More learnable than thou?

Testing knowledge representations with realistic acquisition data

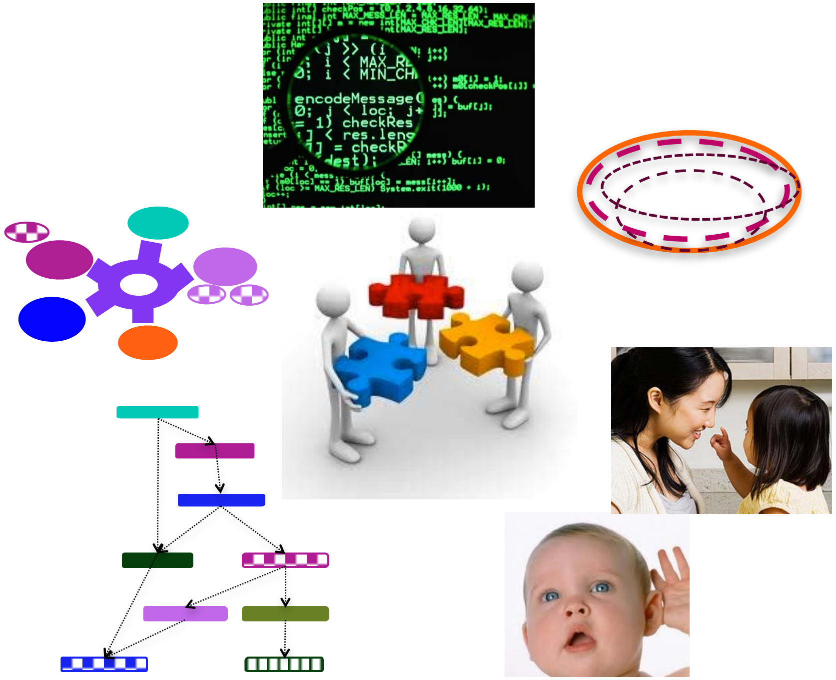
Lisa Pearl

University of California, Irvine

Computation of Language Laboratory
UC Irvine

Zephyr Detrano

Tim Ho



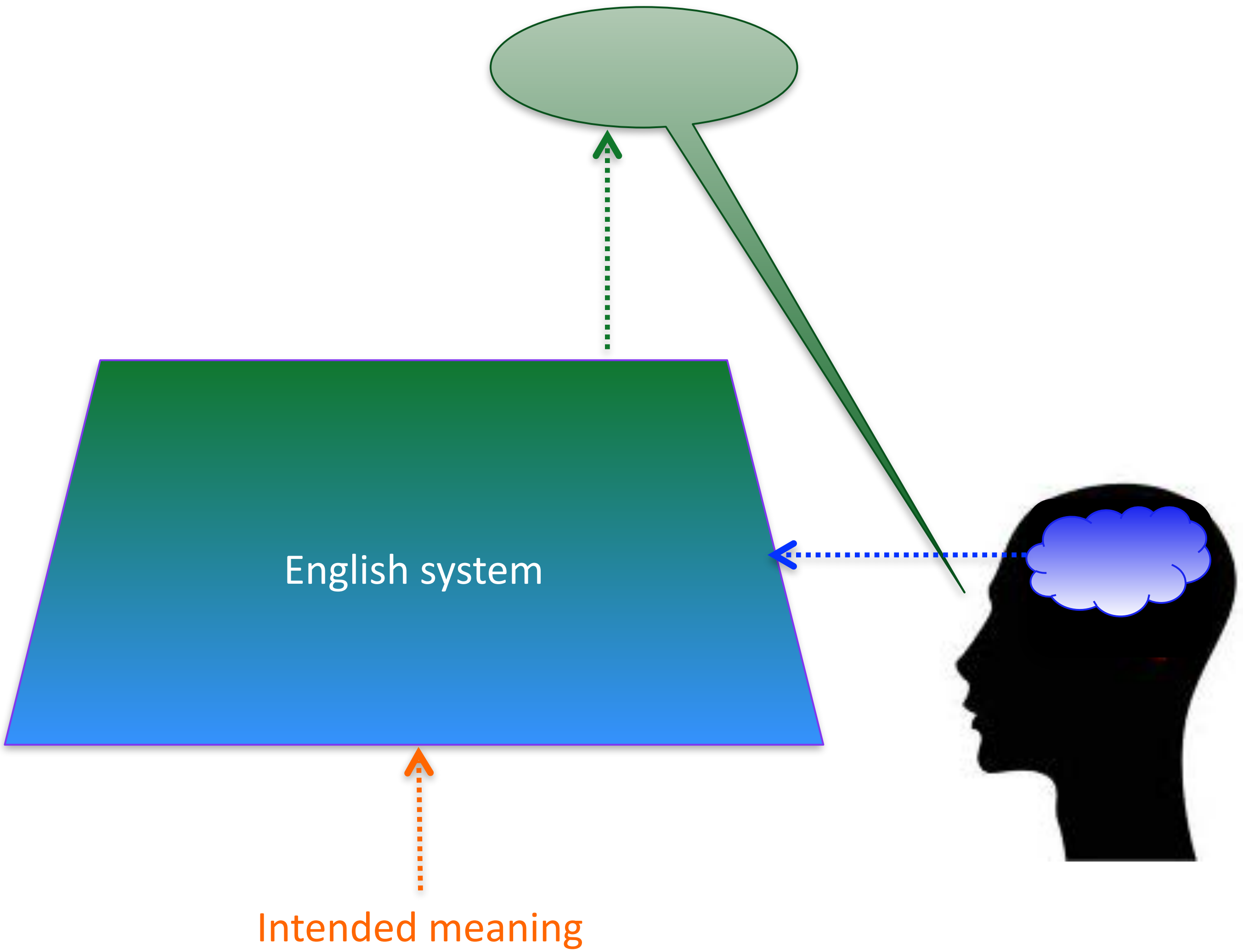
January 17, 2014:

