The role of attraction-repulsion dynamics in simulating the emergence of inflectional class systems

Erich Round, Sacha Beniamine & Louise Esher

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How does predictability evolve?

Why are inflectional classes stable?

How can evolutionary models shed light on cognition?

Outline

- Inflectional classes & predictability
- How to evolve them (Ackerman & Malouf 2015)
  - But: classes are unstable, and no predictability
- New model
  - Stable inflectional classes & predictability
  - Implications for the PCFP

Inflection and predictability

Inflectional classes

- Groups of lexemes which share inflectional exponents

		sg.ind	sg.def	pl.ind	pl.def
Class I	‘bottle’	*flaska*	*flaskan*	*flaskor*	*flaskorna*
Class II	‘chair’	*stol*	*stolen*	*stolar*	*stolarna*
Class III	‘idol’	*idol*	*idolen*	*idoler*	*idolerna*

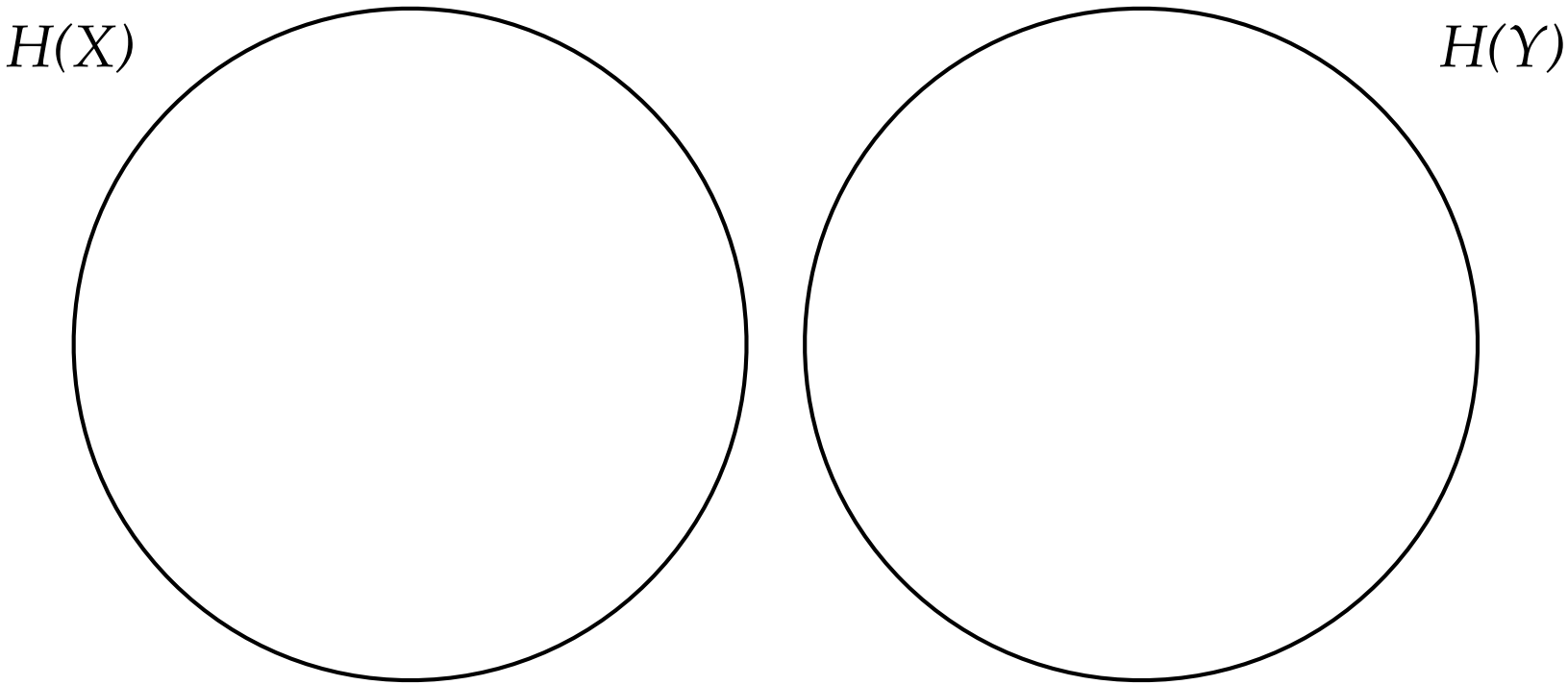
- Morphology-internal, ‘morphomic’ structure
- Psychologically real; productive
- Predictable means of distributing inflectional exponents

Enger, 2014; Round, 2015; Maiden, 2018; Carstairs-McCarthy, 2010; Blevins, 2016

Entropy ≈ uncertainty

- Entropy of cell X ≈ uncertainty when guessing cell X
- Guess 2pl.SUBJ, given that:
  - 90% of lexemes use *-u*, 10% use *-a*
  - 20% use each of {*-u, -a, -is, -on, -e*}
- Inflectional classes contribute to predictability
  - Uncertainty about cell X may be ameliorated by knowing cell Y
  - Entropy of X may be reduced by knowing Y

Mutual Information



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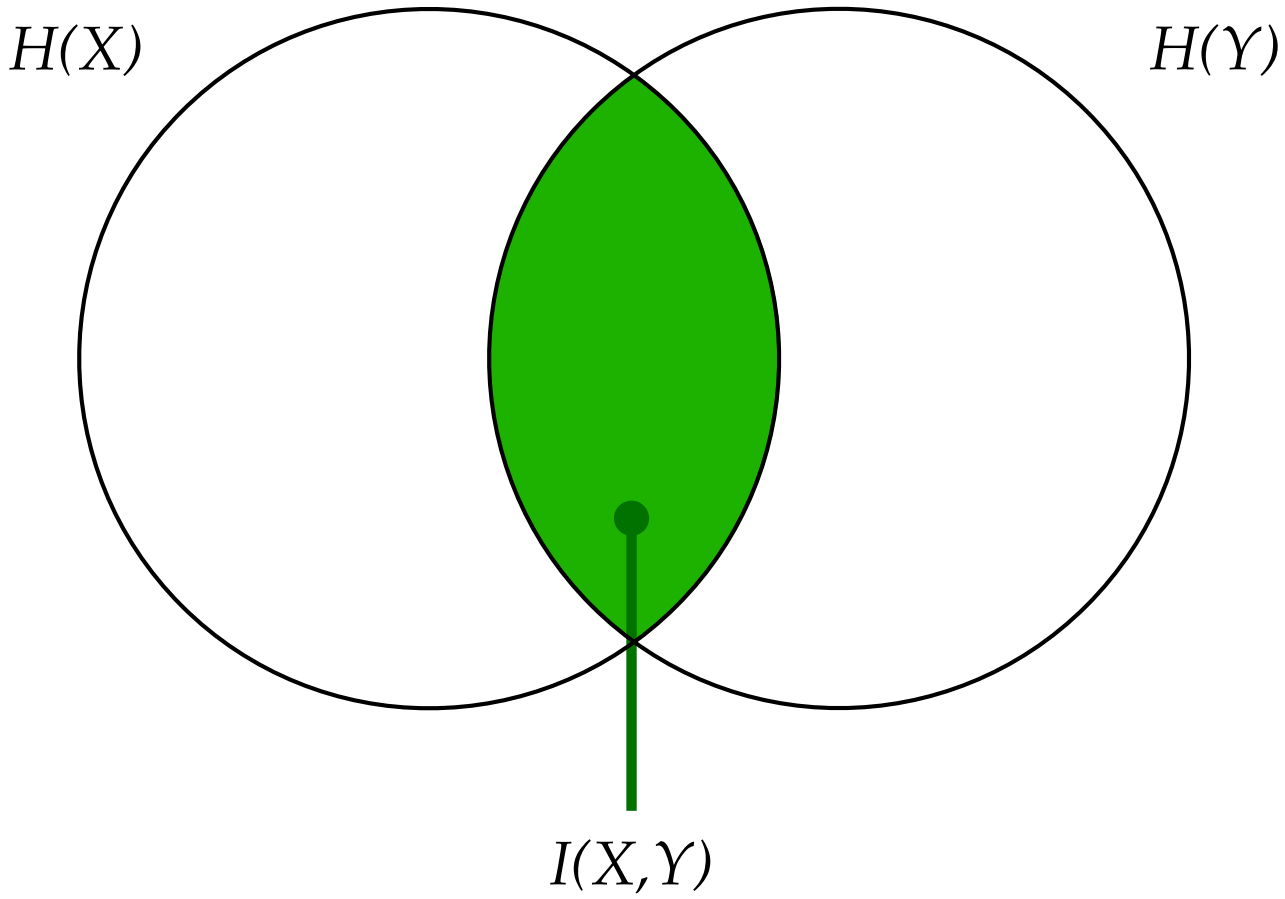
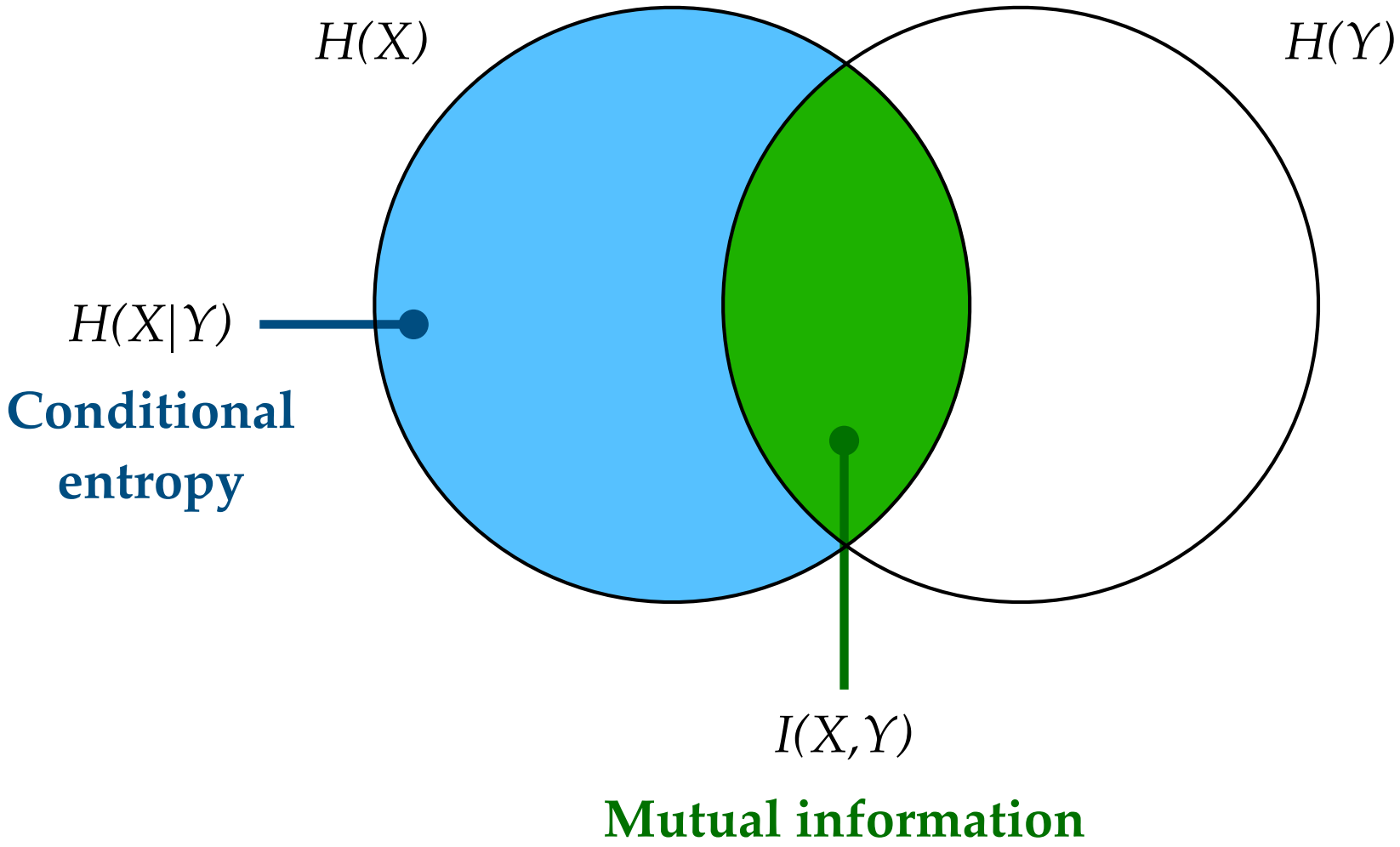


