On the Complexity and Typology of Inflectional Morphological Systems

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What’s *your* native language?

Johns Hopkins University

Do you think your native language more complex than English?

Audience Poll

Question: Who thinks their native language is more complex than English?

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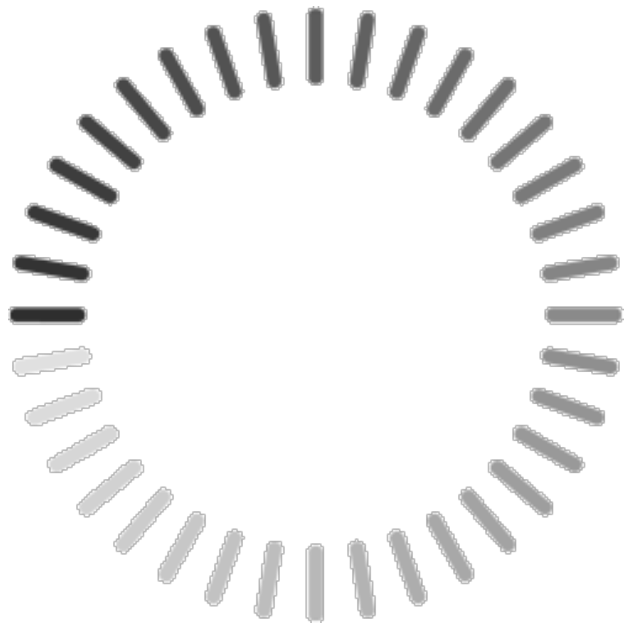
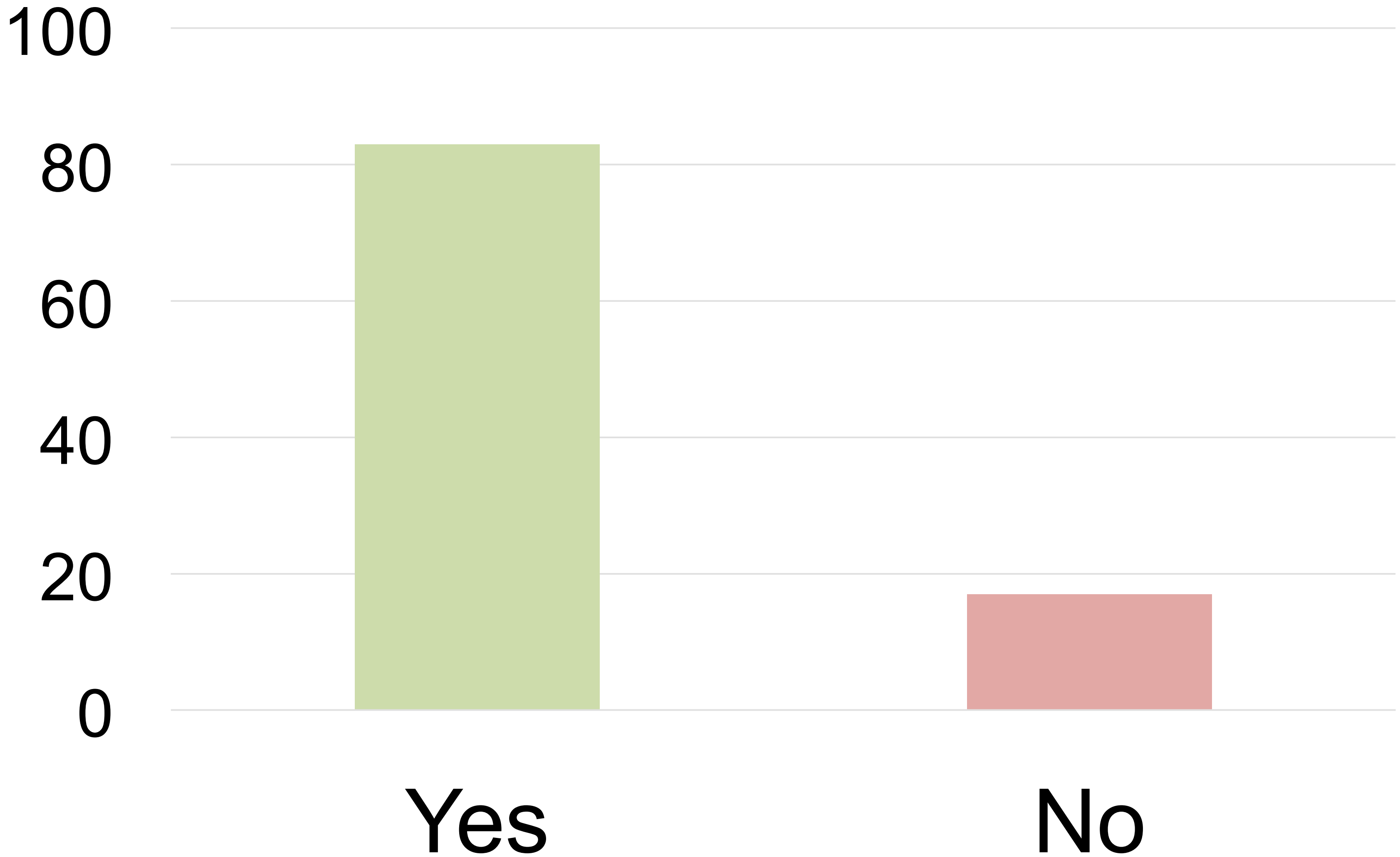


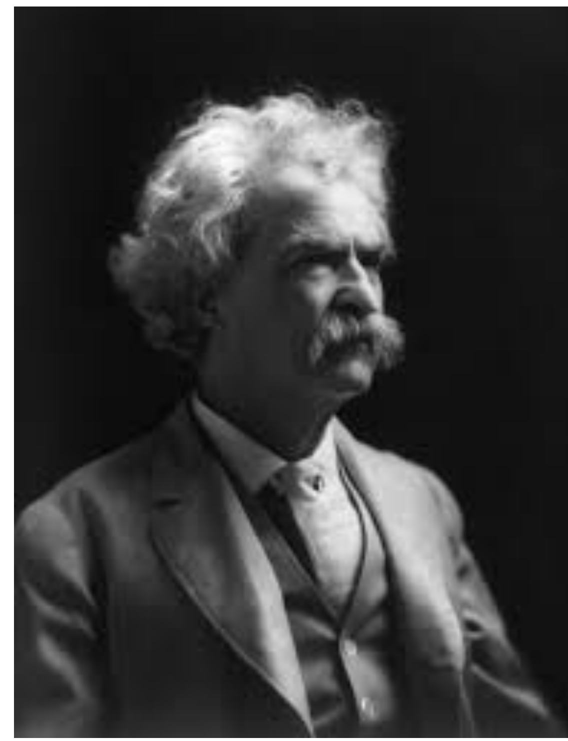
Instant Results



What makes your native language more complex than English?

More Morphological Variants = A More Complex Language

- I agree: a lot of morphological variants can make a language "difficult":
  - Mark Twain said it best: "I'd rather decline two drinks than one German adjective."



- Then, look at how simple English is!
  - Your average verb has four inflections: *run*, *runs*, *ran*, *running*
- Nouns and adjectives don't inflect in English according to case
  - The adjective *good* has one inflection

In Comparison: The Turkish Verb

- **koşmak** = Turkish verb ”to run”
  - (partial) paradigm →
- Tense, mood, evidentiality … marked through morphology
  - 100+ forms in Turkish!
- Archi (Kibrik 1998) has 1.5 million verb forms
  - It’s very, very agglutinative
- This makes a language more complex!

ben	koşıyorum
sen	koşıyorsun
o	koşıyor
biz	koşıyoruz
siz	koşıyorsunuz
onlar	koşıyorlar

ben	koşmadım
sen	koşmadın
o	koşmadı
biz	koşmadık
siz	koşmadınız
onlar	koşmadılar

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Number of Forms is Only One Dimension of Morphological Complexity

- There are (at least) **two types** of morphological complexity
  - **Type 1:** how big are the paradigms? (seen before)
  - **Type 2:** how irregular are the paradigms?

- Ackerman and Malouf (2013) introduce the technical jargon
  - Enumerative Complexity (E-Complexity)
  - Integrative Complexity (I-Complexity)

English versus Turkish: # Forms

- **English**
  - 4 verbal slots
  - 2 nominal slots
  - 1 adjectival slot

7 Total

- **Turkish**
  - 350 verbal slots
  - 8 nominal slots
  - 1 adjectival slots

358 Total

Turkish is more morphologically complex under # forms per verb

English Versus Turkish: Irregularity

- **English**
  - 224 irregular verbs
  - 10 irregular nouns
  - 0 irregular adjectives

234 Total

- **Turkish**
  - 1 irregular verb
  - 0 irregular nouns
  - 0 irregular adjectives