Linguistics Colloquium

University of California, Santa Cruz

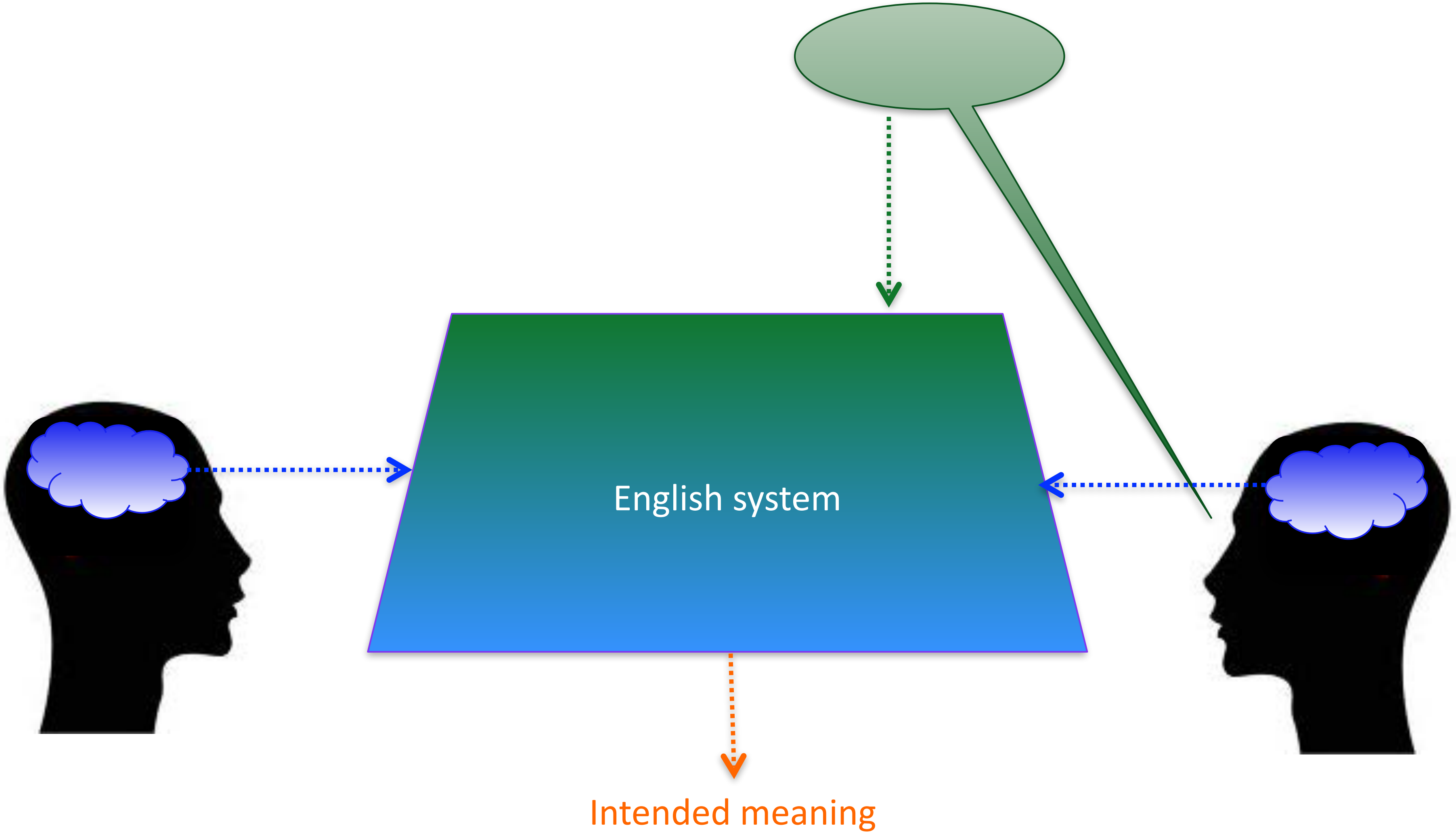
Grammar = Generative system

A language's grammar is often thought of as a generative system speakers use to produce and comprehend the language.