Mutual information

Conditional Entropy



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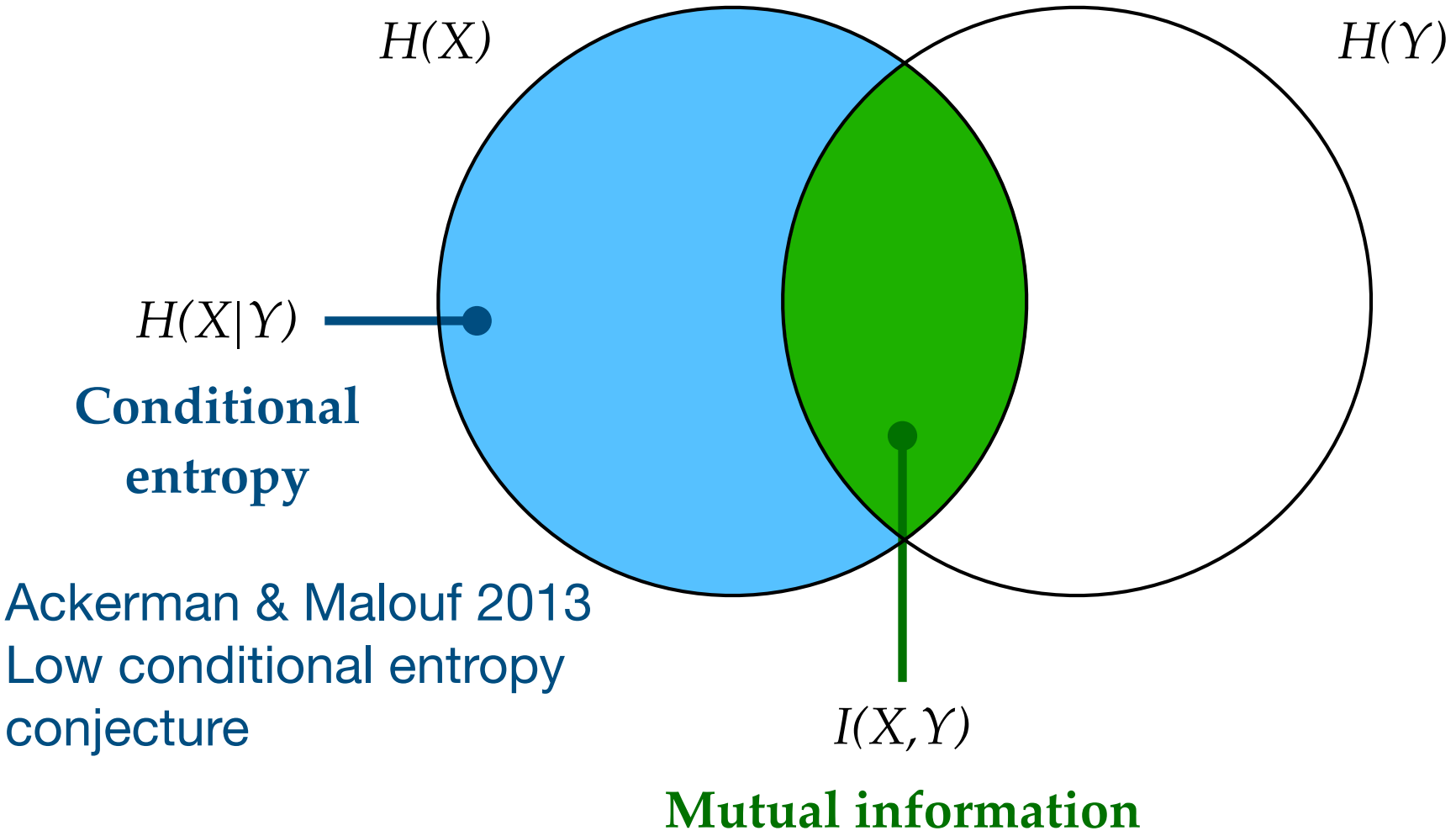


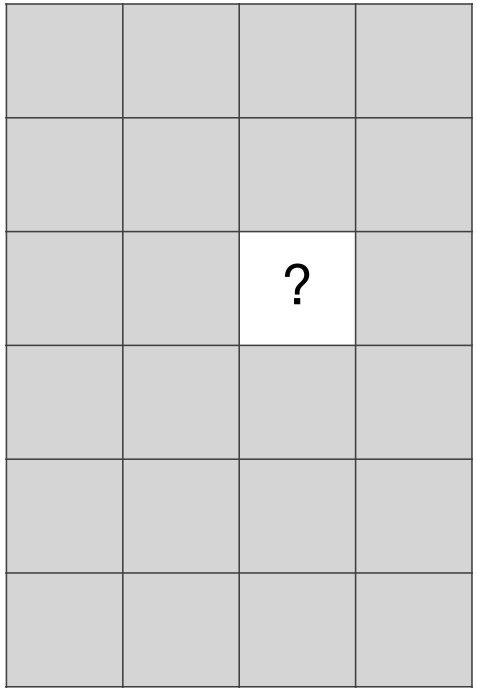
Ackerman & Malouf 2013
Low conditional entropy conjecture

Why be predictable?

