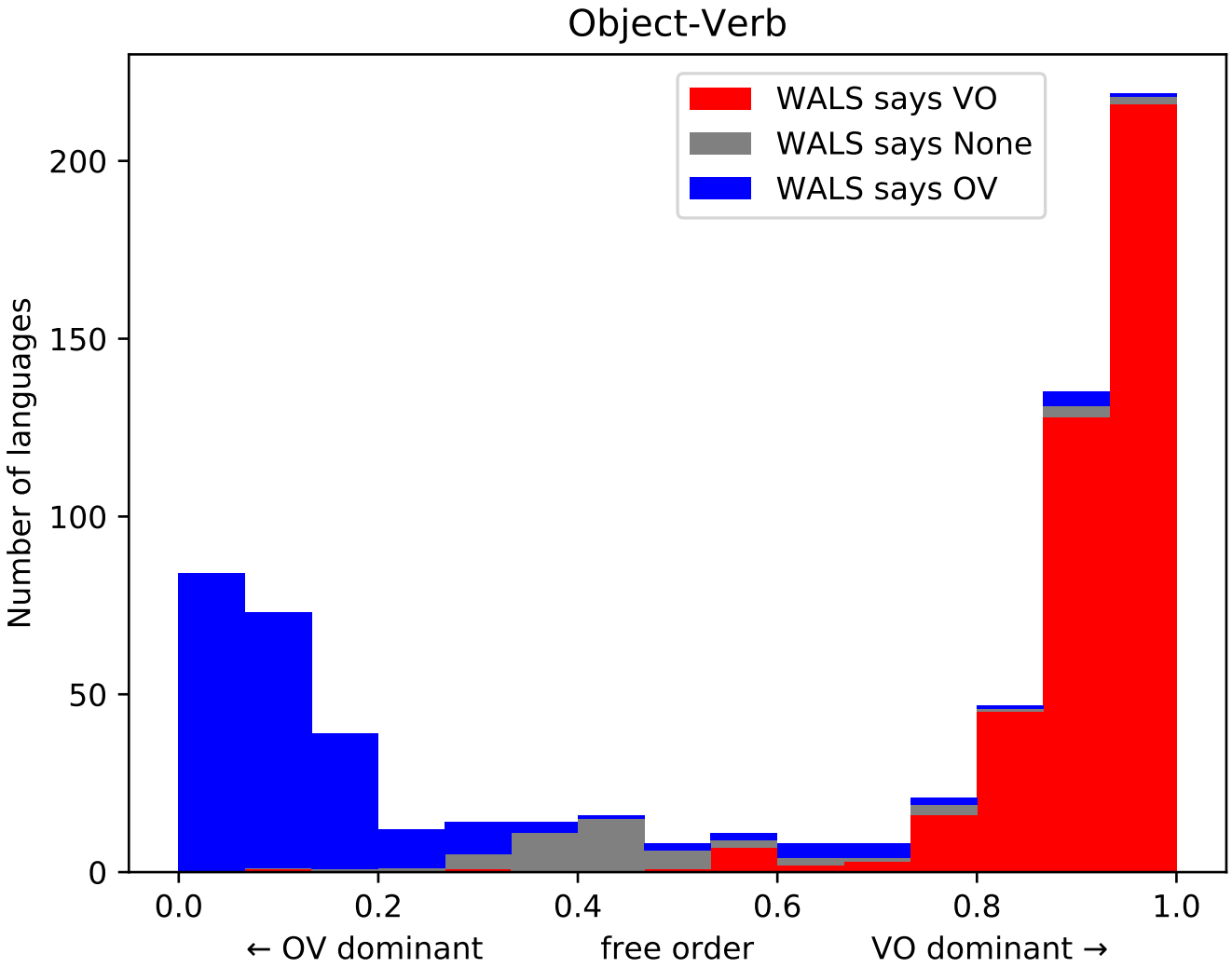
Can we trust this?