Grammar = Generative system

A language's grammar is often thought of as a generative system speakers use to produce and comprehend the language.

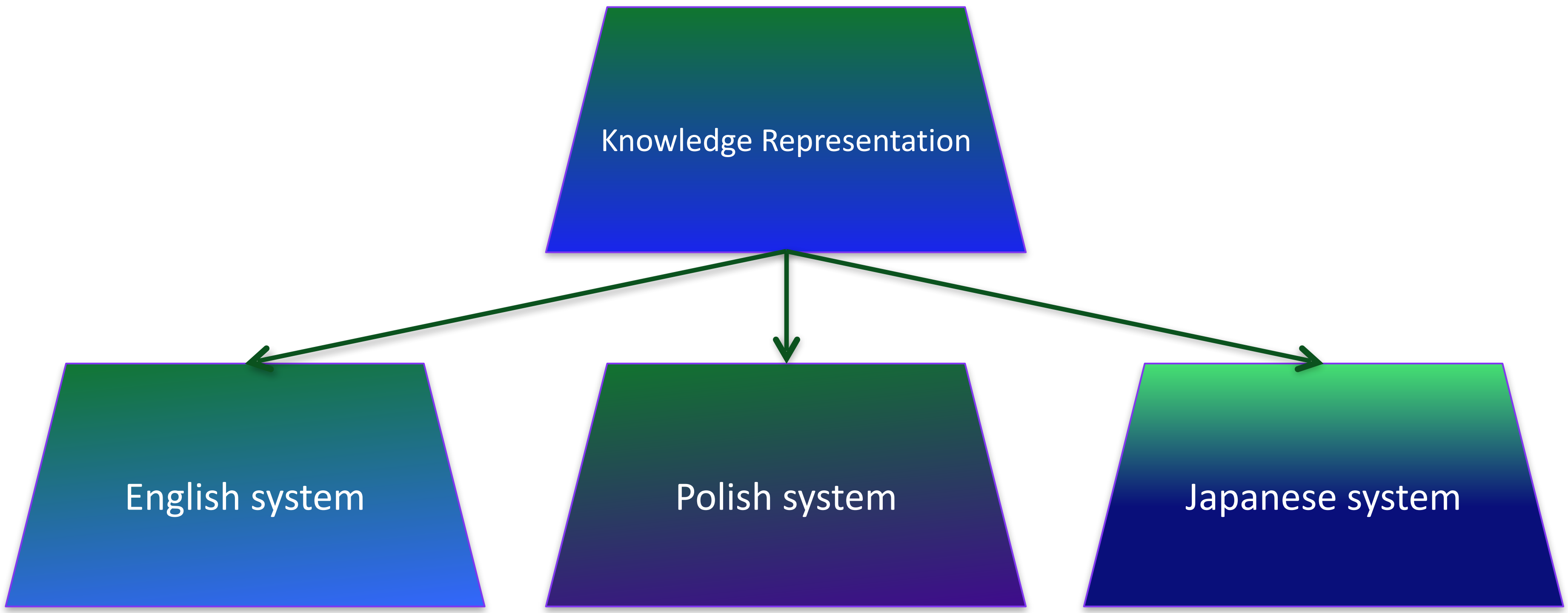


Grammar variation

The generative system can be instantiated in various ways so that it can handle any of the world's languages, and these different ways seem to have something in common.