- Facilitates acquisition
- Facilitates use — comprehend & produce cells by inference

- But, how do languages **become** predictable?
  - Suppose systems change according to some simple process
  - And this spontaneously leads to low conditional entropy
  - What could that simple process be?
  - Evolutionary model

Model process: paradigm cell filling



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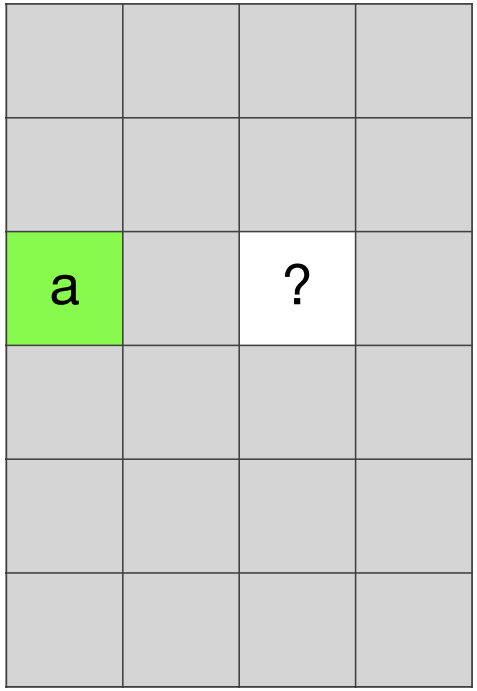

Model process: paradigm cell filling

a			
b			
a		?	
c			
a			
a			

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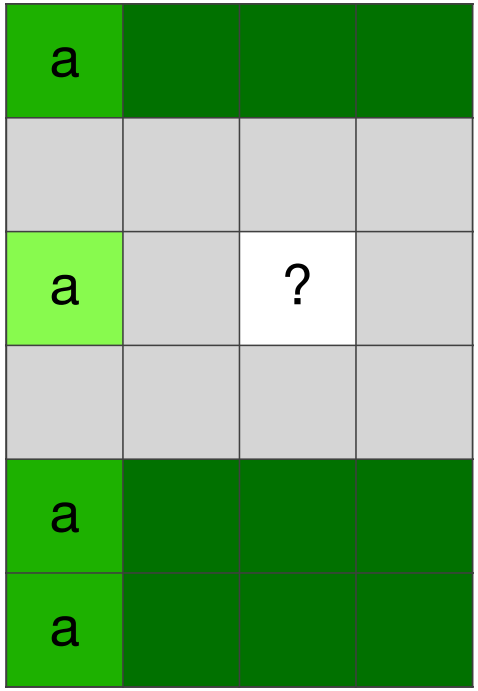

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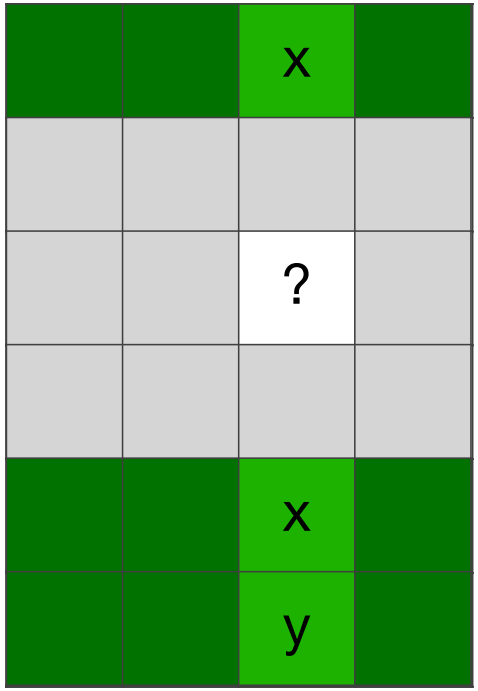

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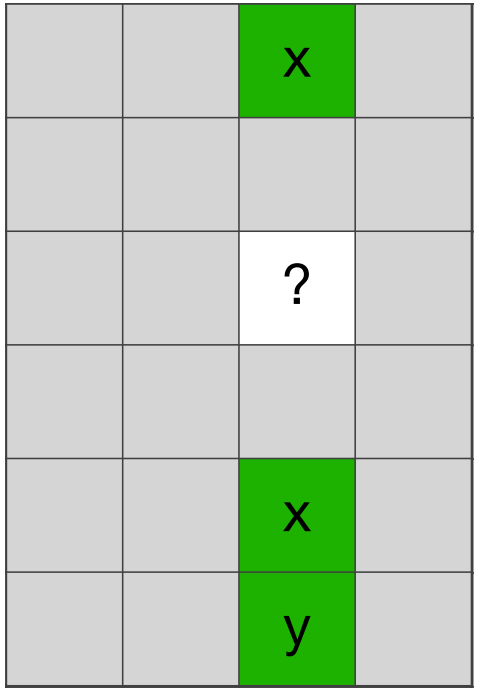

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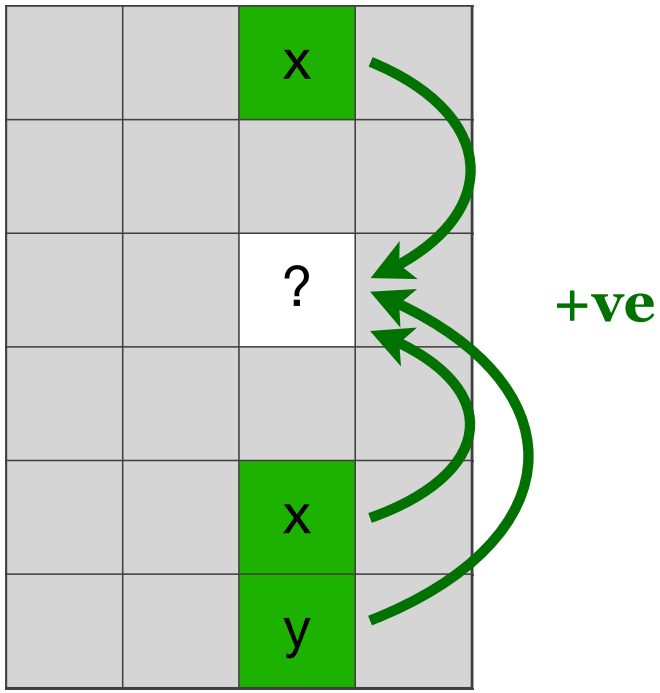

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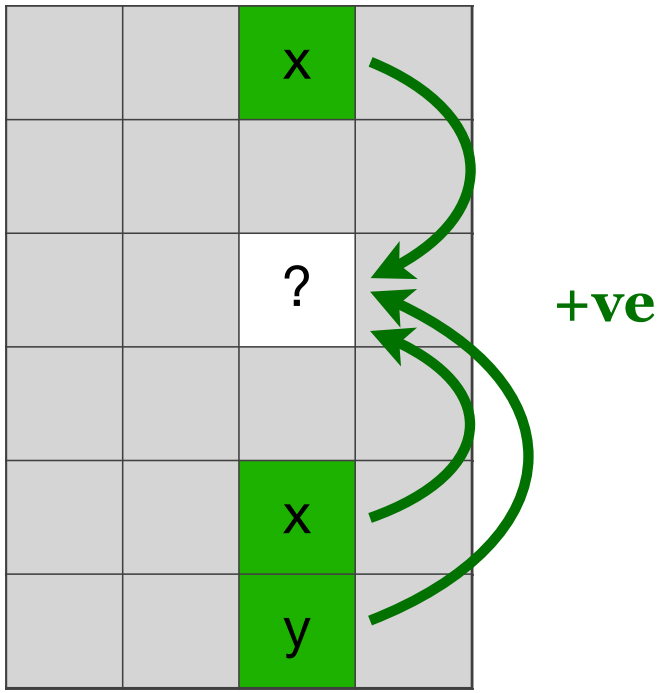