1 Total

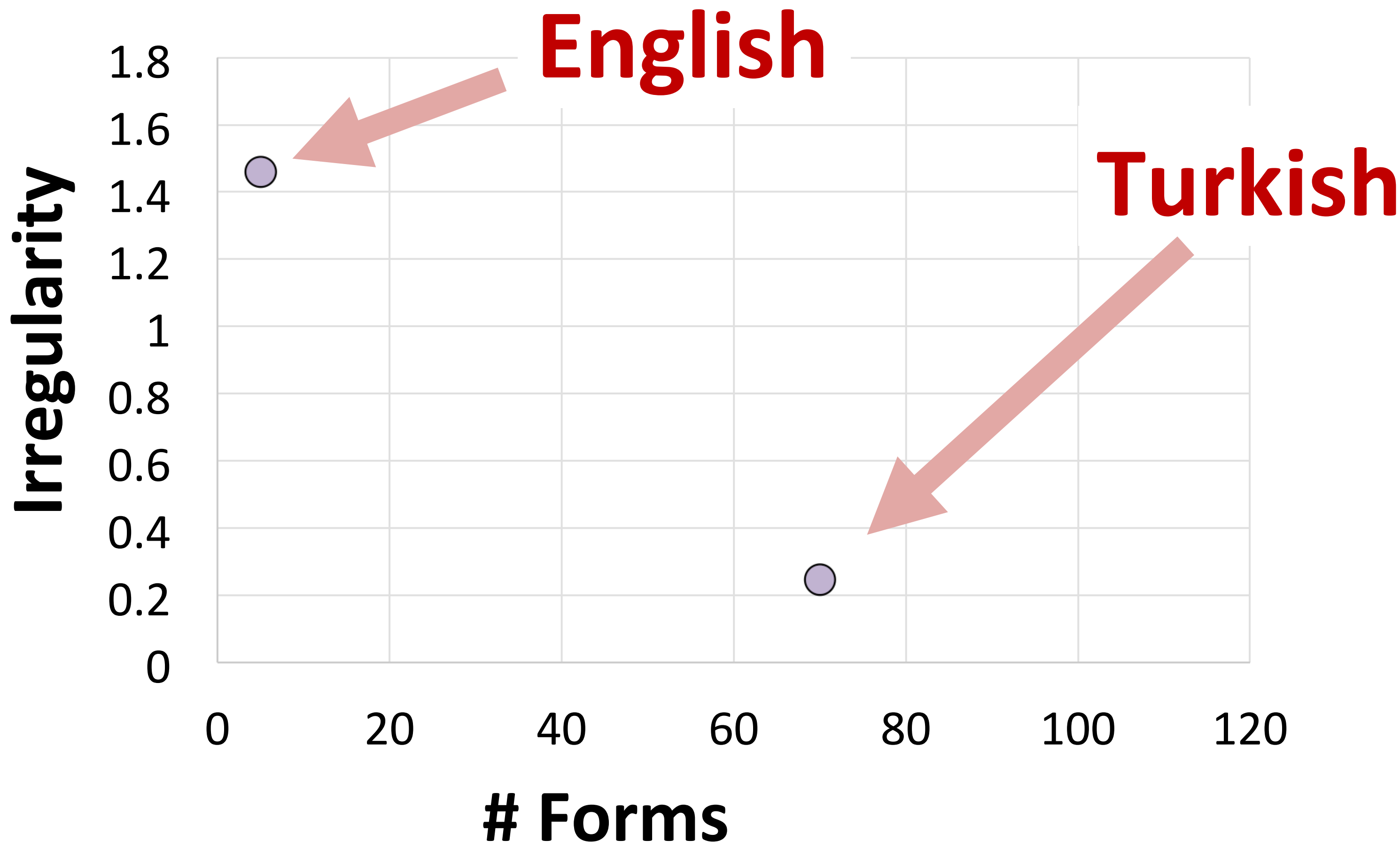
English is more morphologically complex under amount of irregularity

What's *This* Paper About?

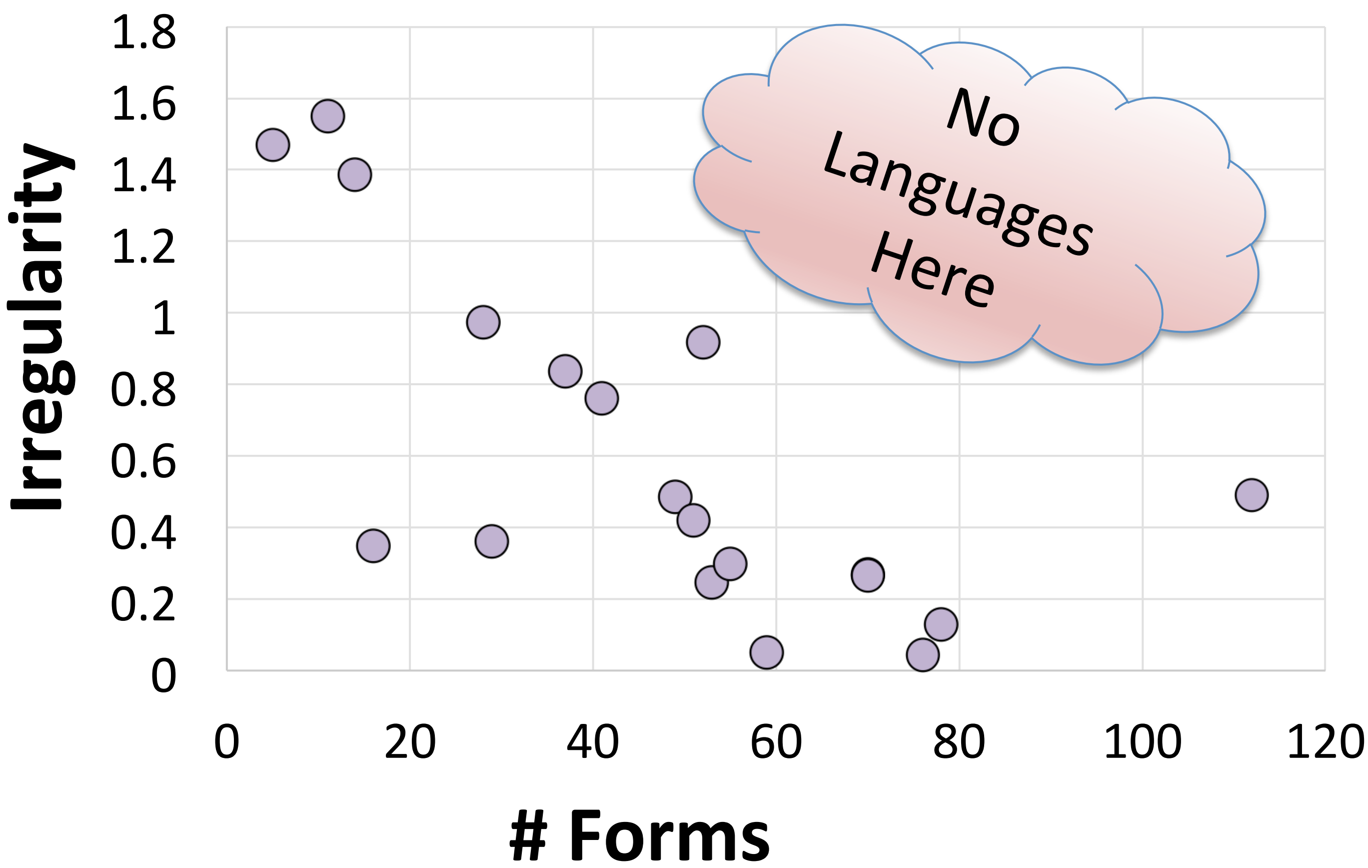
Good Linguistic Question:

How do the # morphological variants and morphological irregularity interact?

Plotting English and Turkish Verbs



What about the Rest of the World's Languages? (For which we have data)



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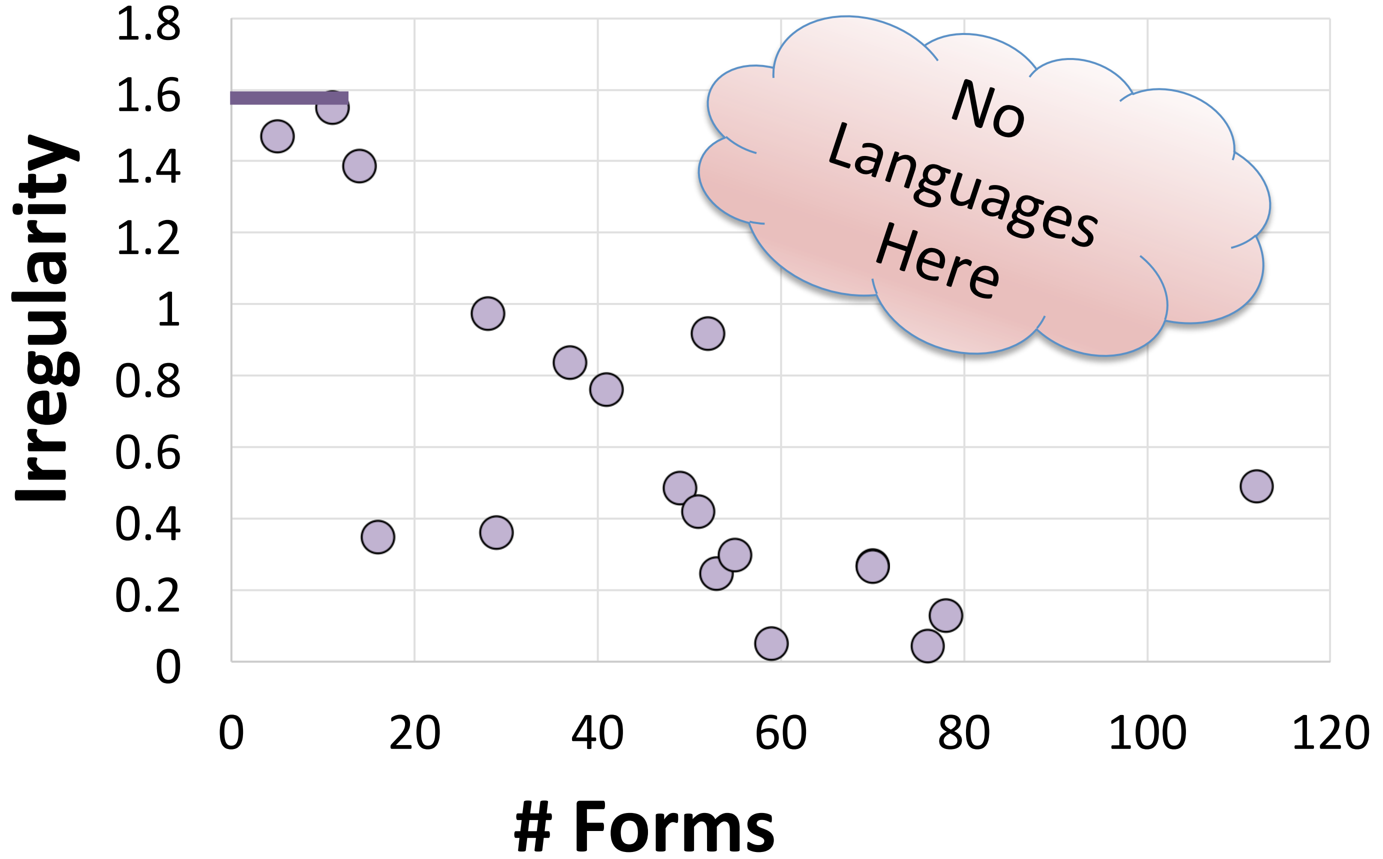