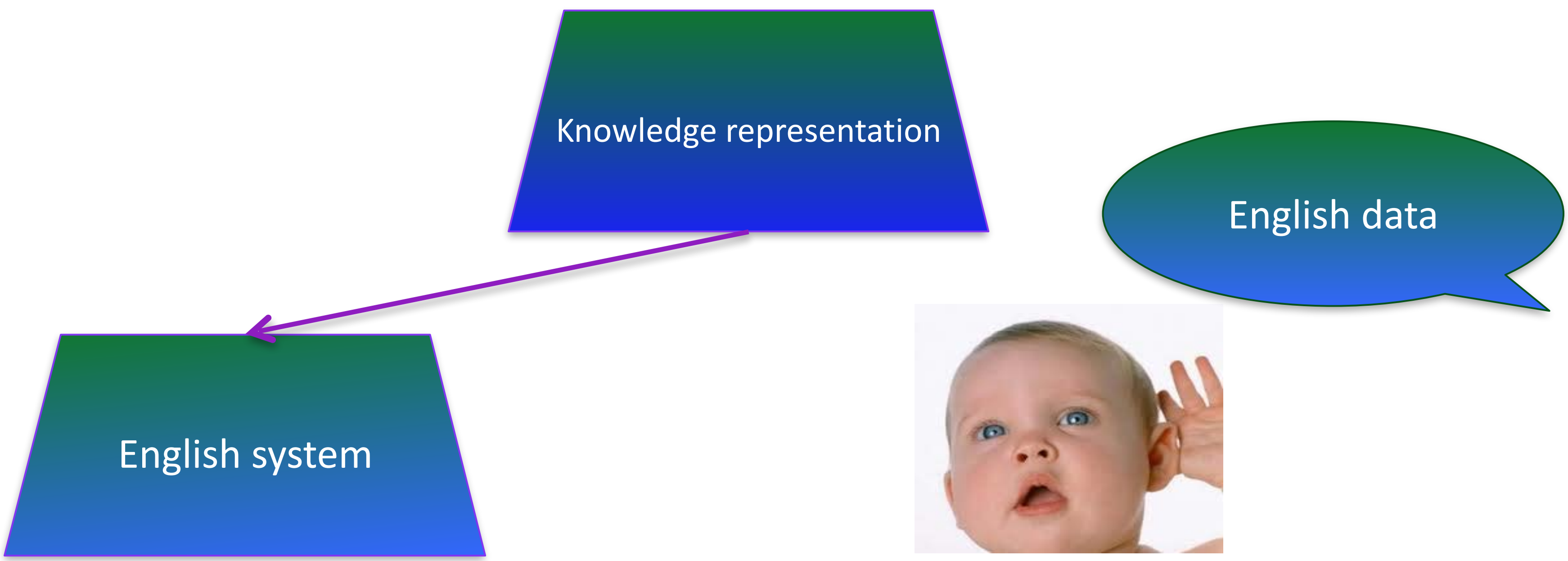
Grammar instantiations = Knowledge representation

The knowledge representation encodes information about the general form that grammars for human languages can have.



Grammar instantiations = Knowledge representation

Idea: If the child already knows the general form that grammars for human languages can have, all she needs to do is learn to instantiate her language's grammar appropriately, based on the input data from her language.

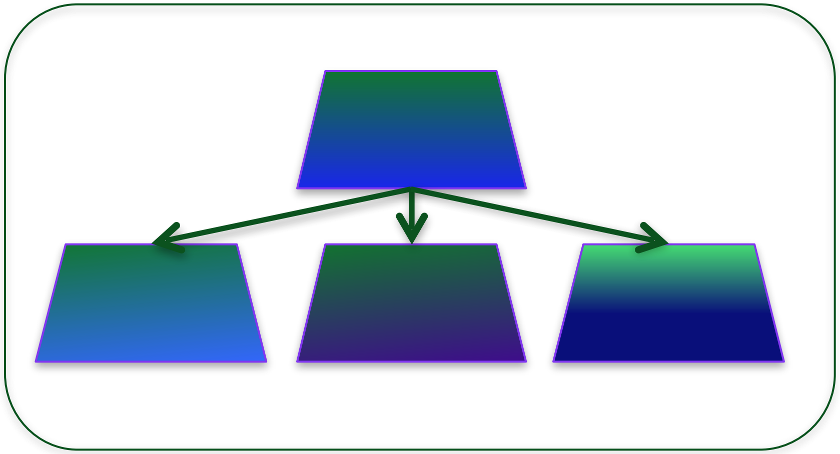


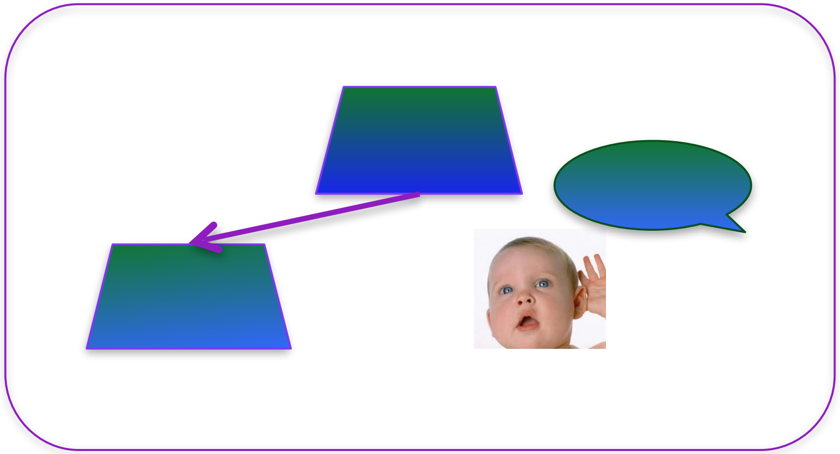
Knowledge representations

This suggests two checkpoints for any knowledge representation:

(1) it should explain constrained cross-linguistic variation

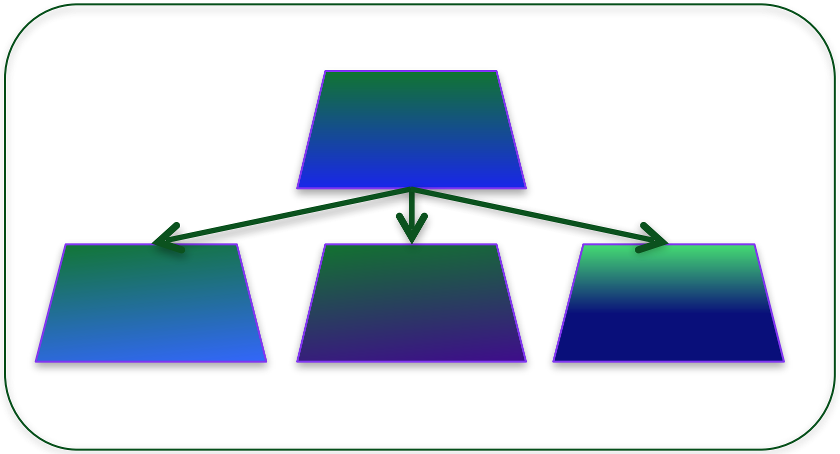
(2) its language-specific grammar should be learnable from the data children encounter

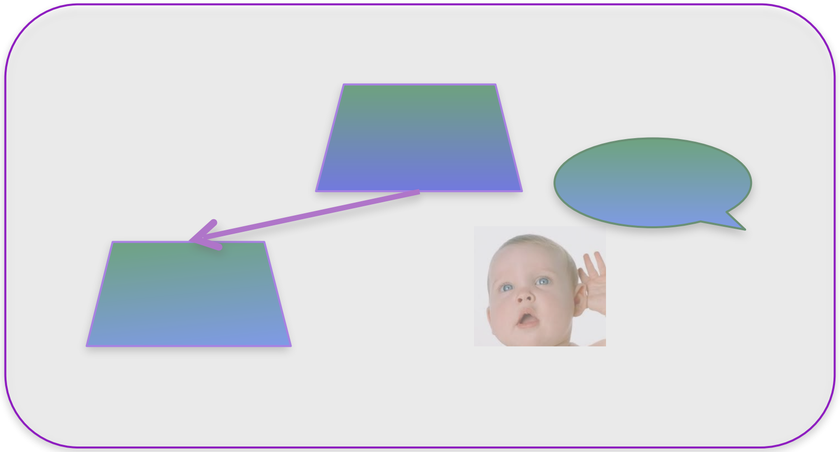




Knowledge representations

Traditionally, proposals for knowledge representations have focused on optimizing the first checkpoint of accounting for cross-linguistic variation, with the (often implicit) assumption that the second checkpoint of learnability would be easily satisfied.





Knowledge representations

Assumption of learnability:
If a child has the right knowledge representation, this makes learning the grammar of a language easy and fast.

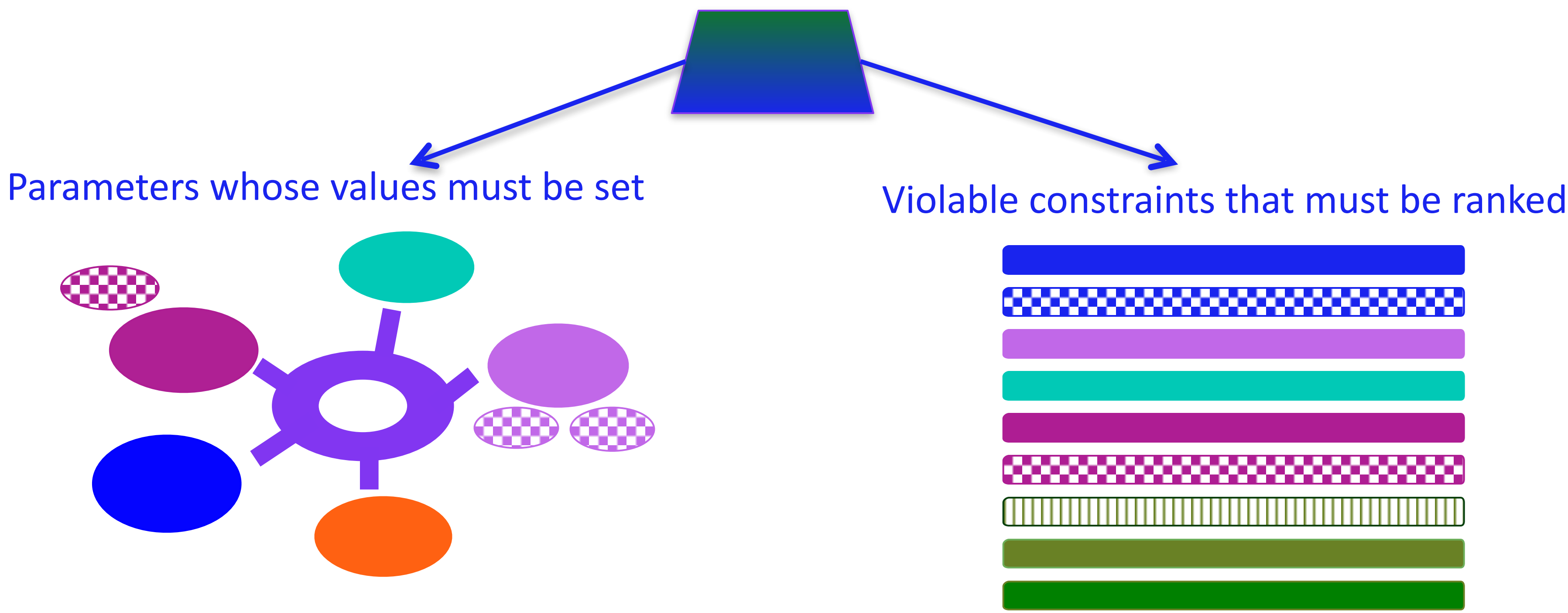
Why? The child is just learning the specific instantiation, instead of having to figure out all the relevant variables from scratch.