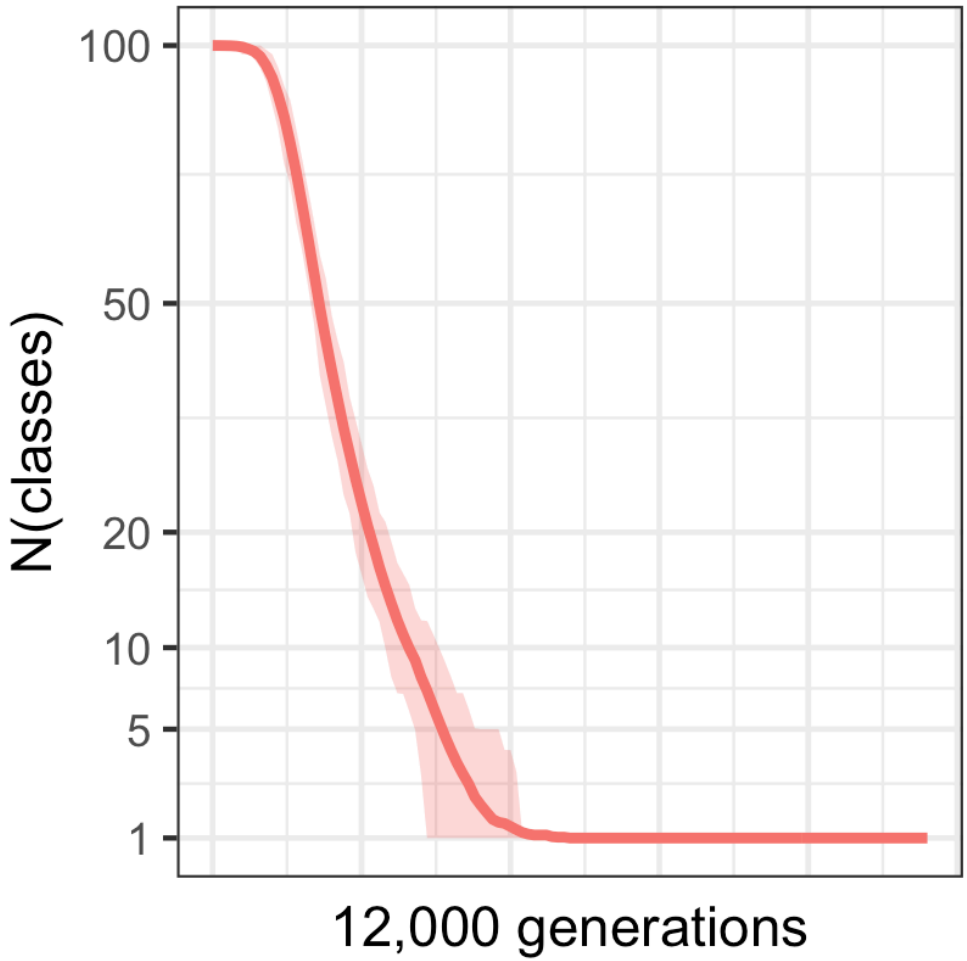

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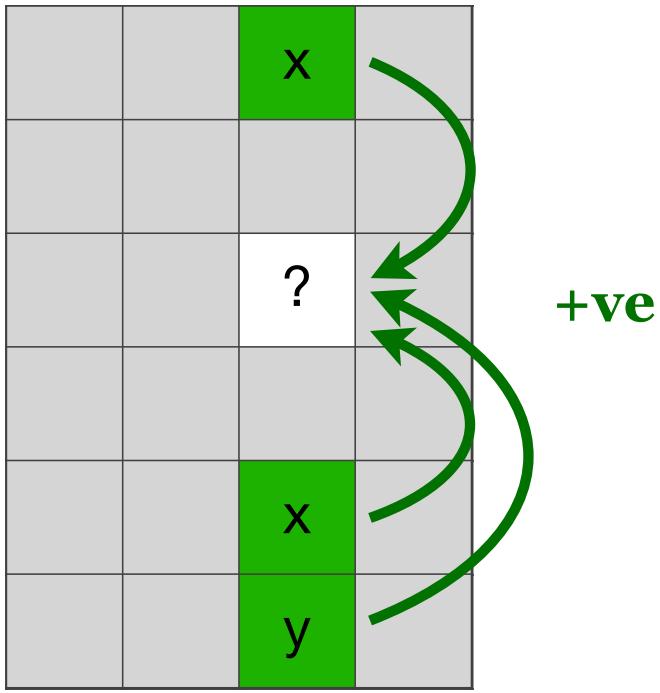
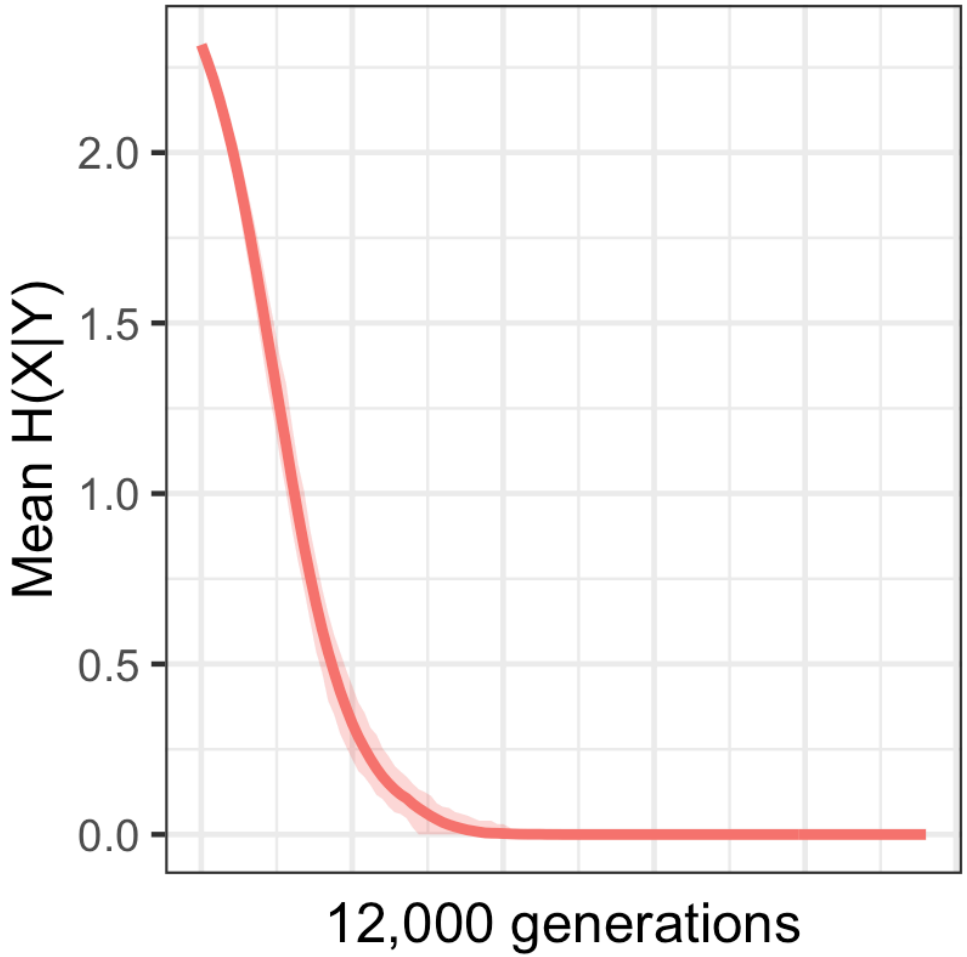




Low conditional entropy emerges

- In this model, low conditional entropy
  - is not stipulated
  - steps not defined as “decrease conditional entropy”
  - rather, an **emergent property** when systems change

The value of modelling

- Aim is **not** to claim:
  - ‘low conditional entropy is due to this process’
- Rather, to investigate: how good the conformity is between
  - Observed properties of real systems
  - Outcomes from the model
- Establish *prima facie* grounds for seriously entertaining certain kinds of explanatory theories in morphology

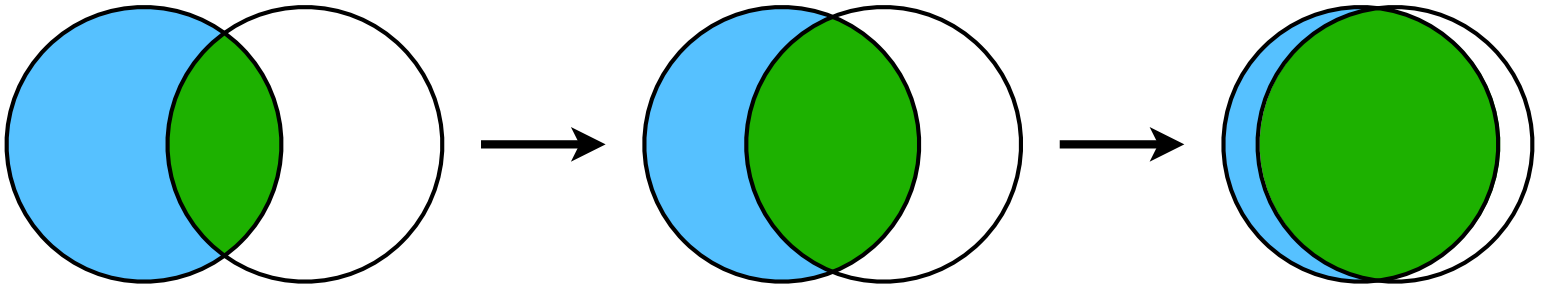
Two problems

- Apparent successes of the AM model :
  1. System self-organises into coherent inflectional classes
  2. Low conditional entropy emerges

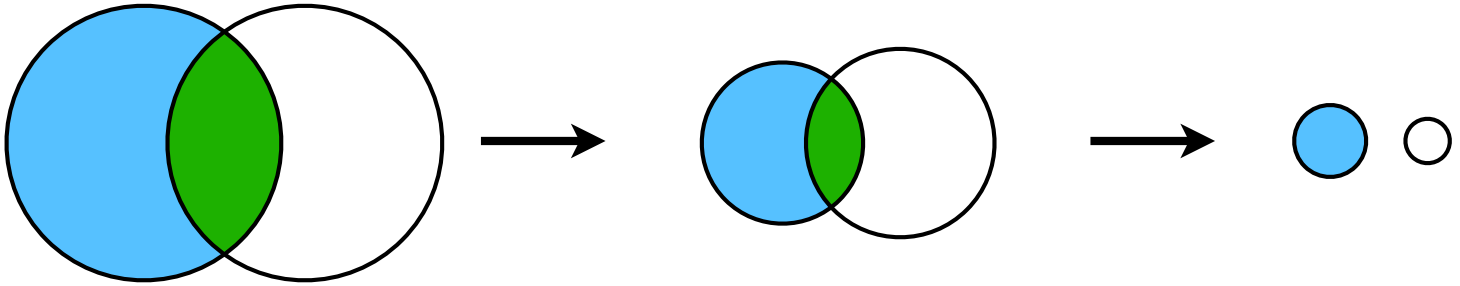
- Problems:
  1. Inflectional classes always unstable and collapse
     - cf. real systems—multiple, stable inflectional classes
  2. Low conditional entropy emerges for the wrong reason