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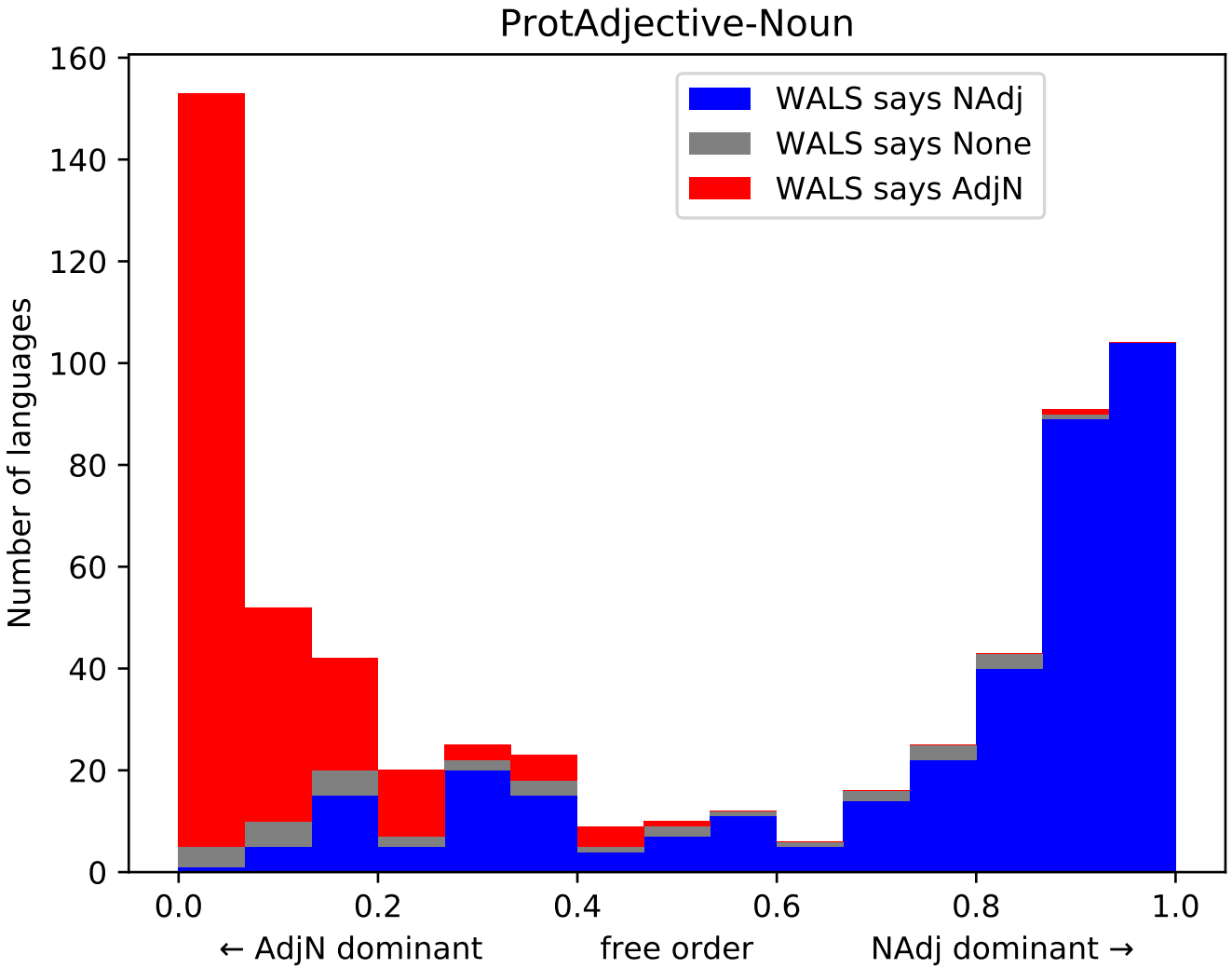
Can we trust this?