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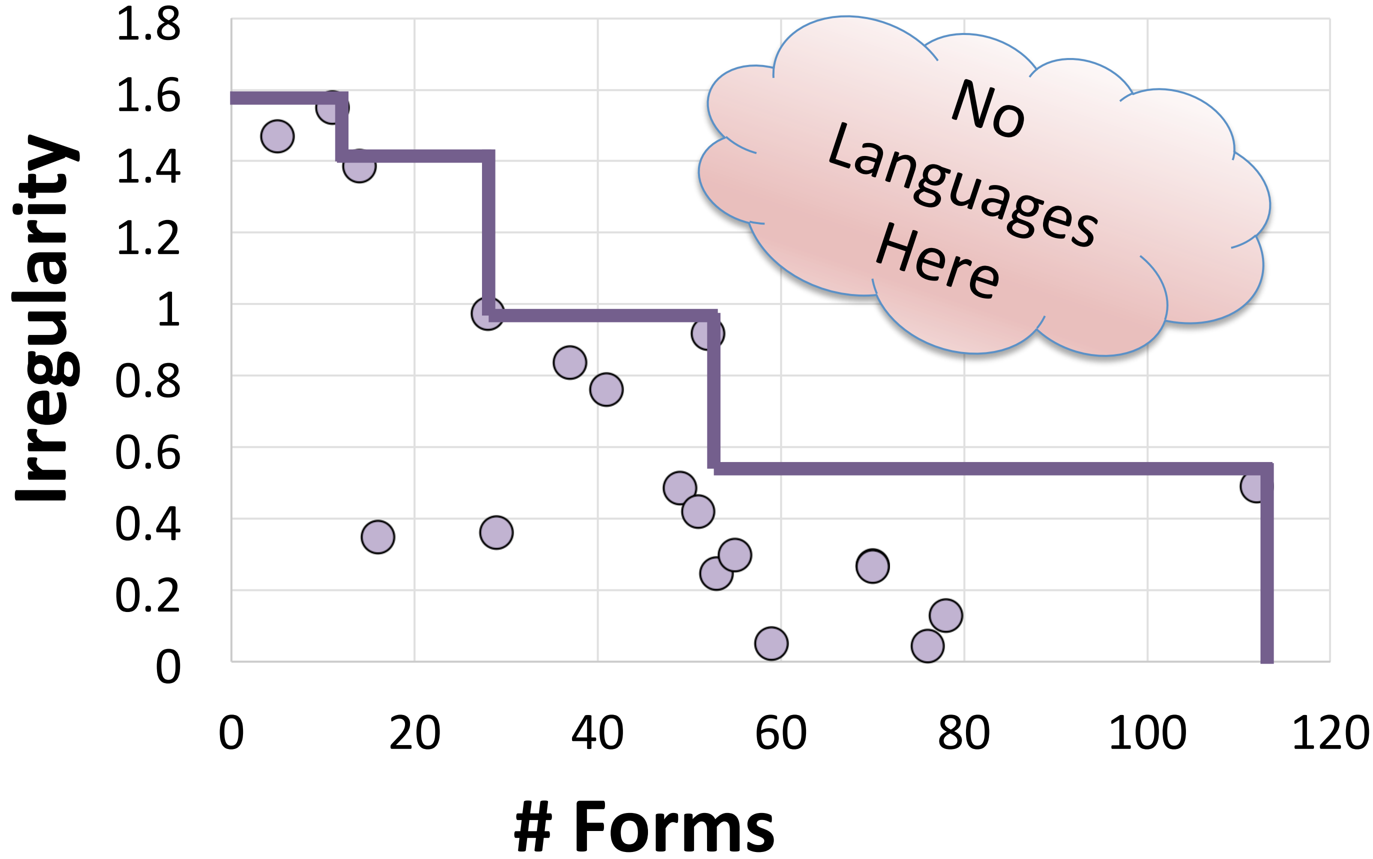

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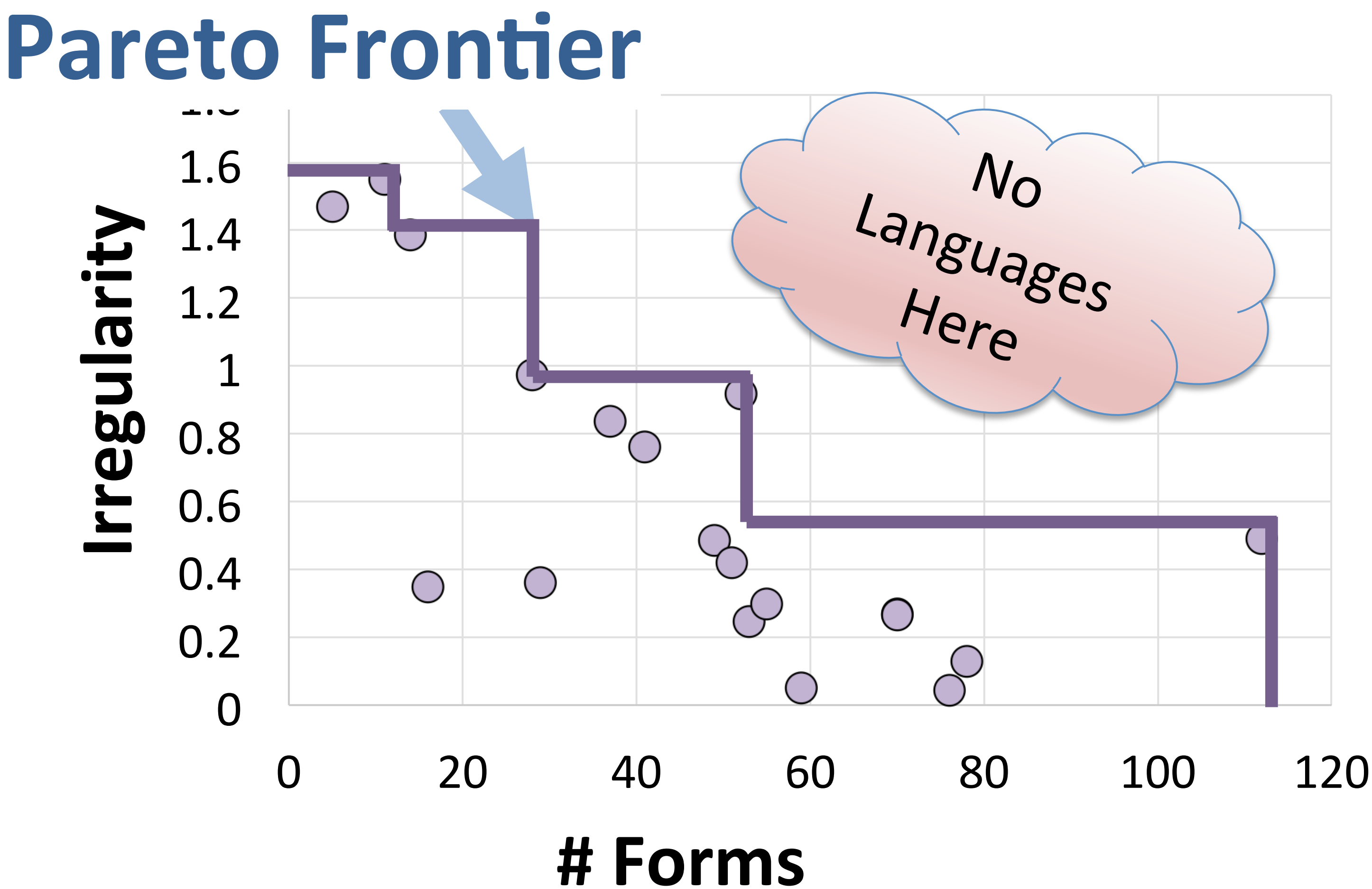

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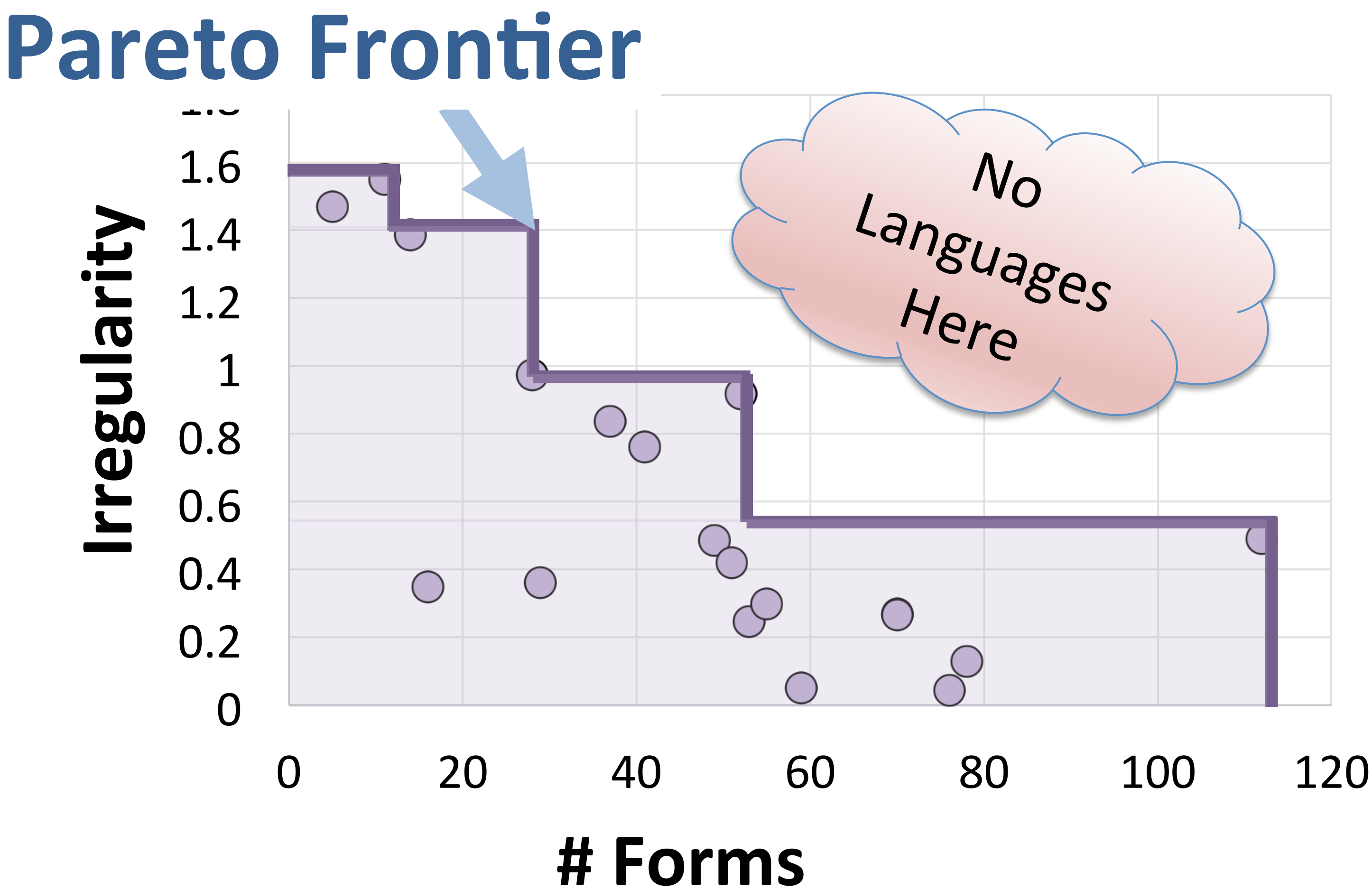
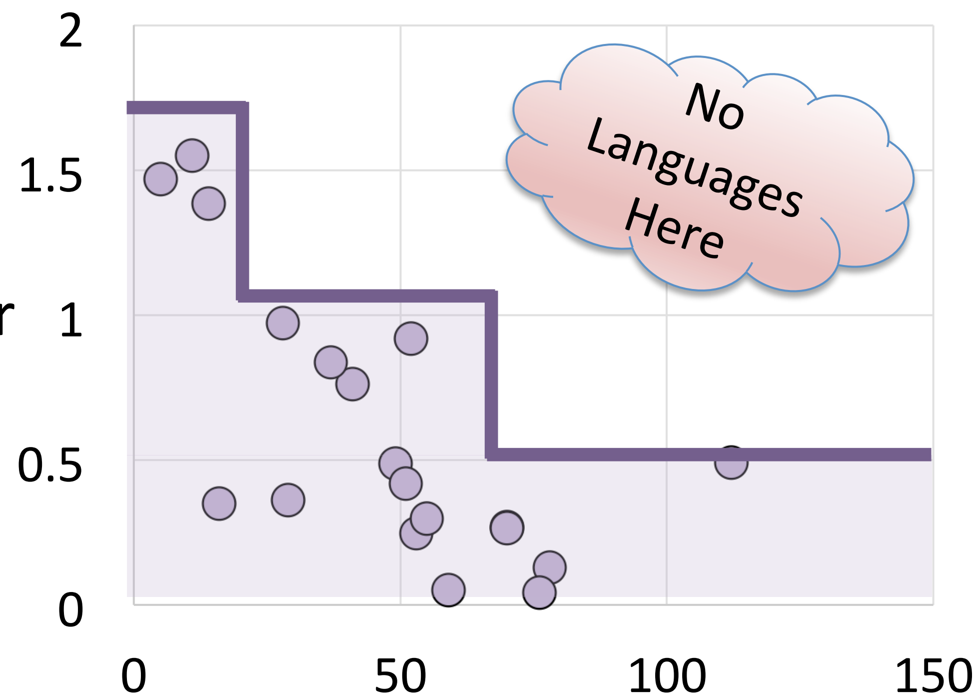