Two ways for H(X|Y) to decrease

- Decrease due to increasing predictability

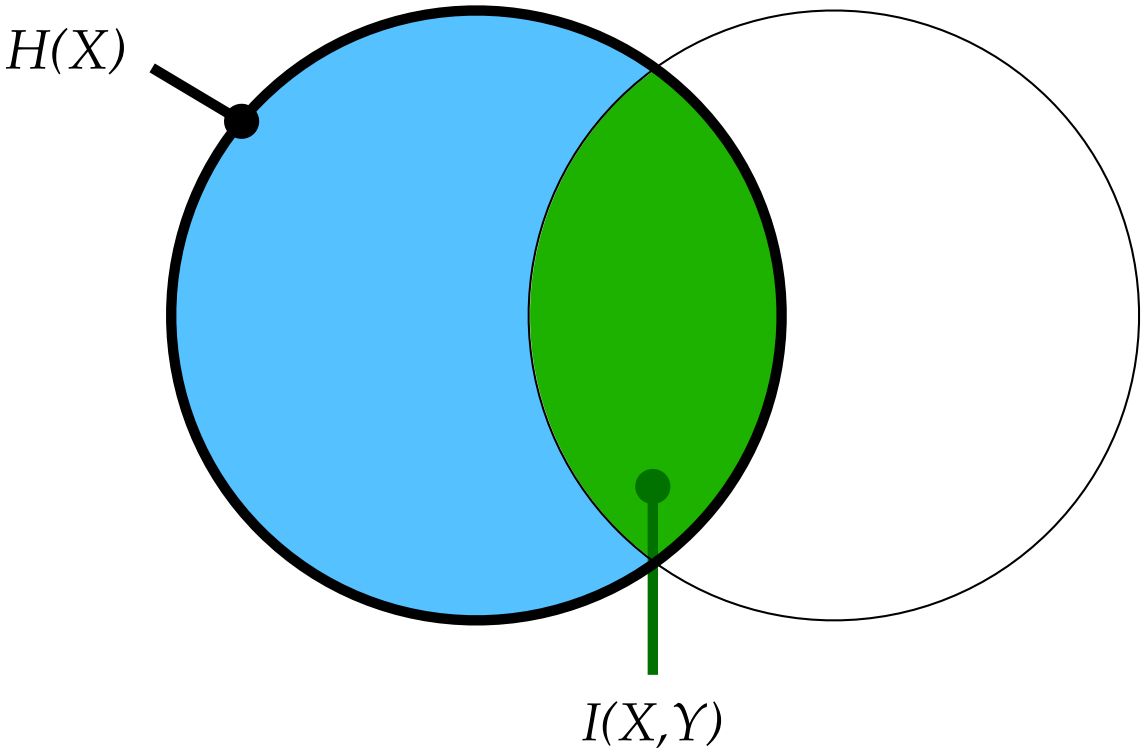


- Decrease due to shrinking H(X), i.e., circles get smaller:



Theil's U

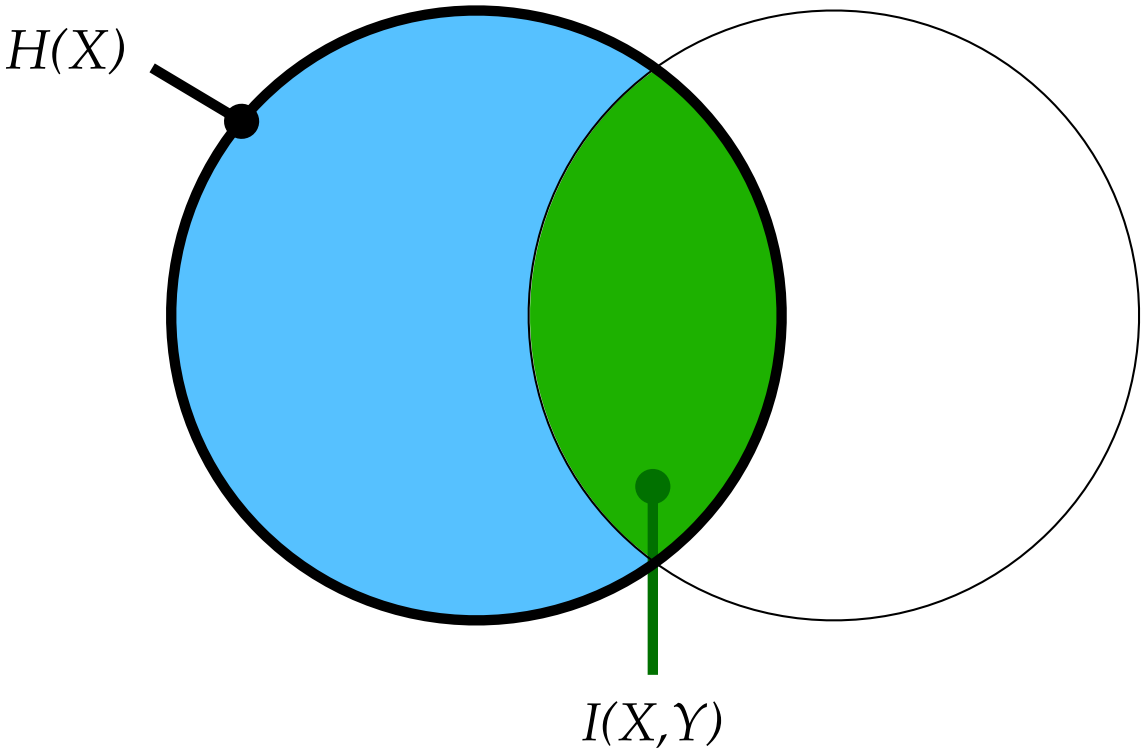
- $U(X|Y) = \frac{}{} = \frac{I(X, Y)}{H(X)}$



Mutual information

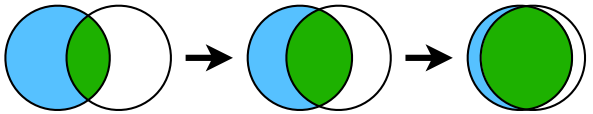
Theil's U

- $U(X|Y) = \dfrac{\text{green}}{\text{blue}} = \dfrac{I(X,Y)}{H(X)}$

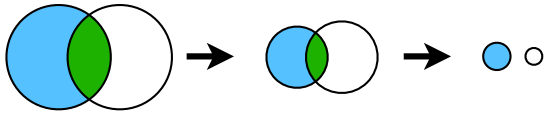


Mutual information

- Rising U(X|Y):



- Falling U(X|Y):



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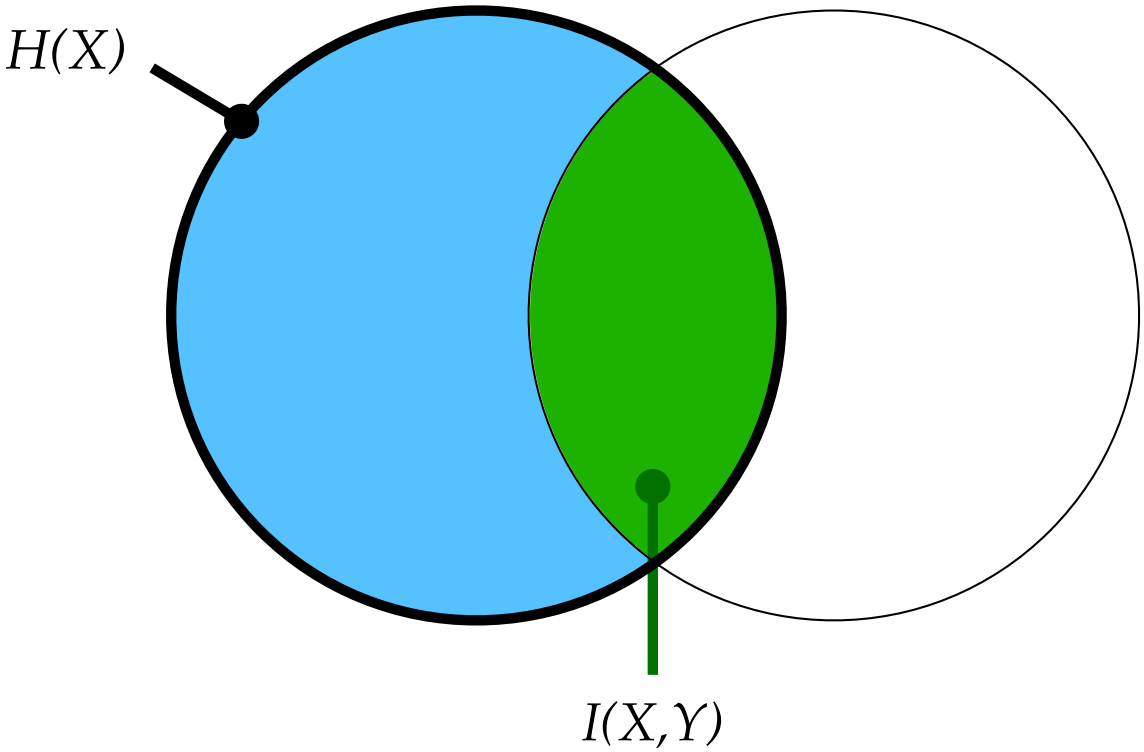