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Explaining differences

- Sometimes the translation differs from the linguist's description
- Turns out adjectives are not a perfect syntactic category
- Individual words often behave different (French, Tok Pisin, ...)
- In some cases (Tagalog) there are complex interacting rules

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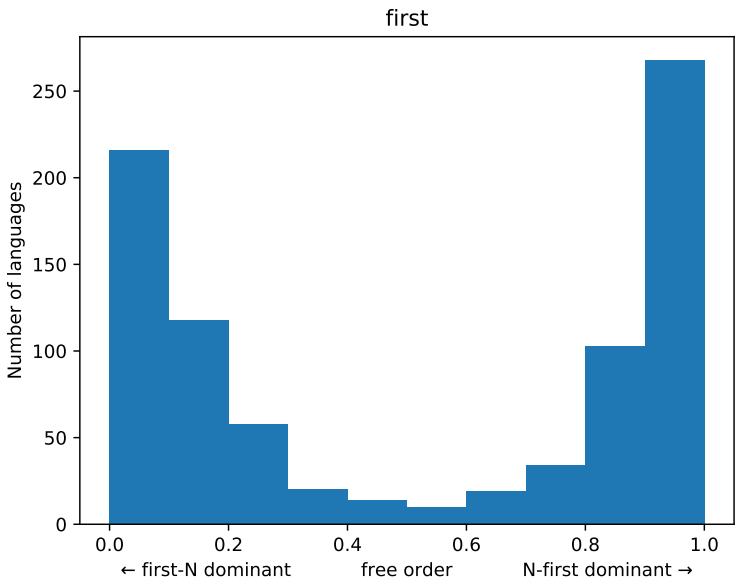
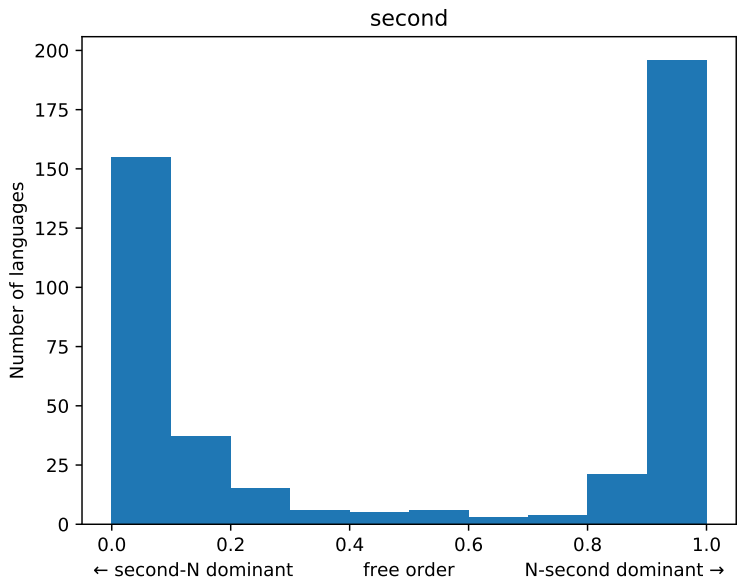
Variability within languages