Scientific Hypothesis about Language

- Use machine learning techniques to test hypothesis about Language
- Morphological systems can have *either* a lot of forms or lot of irregularity
  - But not both!
- Why? Speculative reason: memorizing a lot of irregulars would tax human memory



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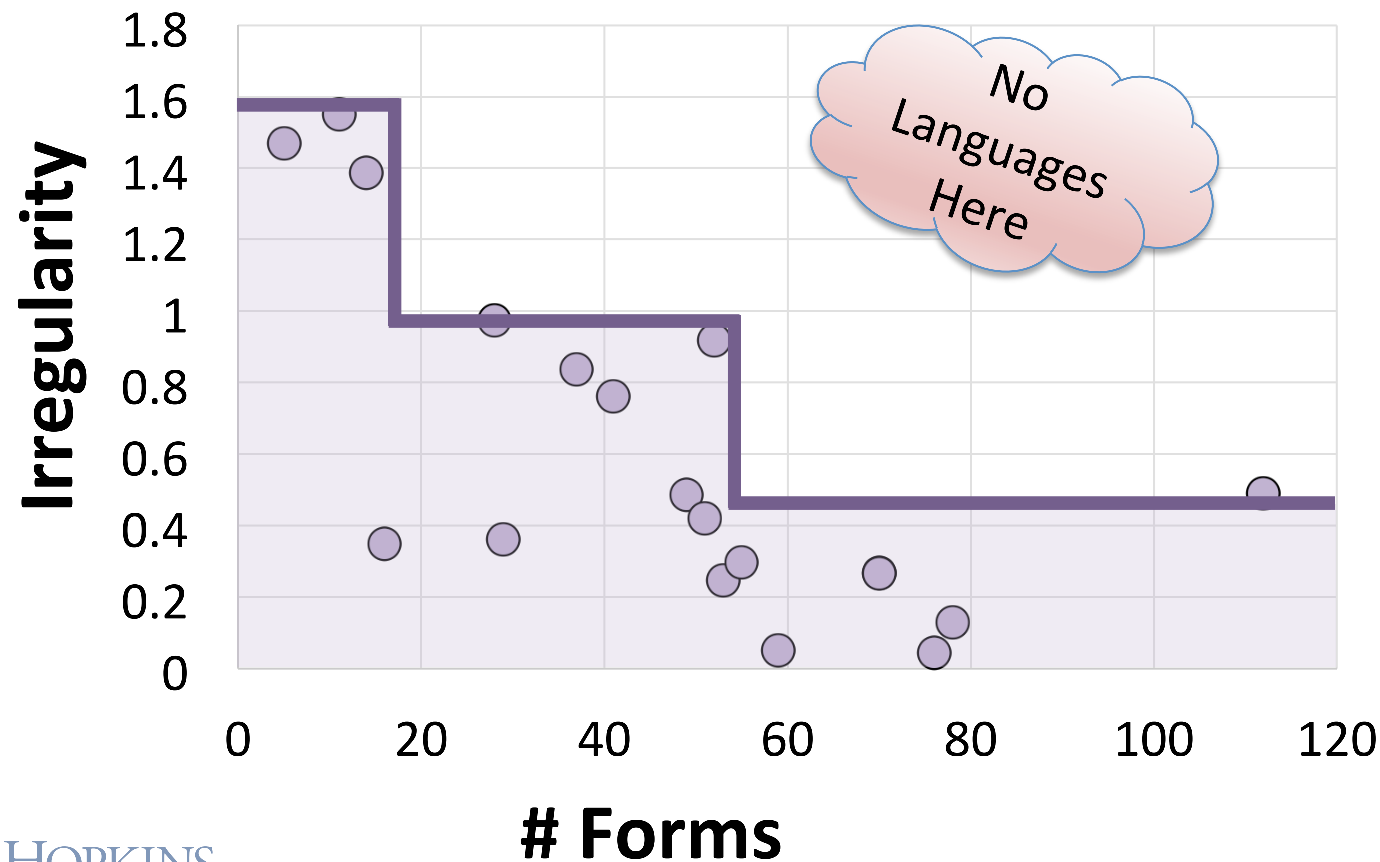
Chinese is Low on *Both* Dimensions of Morphological Complexity

- **Morphology in a language is not necessary!**
- Let’s look at the Chinese verb “to drink”
  - drink = 喝
  - drinking = 喝
  - drank = 喝

- Look mommy, no inflection!

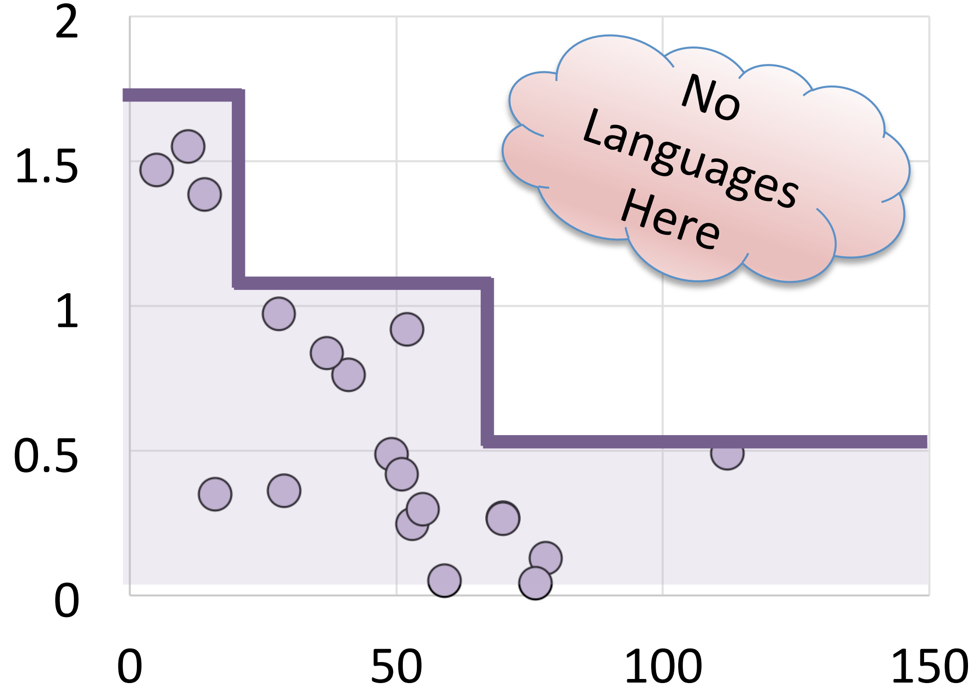
Our Hypothesis Again

- Inflectional, morphological systems have a lot of forms, or a lot irregularity, but not both