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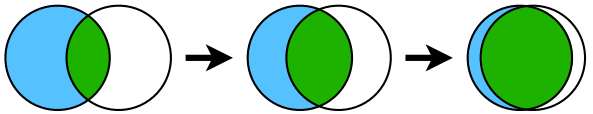

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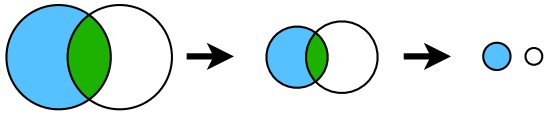
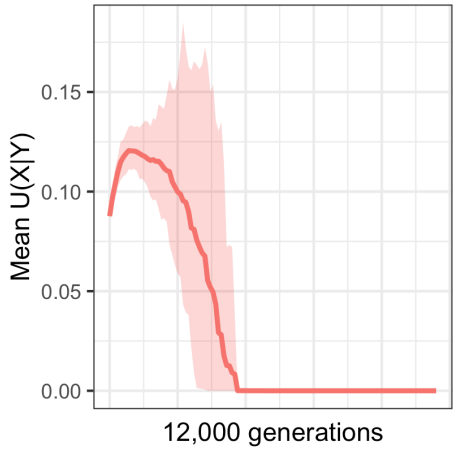


- AM model:



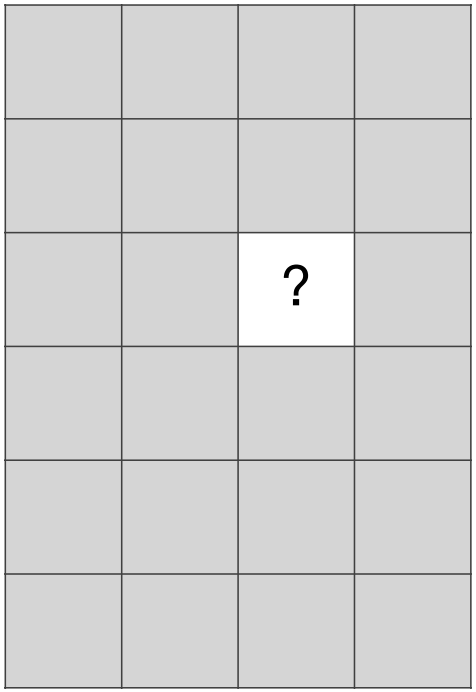
Variants of AM, same behaviour

- Sample lexemes with realistic (Zipfian) bias
- Sample at more lexemes
- Sample more cells
- Results are the same

A new model

Our model

- Make good use of evidence available in the system



Simon 1955, Griffiths 2020, Voorspoels et al. 2015

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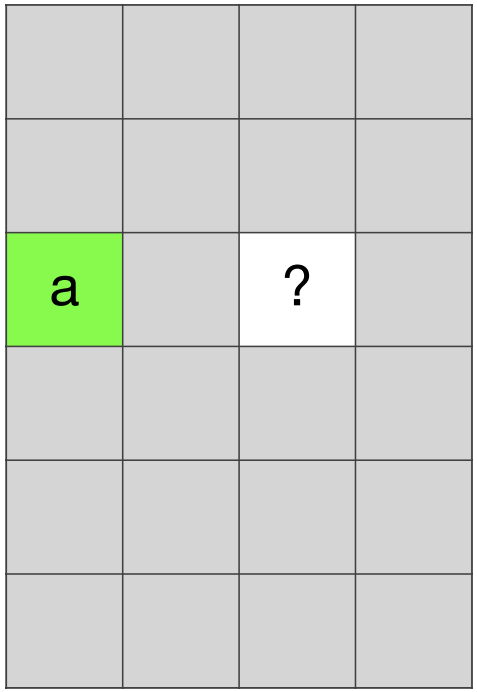

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a			
b			
a		?	
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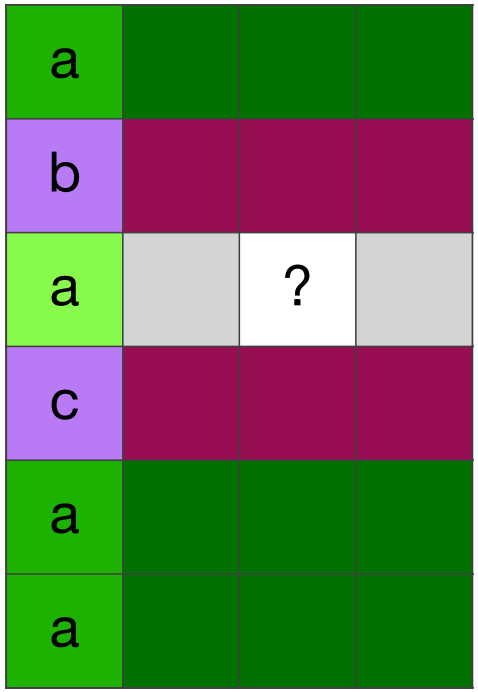

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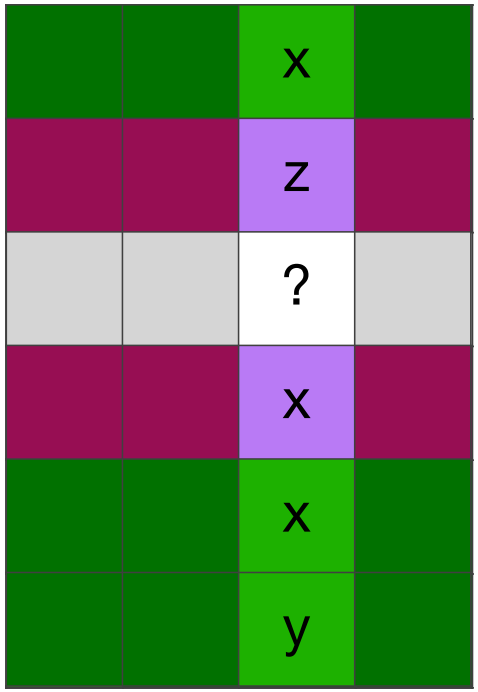

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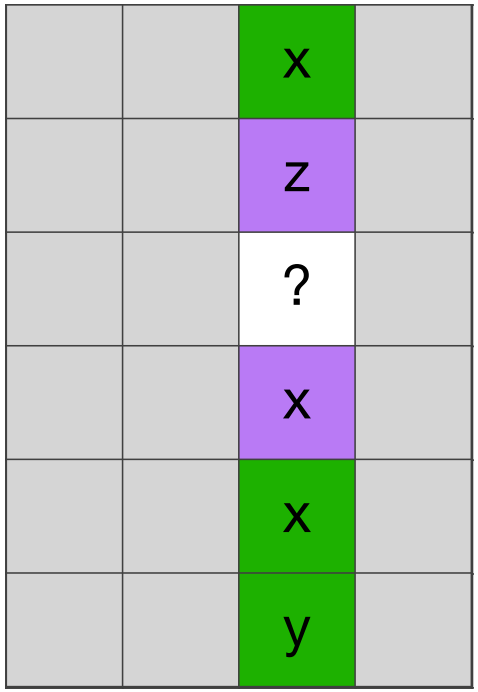

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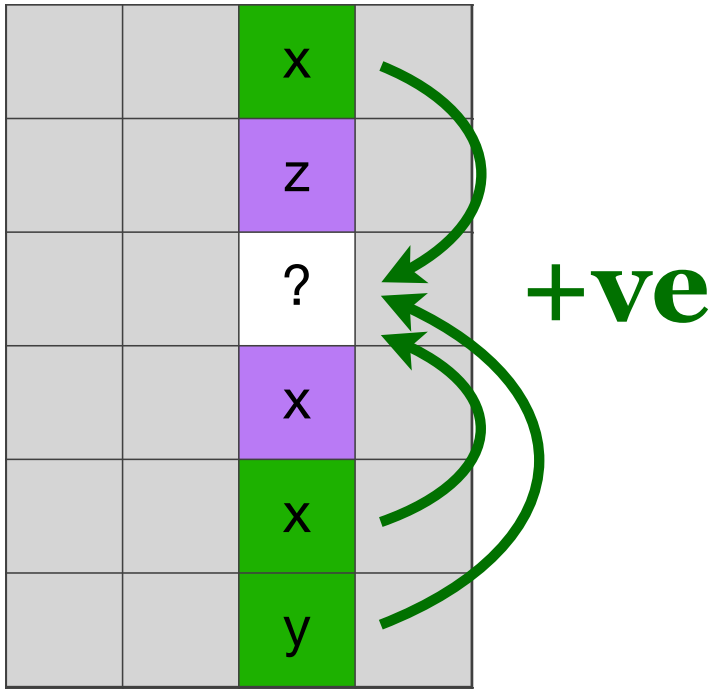