Basic point: The right knowledge representation is helpful for acquisition
(Chomsky 1981, Crain & Pietroski 2002, Dresher 1999)

Knowledge representations

Focus on cross-linguistic variation:

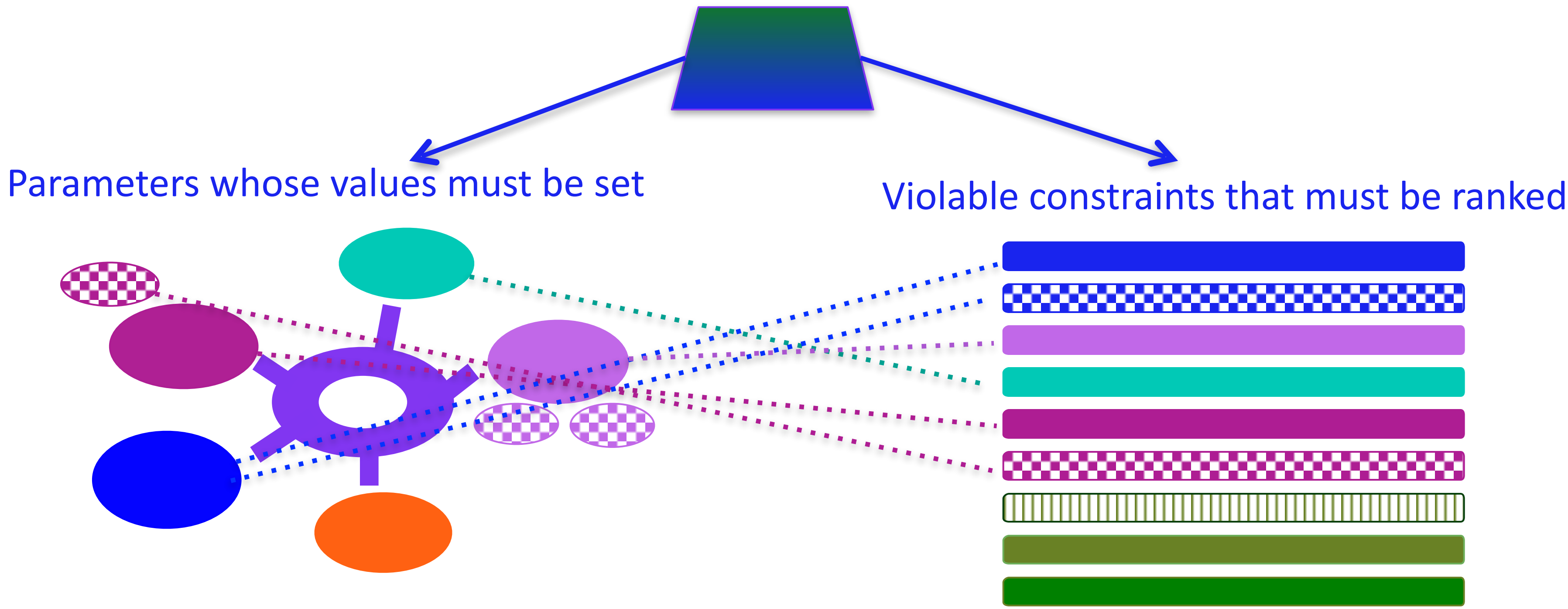
This has led to several knowledge representations for the different aspects of linguistic knowledge. For example, proposals in metrical phonology have included both parametric and constraint-ranking systems.