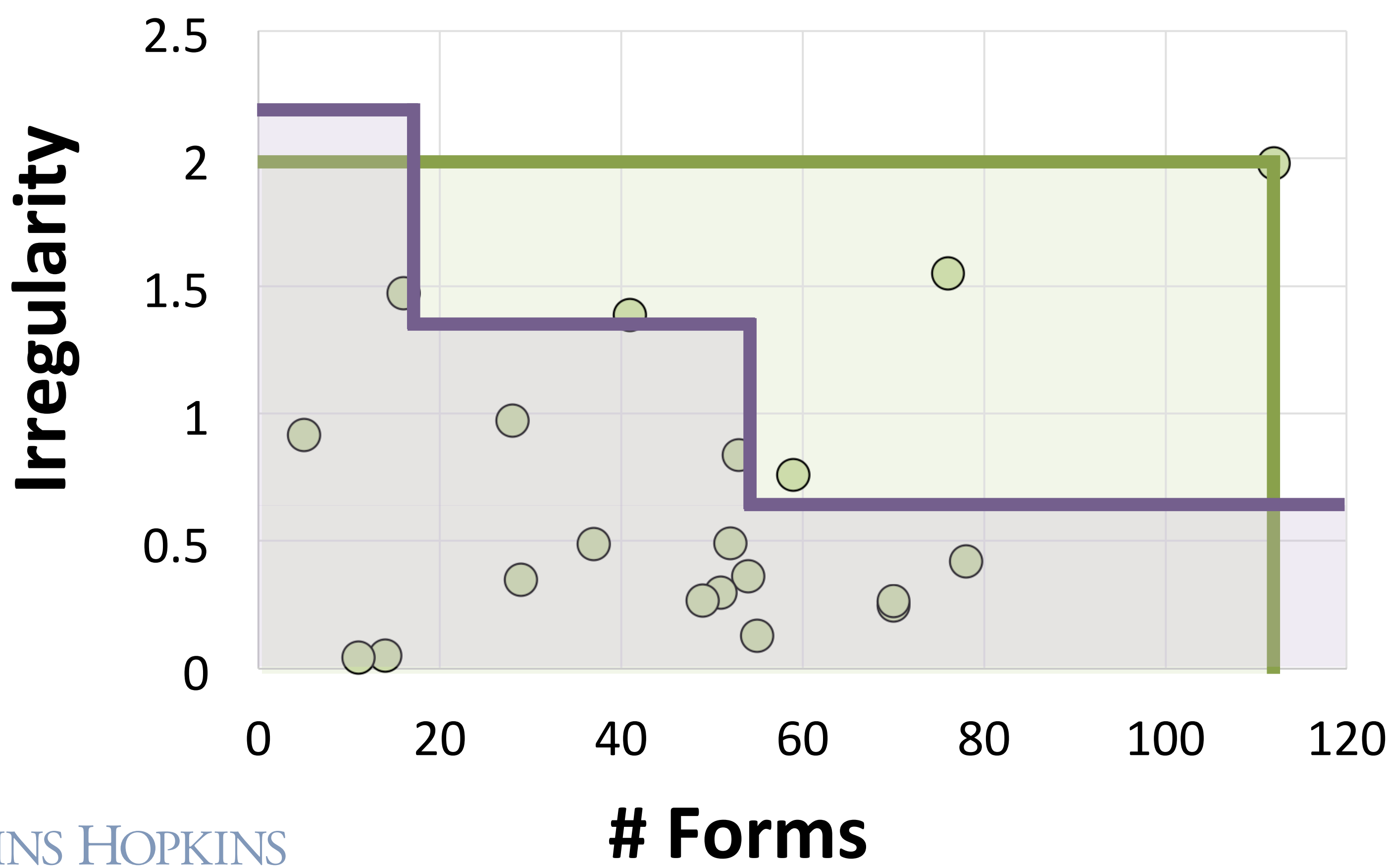


A Paired Permutation Test

- There *appears* to be a trend, but is it significant?
  - Is the upper right-hand corner more empty that it would be by chance?
- New Significance Test
  - Keep x-axis in tact, shuffle y-axis
  - compare area under the Pareto curve
  - Non-parametric test



Random Morphological Trade-Off



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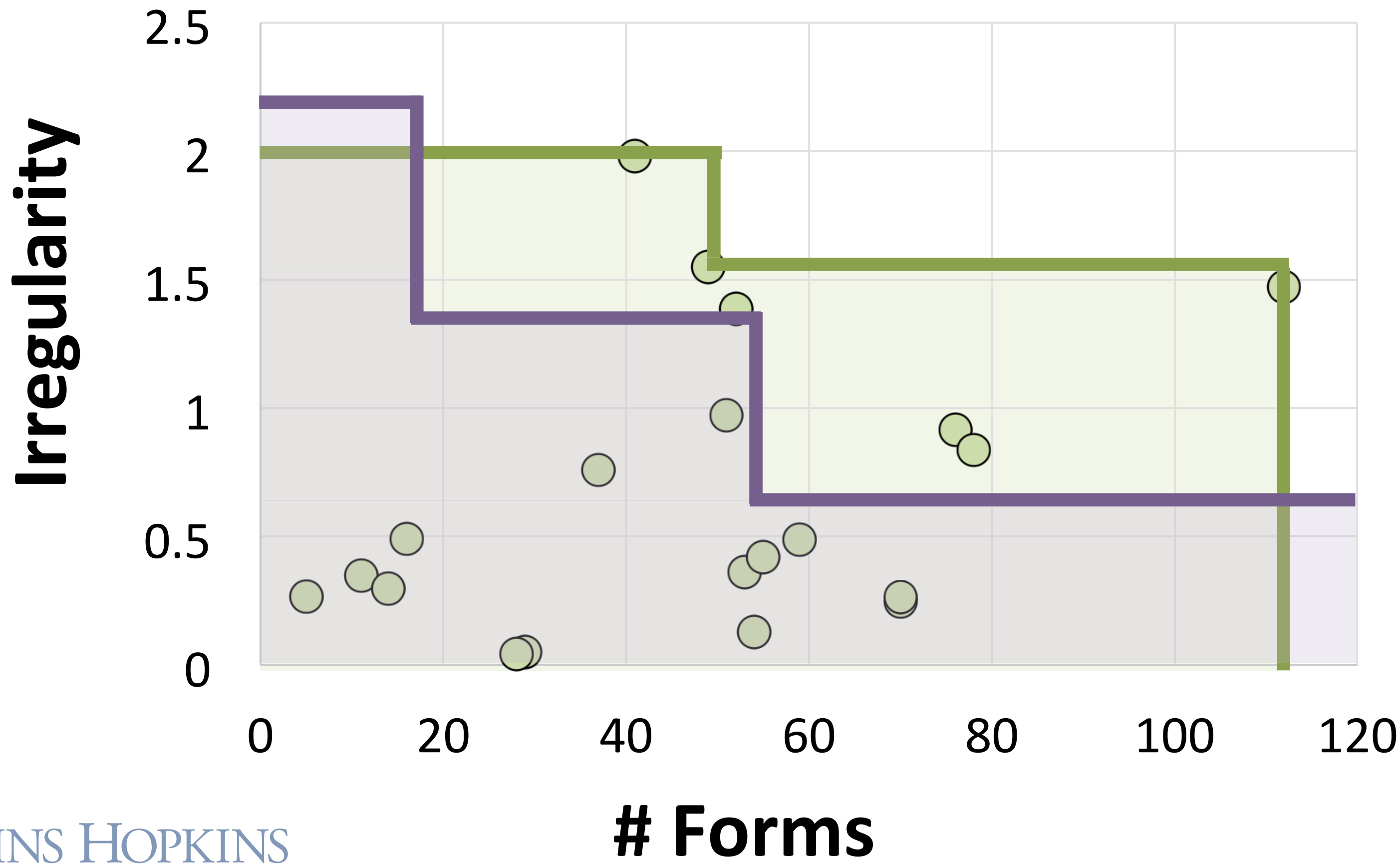

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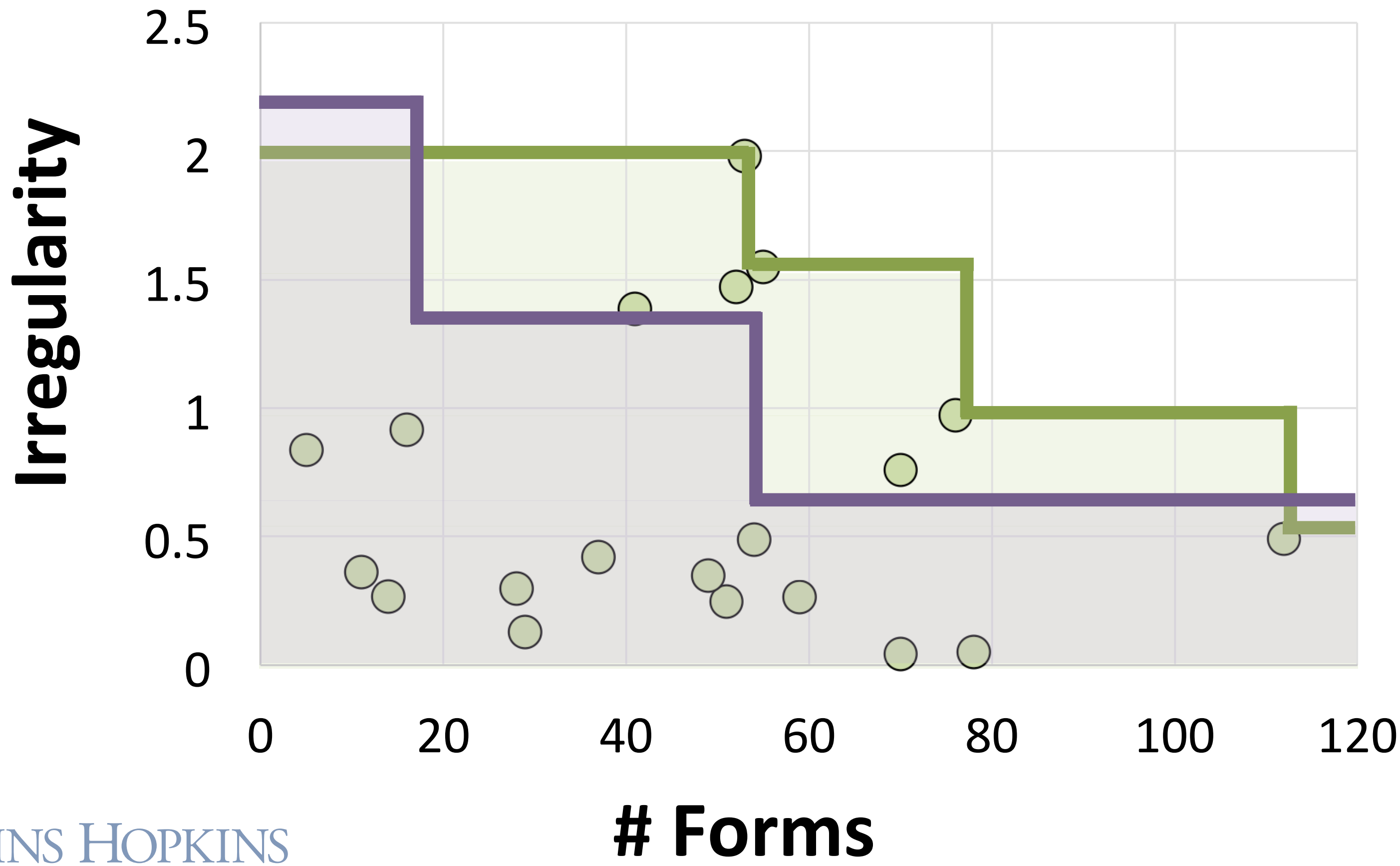