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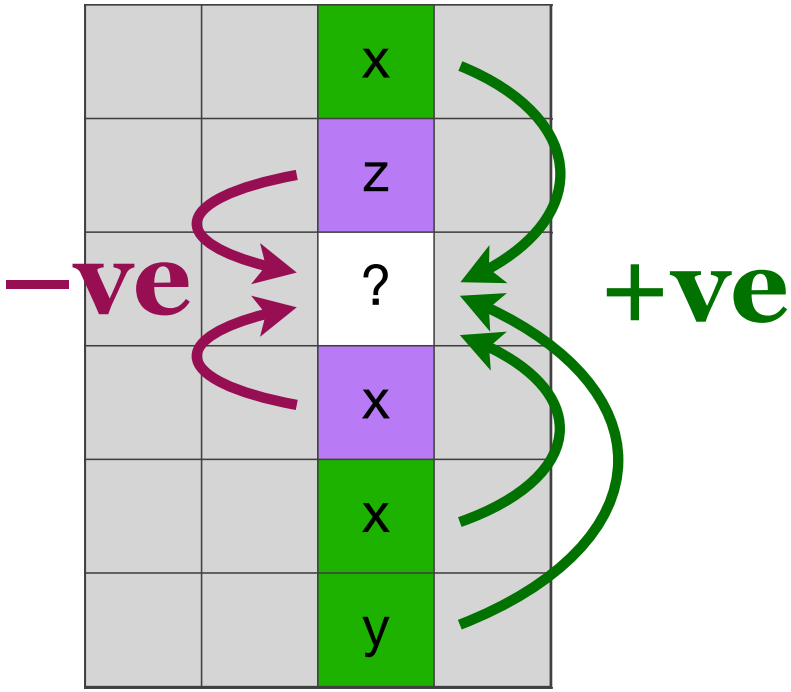
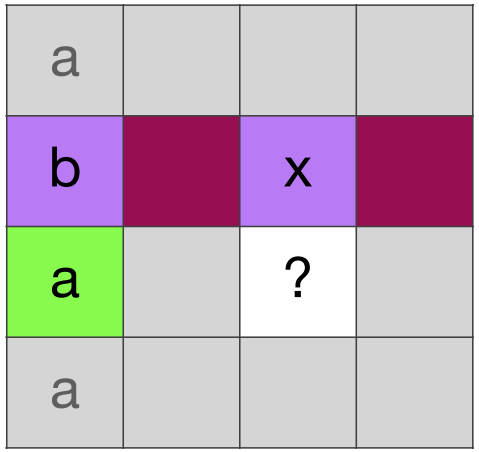


Simon 1955, Griffiths 2020, Voorspoels et al. 2015

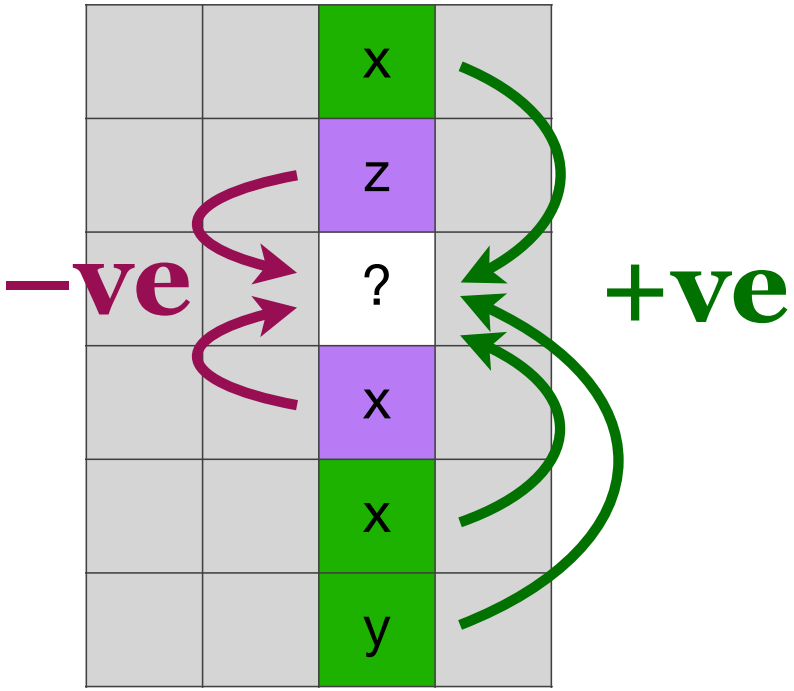
What justifies negative evidence?

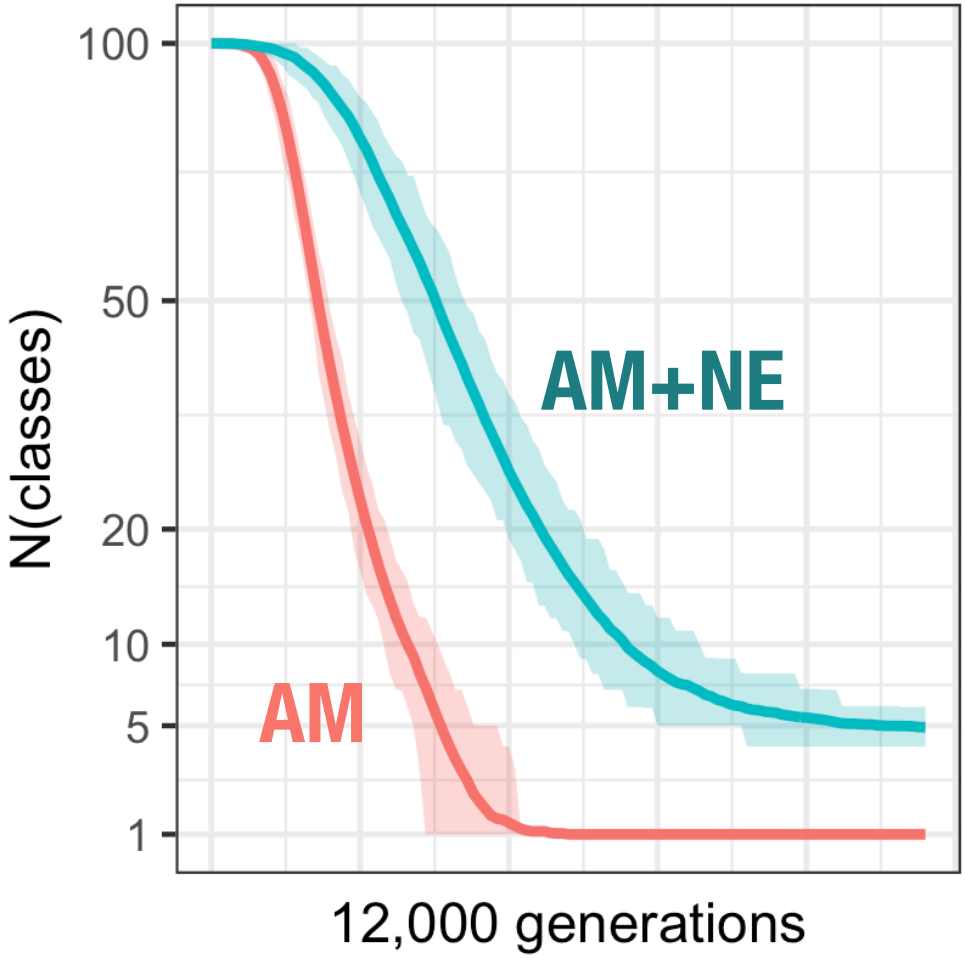
- Suppose that
  1. My current estimate is that [?] has a 20% probability of x
  2. Next, I observe that a **different** inflectional class uses x



- I have just learnt: some x's have been "used up" by this class
- Rational response: update probability of [?] = x to <20%.

Our model (AM+NE) — results





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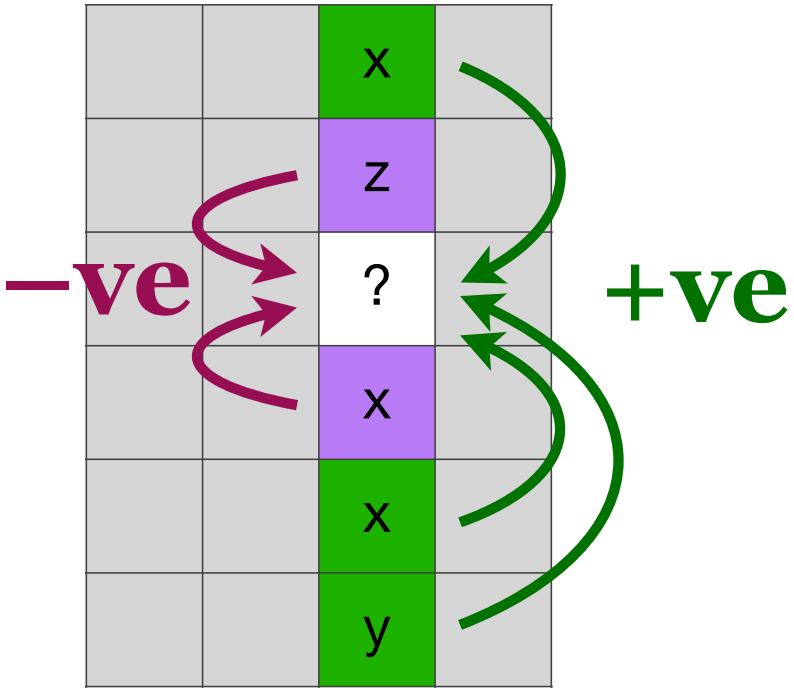