Knowledge representations

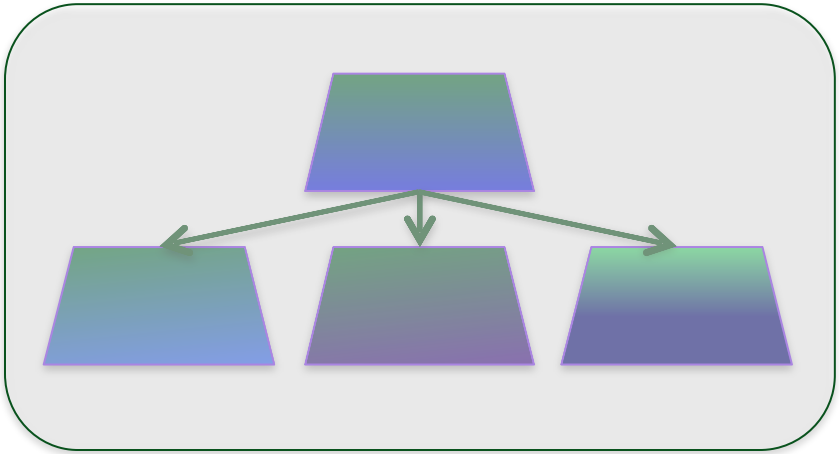
Focus on cross-linguistic variation:

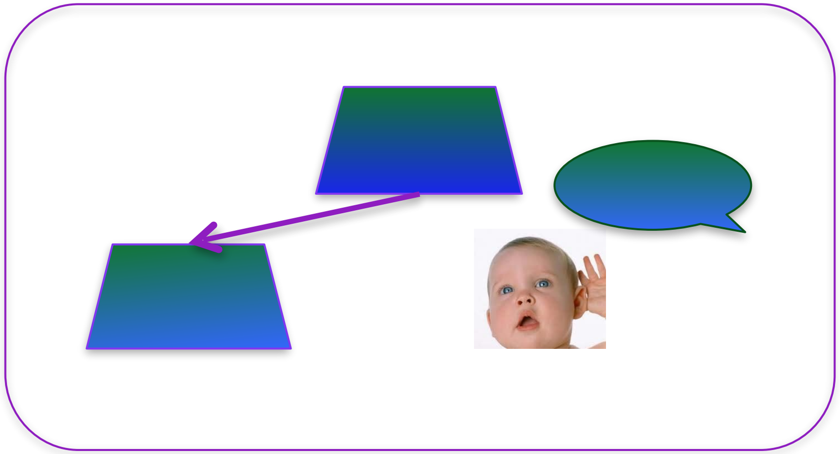
This has led to several knowledge representations for the different aspects of linguistic knowledge. For example, proposals in metrical phonology have included both parametric and constraint-ranking systems.



Knowledge representations

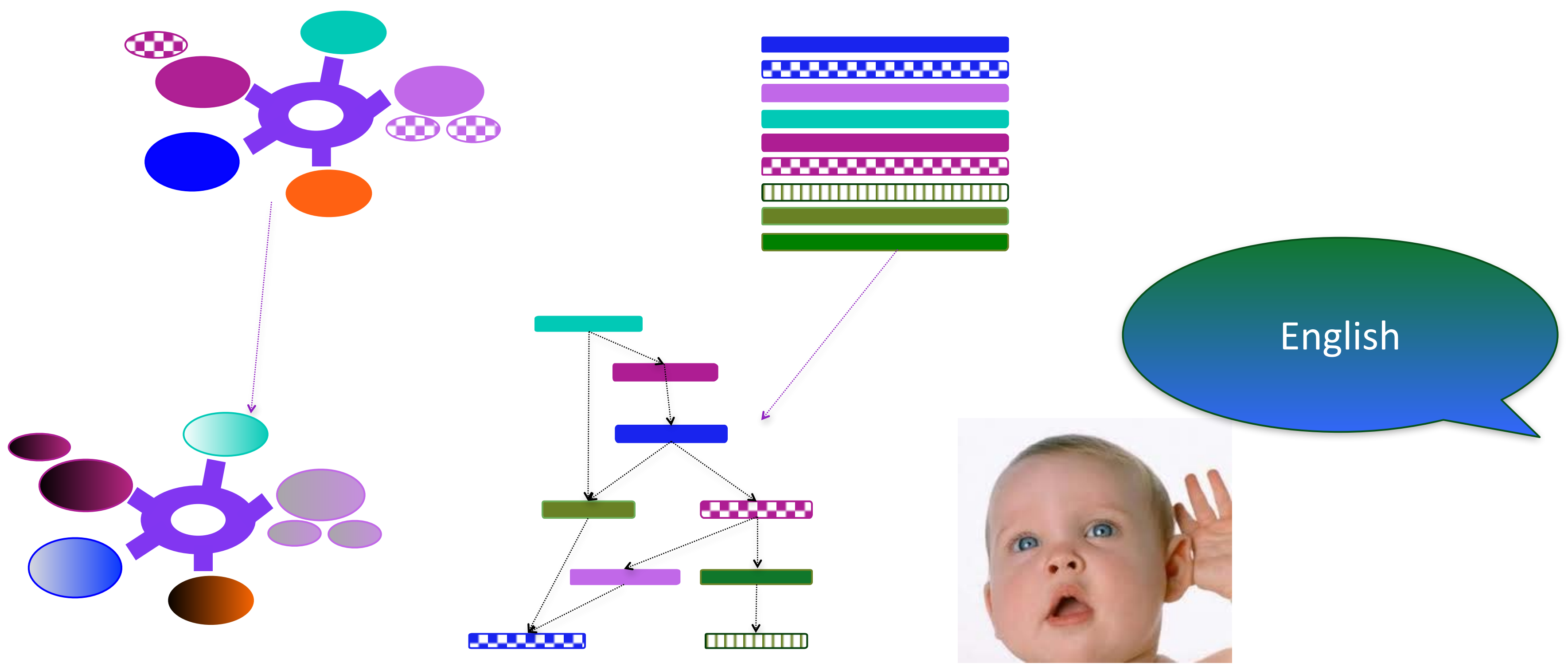
When we have several proposals that satisfy the first criterion of accounting for constrained cross-linguistic variation, it seems reasonable to focus on the second criterion of learnability.