"first" is less strict than "second" on average

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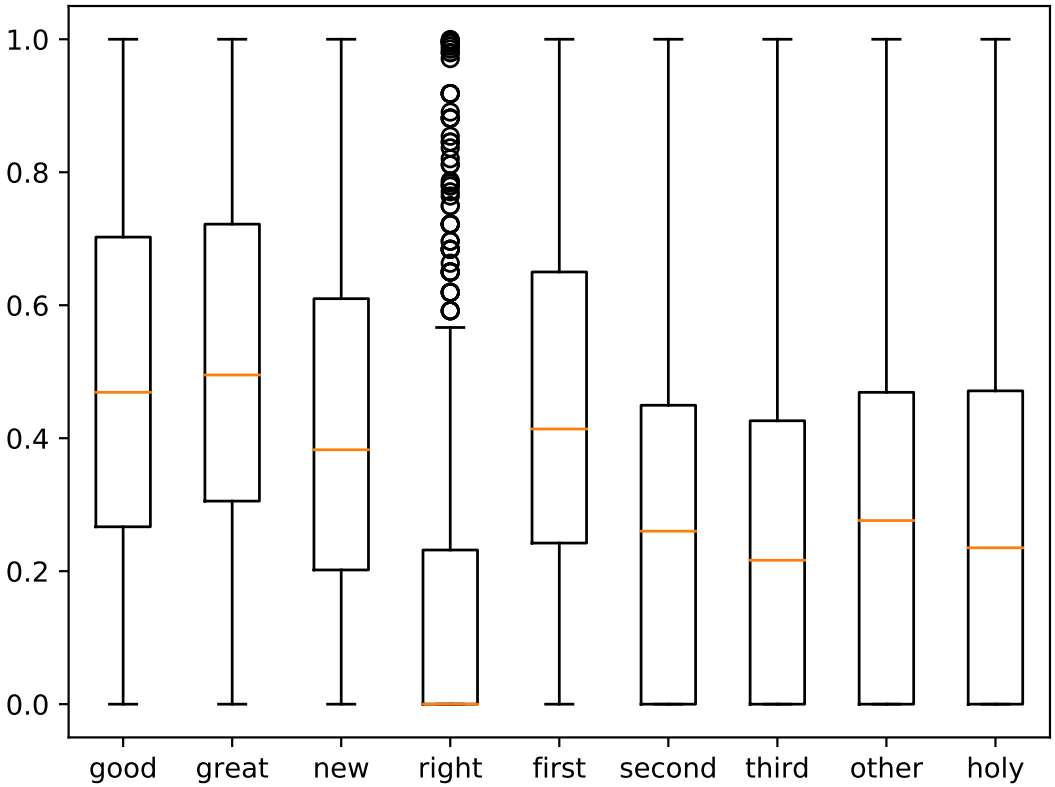
Variability within languages



Word order entropy per adjective-like concept across languages

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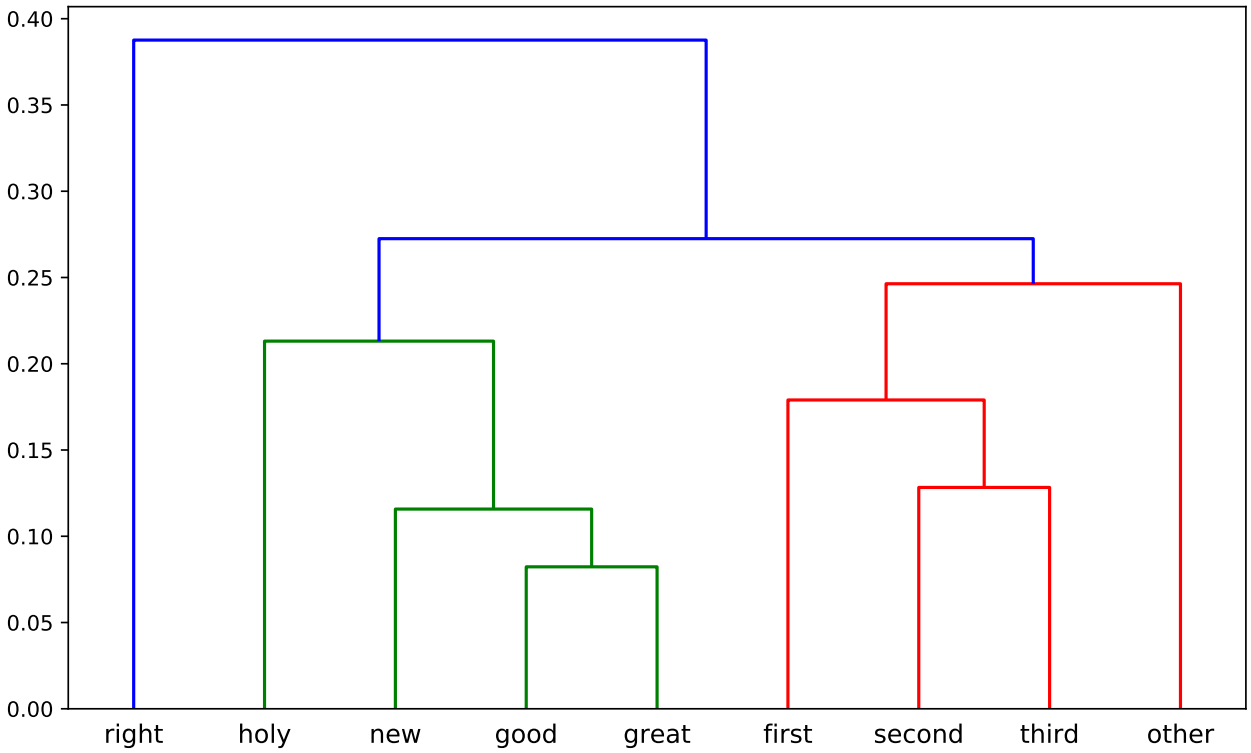
Syntax vs Semantics