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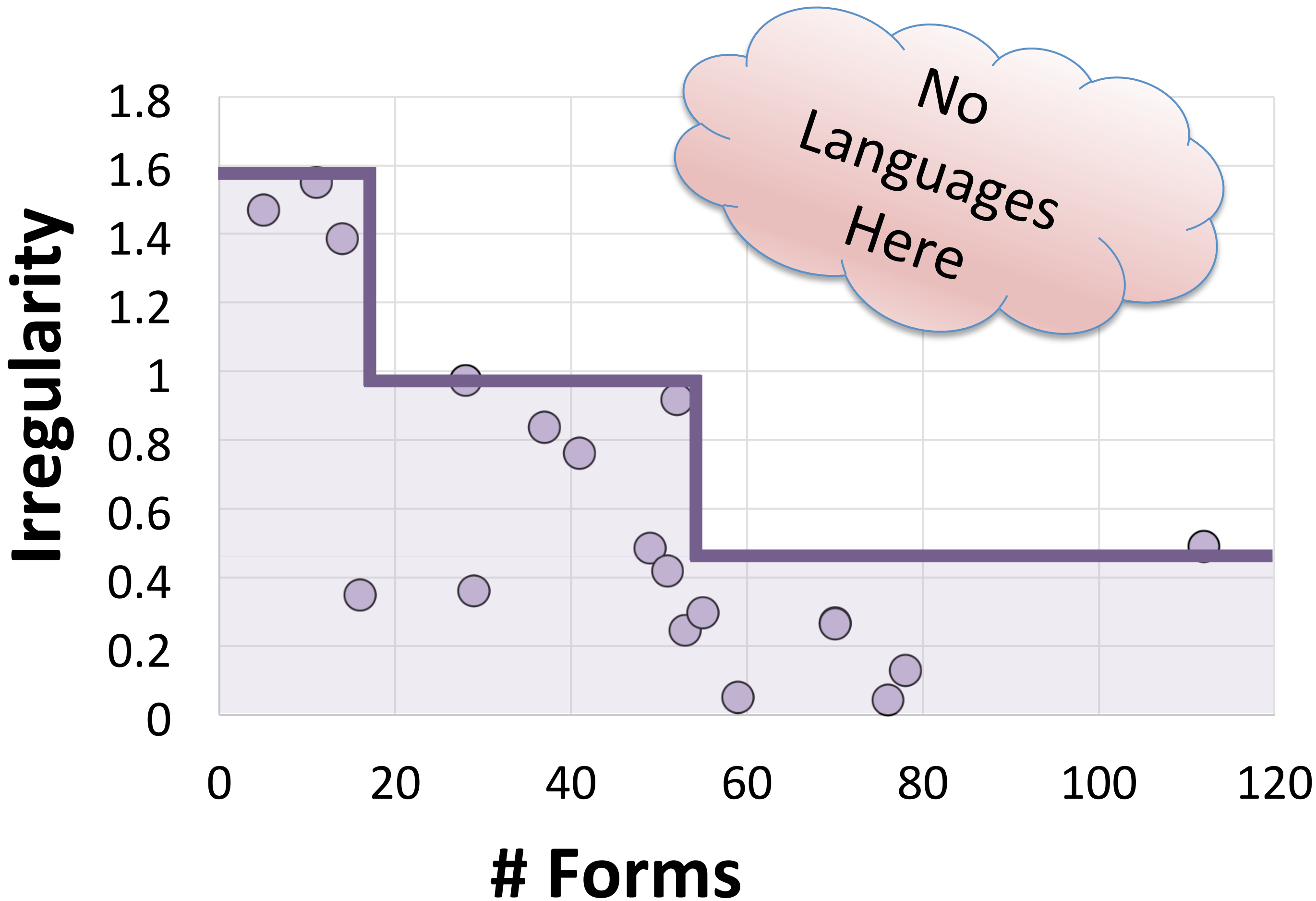
Scientific Finding

Gap in the upper right-hand size with $p < 0.05$



Caution: Limited # Of Languages

- We need to be very cautious about reporting the results!

- The languages are not i.i.d.
  - Some of them are genetically related
  - Focus on Western European Languages

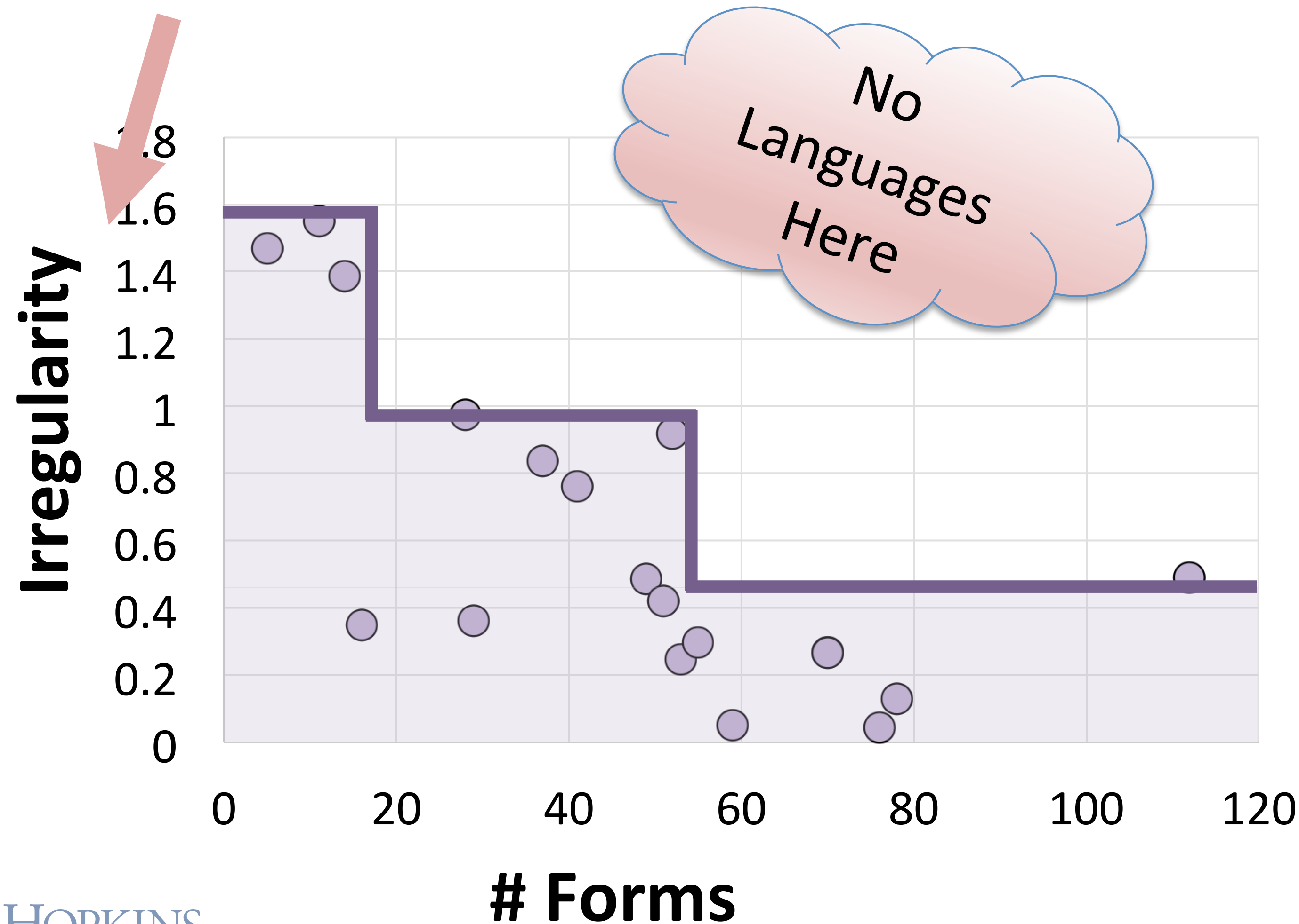
- We have a small sample of size of languages
  - There might be unobserved counterexamples
  - For *this sample*, the Pareto frontier leaves an unusually large gap in the upper right

Technical Contribution:

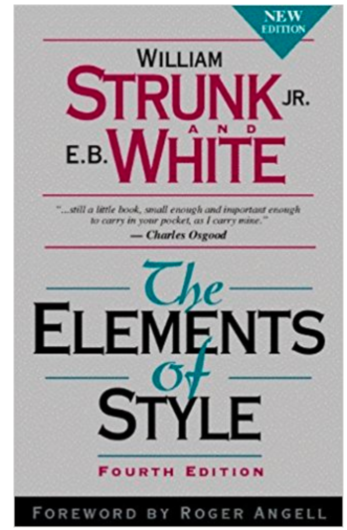
Operationalizing Morphological Irregularity

Where did the *y*-axis come from?

What do those numbers mean?



What’s an Irregular Verb?



- **TL;DR:** some grammarian said so
- **Example:** Spanish has three types of regular verbs
  - *ar, er, ir*
- The rest are “irregular”
  - Why???
- Are they equally irregular?
  - Or are some verbs more irregular than others?

CANTAR	BEBER	VIVIR
cant-é	beb-í	viv-í
cant-aste	beb-iste	viv-iste
cant-ó	beb-ió	viv-ió
cant-amos	beb-imos	viv-imos
cant-asteis	beb-isteis	viv-isteis
cant-aron	beb-ieron	viv-ieron

New Insight: We will tackle morphological irregularity *probabilistically*

Regularity = Predictability

- For each language
  - **Step 1:** Build a really good generative probability model *p* of the morphological paradigm
  - **Step 2:** Train its parameters on some data
  - **Step 3:** Irregularity = -log *p*(**held-out data**)

Morphological Reinflection

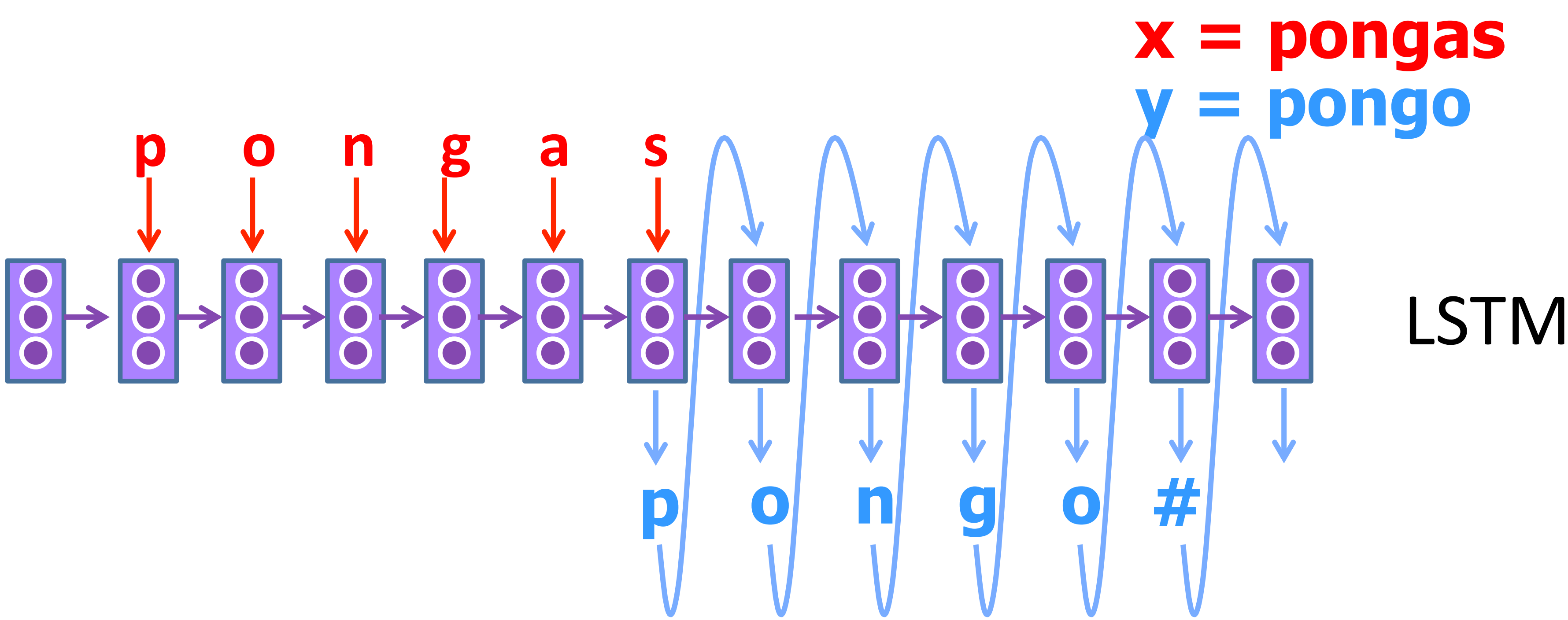
- Start with pair-wise probability distributions