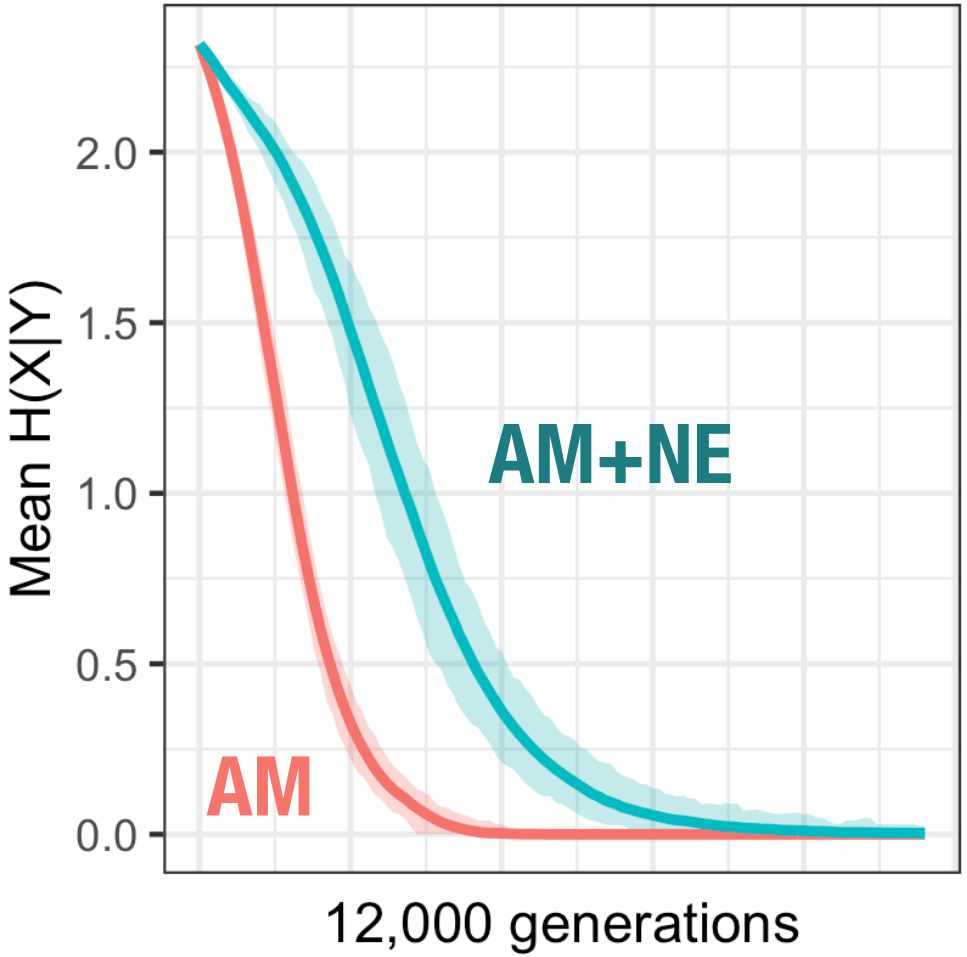

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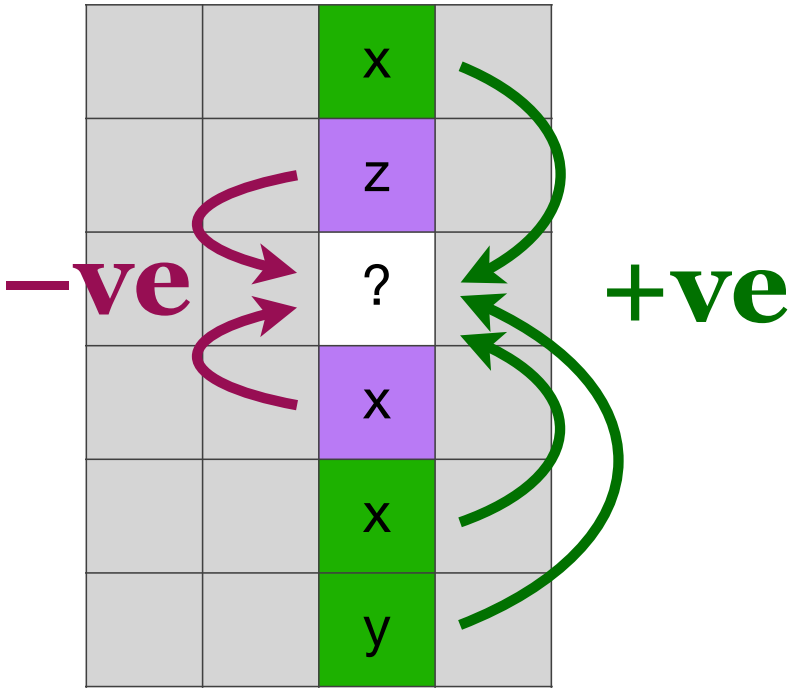

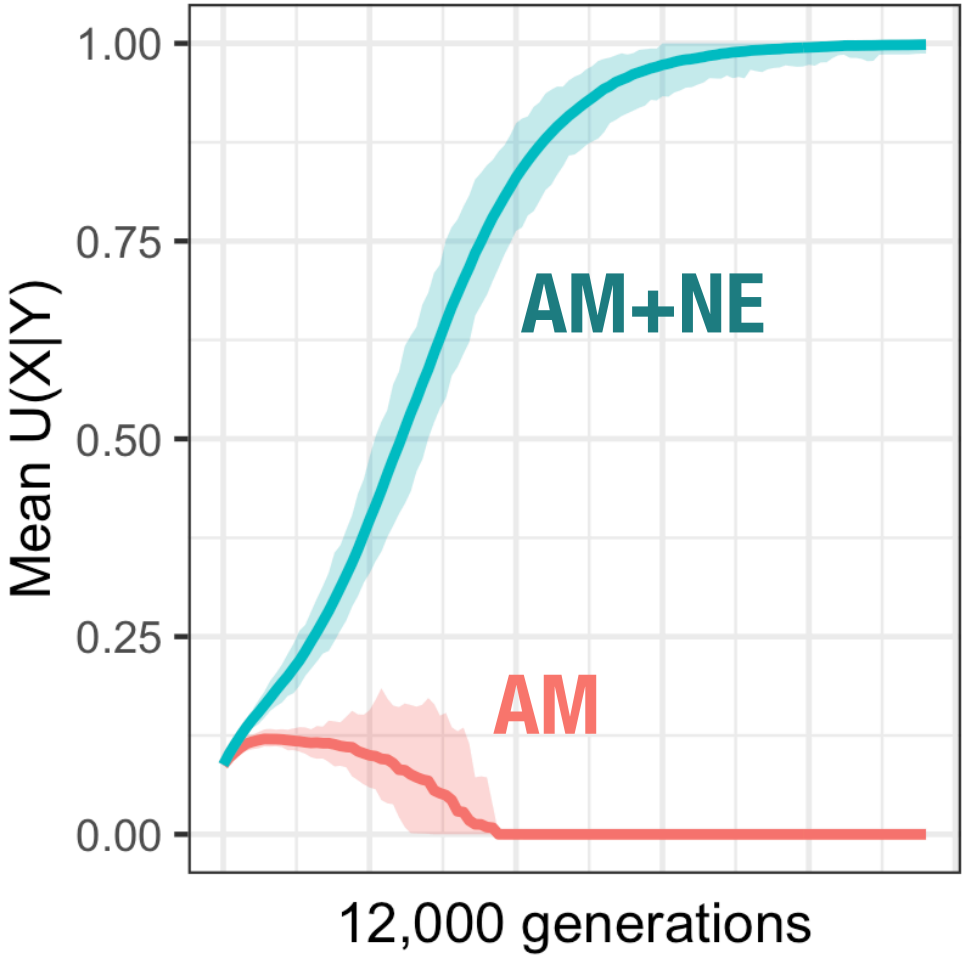

Discussion

Approach & results

- In the spirit of Ackerman & Malouf (2015)
  - Invoked a very simple process of change
  - Examined the conformity between:
    - Properties of real systems (stable classes; predictability)
    - Outcomes from the model
- Out of our model emerge:
  - Distinct, stable inflection classes
  - True predictability, U(X|Y)

	AM model	AM + Negative Evidence
Processes of change	Lexemes only get more similar	(Dis)similar get more (dis)similar
Evolutionary dynamics	Pure attraction	Attraction & repulsion
Evolutionary outcomes	Inescapable collapse of all classes	Coalescence, but stable maintenance of distinctions

Conclusions

- Plausible route: stable inflectional classes emerge
- Mechanism: PCFP, inference sensitive to negative evidence

- Potential of evolutionary models to shed light on cognition:
- Argument from evolutionary consequences: in the PCFP,
  - Negative evidence may play an important role
  - Needs to be taken into account

Thank you!

Future directions

- The PCRP — paradigm cell recognition problem
- PCFP with additional conditioning factors
- Hierarchical Bayesian models of acquisition + use
- Model runs with
  - non-random initialisation
  - additional historical perturbations
- …