Adjective-like concepts clustered by word order across languages

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Sign languages

- In many ways similar to spoken languages
- Balance of constraints is somewhat different
- *Iconicity* plays a larger role
- Ease of learning *vs* ease of use
  Example: *head*, *belly*, *foot*

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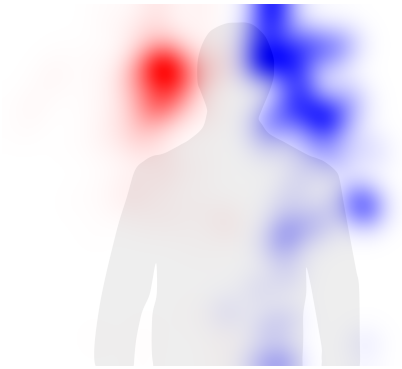
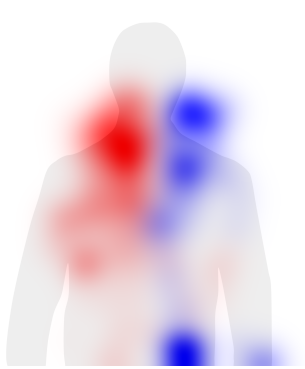
Iconicity



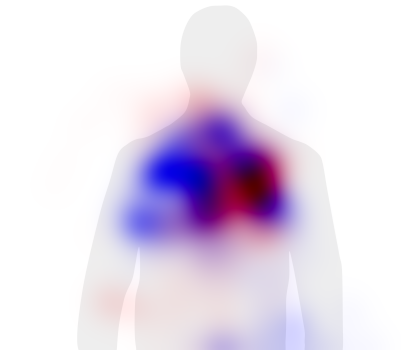
THINK (28 signs)

HEAR (25 signs)

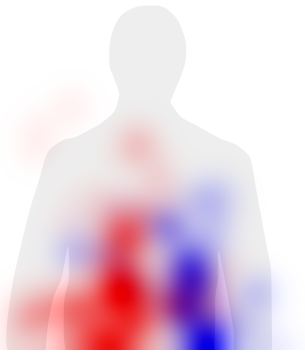


SAY (25 signs)

FOOD (25 signs)



LOVE (25 signs)



HUNGRY (24 signs)