$$p\,(\text{pongamos} \mid \text{pongo})$$

1ps;prs;sbjv;pl 1ps;prs;ind;sg

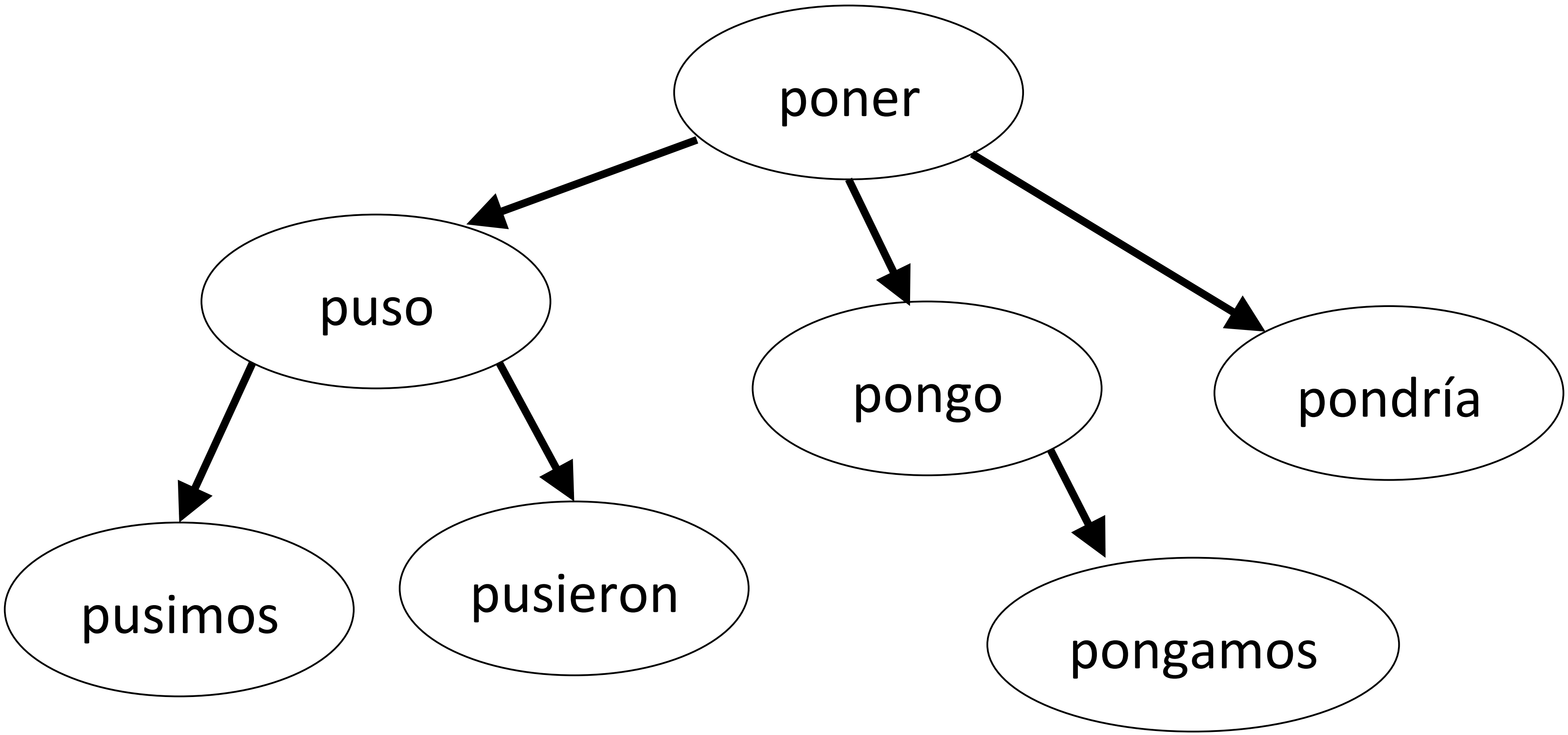
- In NLP, this task is known as **morphological reinflection**
  - Three shared tasks: SIGMORPHON (2016), CoNLL (2017, 2018)
  - Cotterell et al. (2016,2017) for overview of the results
  - State of the art: LSTM seq2seq model – same as MT

Sequence-to-Sequence Model

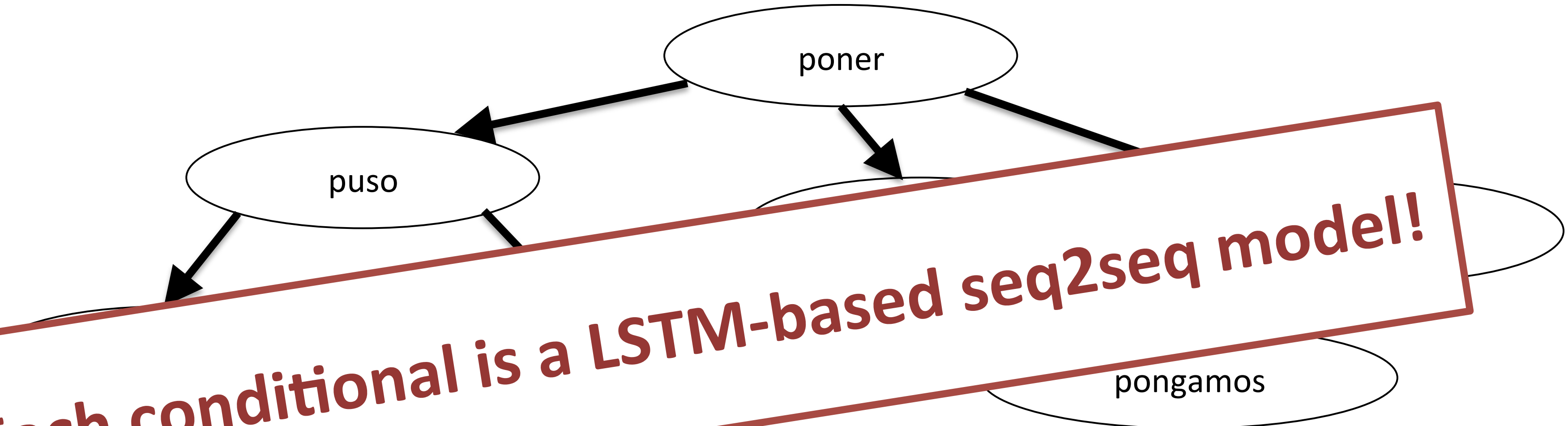


p(**y** | **x**) reads **x**, then stochastically emits chars of **y**, 1 by 1, like a language model

Arrange into a Bayesian Network



Neural Graphical Model Over Strings

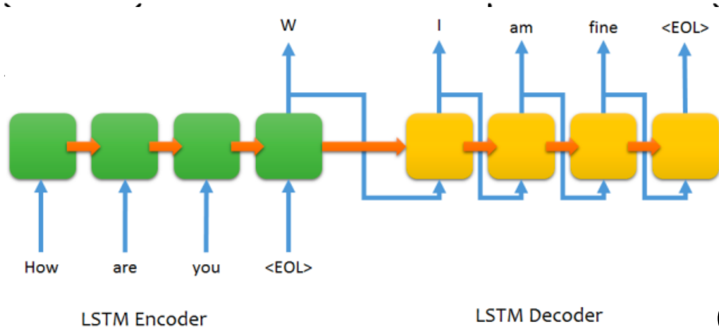


Each conditional is a LSTM-based seq2seq model!