Place of articulation for some concepts across sign languages

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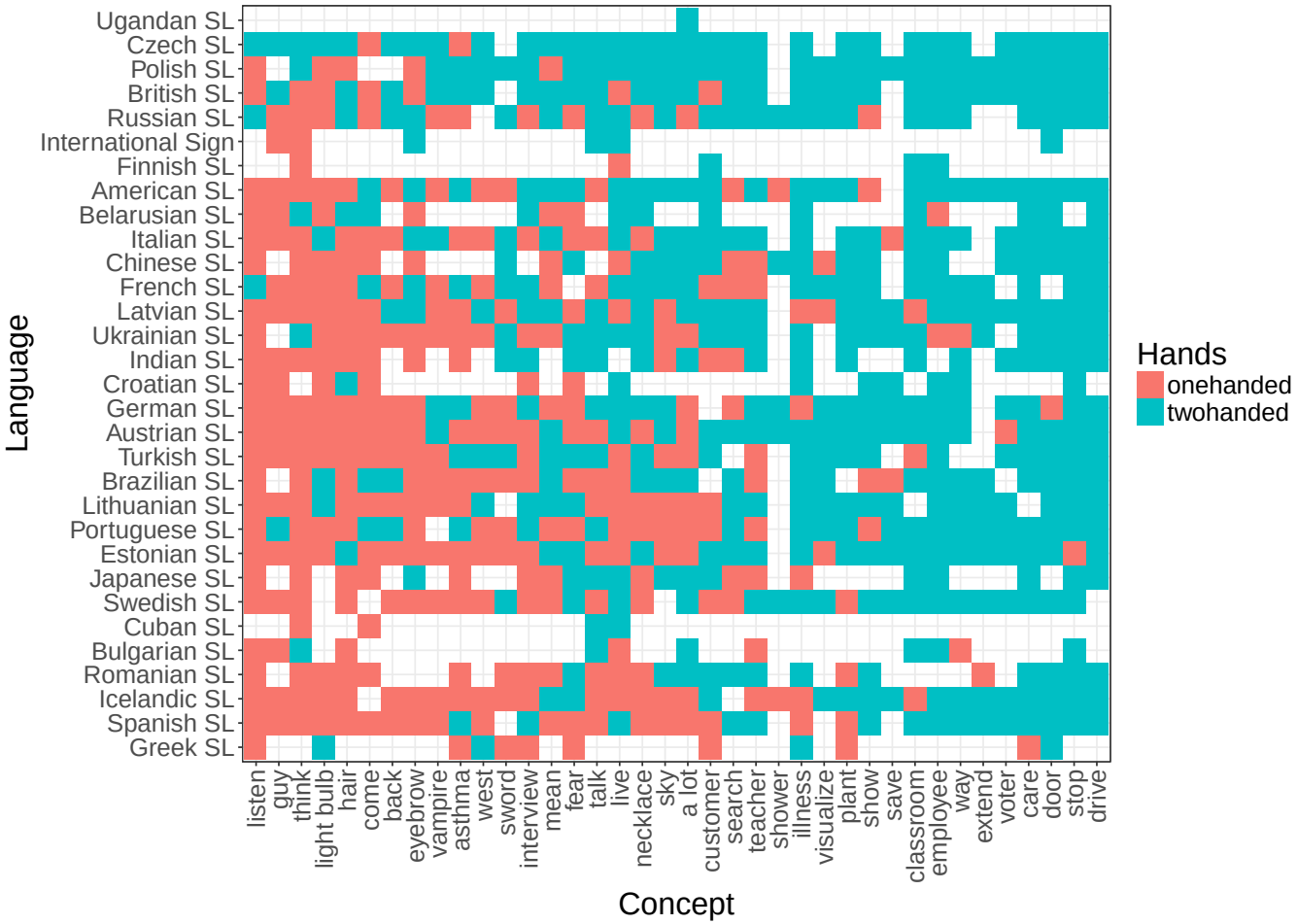
One factor: inherent plurality



Number of hands used per concept per language, non-plural concepts

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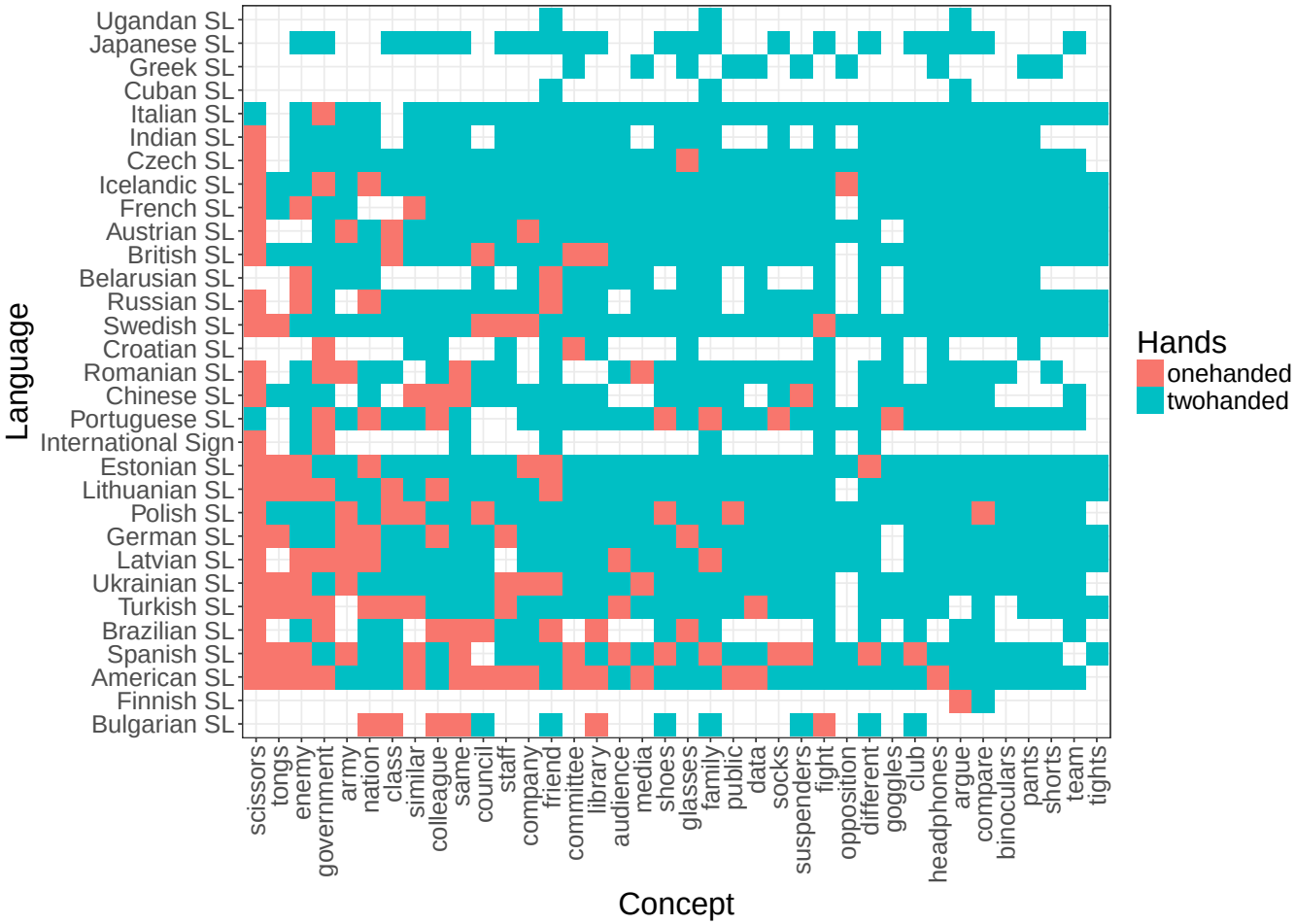
One factor: inherent plurality



Number of hands used per concept per language, plural concepts

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Summary

- Languages are fascinating
- There are tons of parameters you can extract
- The Bible is an excellent data source with structured variation
- Start calculating!

$$\begin{bmatrix} L_1(x_1) & L_1(x_2) & \dots & L_1(x_n) \\ L_2(x_1) & L_2(x_2) & \dots & L_2(x_n) \\ \vdots & \vdots & \ddots & \vdots \\ L_m(x_1) & L_m(x_2) & \dots & L_m(x_n) \end{bmatrix}$$

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