$$p(\text{pusieron} \mid \text{puso})$$

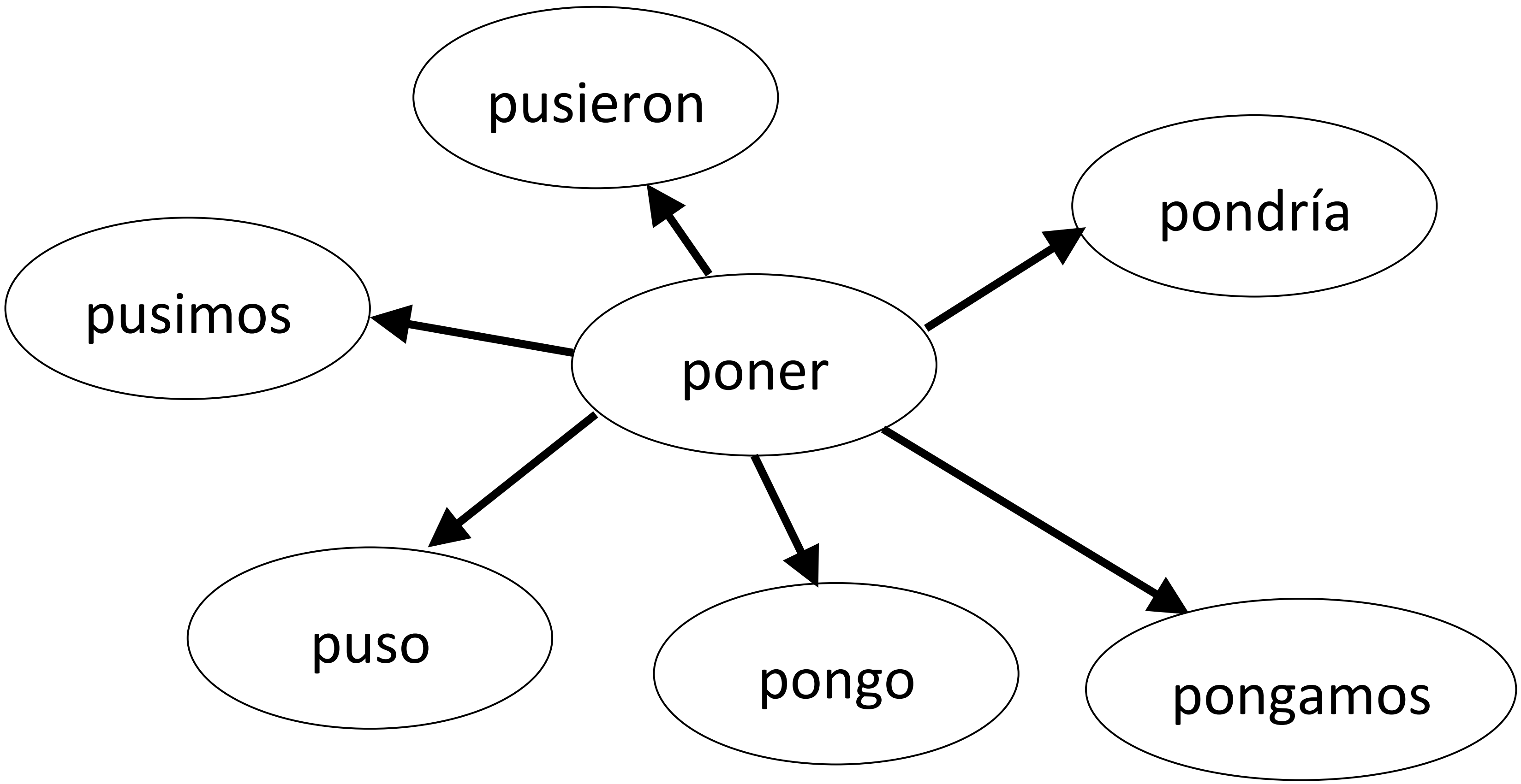
$$p(\text{pusimos} \mid \text{puso}) \cdot p(\text{pusieron} \mid \text{puso}) \cdot p(\text{puso} \mid \text{poner}) \cdot$$

$$p(\text{pongo} \mid \text{poner} \quad \ldots \quad) \cdot p(\text{pongamos} \mid \text{poner})$$



Cotterell et al. (2017) @ EACL 2017

Many Possible Networks



How to Choose Best Tree?

- Standard structure learning problem in graphical models
- Strategy: Tie parameters among all conditionals
  - Conditionals for every possible tree trained together
- Inspired by Chow-Liu Algorithm
  - Use Chu-Liu-Edmonds
  - Finds optimal directed spanning tree in $O(n^3)$ time

Experimental Languages

- Data from the UniMorph (Kirov et al. 2018)
- Selected languages with "enough" training examples
- Verbal Paradigms:
  - 23 languages / 3 families
- Nominal Paradigms
  - 31 languages / 3 families

Cross-linguistically Compatible Labels

Akademie	Akademie	N;ACC;SG
Akademie	Akademie	N;DAT;SG
Akademie	Akademie	N;GEN;SG
Akademie	Akademien	N;ACC;PL
Akademie	Akademien	N;DAT;PL
Akademie	Akademien	N;GEN;PL
Akademie	Akademien	N;NOM;PL
Akademie	Akademie	N;NOM;SG
Akademiker	Akademiker	N;ACC;PL
Akademiker	Akademiker	N;ACC;SG
Akademiker	Akademiker	N;DAT;SG
Akademiker	Akademiker	N;GEN;PL
Akademiker	Akademikern	N;DAT;PL
Akademiker	Akademiker	N;NOM;PL
Akademiker	Akademiker	N;NOM;SG
Akademiker	Akademikers	N;GEN;SG
...		

German Nominal Paradigms

Plug For UniMorph

- Now data for over 100 languages!
- Freely downloadable from unimorph.github.io

UniMorph
Universal Morphological Annotation

Schema Software Publications Contact

UniMorph

The Universal Morphology (UniMorph) project is a collaborative effort to improve how NLP handles complex morphology in the world's languages. The goal of UniMorph is to annotate morphological data in a universal schema that allows an inflected word from any language to be defined by its lexical meaning, typically carried by the lemma, and by a rendering of its inflectional form in terms of a bundle of morphological features from our schema. The specification of the schema is described here and in Sylak-Glassman (2016).

Estimating the Parameters

- Estimating morphological irregularity is now a standard machine learning problem

- Model is trained using gradient descent on UniMorph data
  - Best model selected on development data

- Irregularity = loss on held-out data

But why is there a trade-off?

- This paper shows the existence of a trade-off between two types of morphological complexity
- The real scientific question is *why*?
- On-going work guesses that it has to learnability and the learning infrequent, irregular forms
  - I.e., rare forms tend to regularize
- Artificial learnability study already available
  - Preliminary version on arXiv

Linguistic Complexity More Broadly

A Twitter Poll About Complexity

Ryan D. Cotterell
@_shrdlu_

Do you think your native language is more complex than English? (If you speak a language other than English natively.) #acl2018

Also, come to my talk at 17:00 tomorrow @acl2018 on that very topic!

79%	Yes
21%	No

109 votes • 1 day left

Equal Complexity Hypothesis

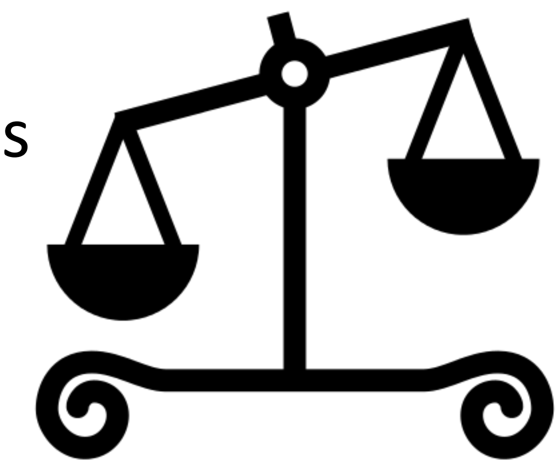
- Hockett (1958) argued that all languages are equally complex
- Idea goes back much further in the linguistics literature

- All languages appear to optimize for efficient communication subject to learnability

Complexity Trade-Offs

- **Corollary**: if one facet of a language is more complex, another is simpler to compensate

- **Trade-Off Example**:
  - German has more inflected forms than English (morphology)
  - English has a more complicated tense system (syntax)

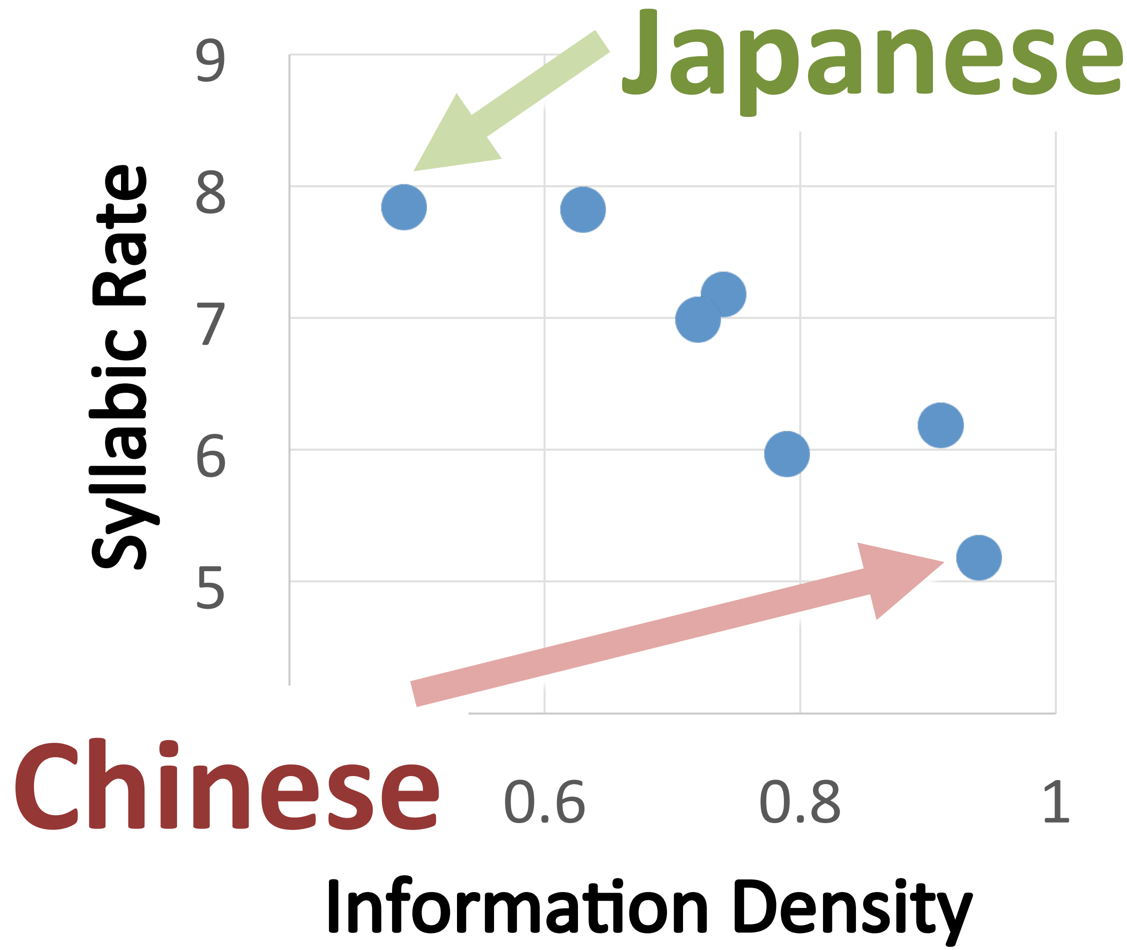


Example: Rate Of Speech (Pellegrino 2011)

- Are all languages spoken equally fast?

  No!

- Spoken Rapidly
  - Spanish, Japanese
- Spoken Slowly
  - English, Chinese



John McWhorter on Creoles

- McWhorter wrote the seminal paper in 2001
- Argues creoles are in fact less complex
- Complexity accretes over time
  - Creoles are new languages

Published Work

- Check out our NAACL 2018 paper: *All Are Languages Equally Hard to Language-Model?*

Future Work

- We only looked a specific trade-off in morphological complexity
  - Data-driven methods for trade-offs in other areas of linguistics

- Extensions look at language more holistically
  - Trade-offs between morphology and phonology
  - Trade-offs between morphology and syntax

- Why didn't linguistics already solve this problem?
  - No big data, no methods

Fin