Knowledge representations

Learnability criterion: Is a language's specific grammar in that knowledge representation learnable from the kind of data children of the language encounter?



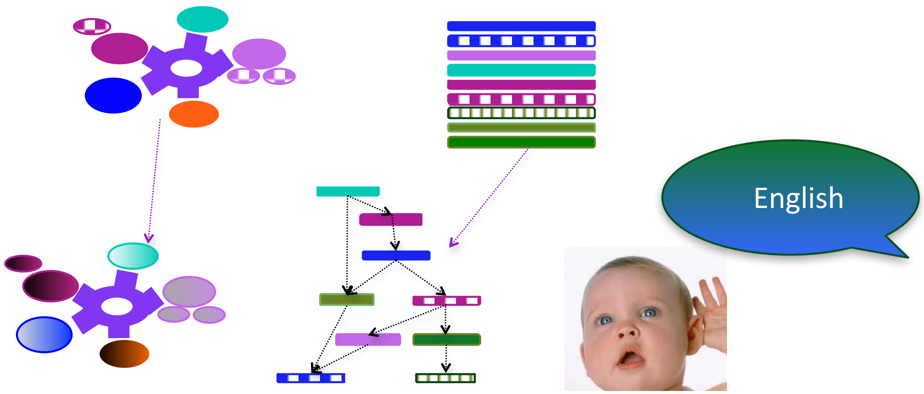
Road map

Empirically grounding & quantifying learnability

Case study:

Knowledge representations in metrical phonology

- Knowledge representation comparison
- English as a tricky learning scenario
- Learnability results & implications



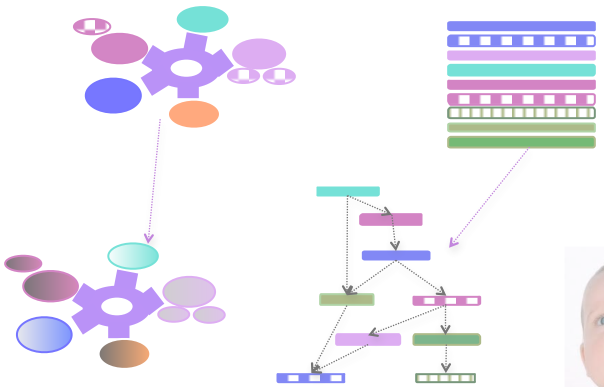
Road map

Empirically grounding & quantifying learnability

Case study:

Knowledge representations in metrical phonology

- Knowledge representation comparison
- English as a tricky learning scenario
- Learnability results & implications



Learnability

How easily does a knowledge representation allow children to learn their specific language's grammar, when given realistic data?

Learnability analysis provides a quantitative way to compare competing knowledge representations (Pearl 2011, Legate & Yang 2012)

Working premise: Rational learners

Learnability

How easily does a knowledge representation allow children to learn their specific language's grammar, when given realistic data?

Learnability analysis provides a quantitative way to compare competing knowledge representations (Pearl 2011, Legate & Yang 2012)

Working premise: Rational learners

A learner trying to learn which grammar is the right one for the language will choose the grammar perceived to be the best.

Learnability

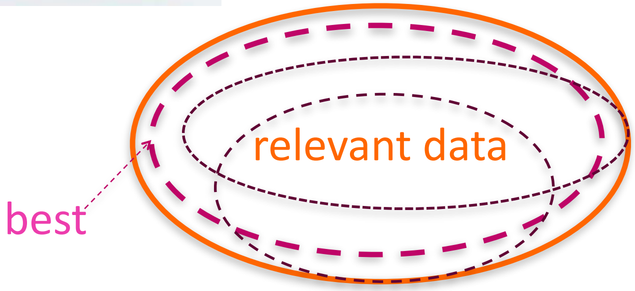
How easily does a knowledge representation allow children to learn their specific language's grammar, when given realistic data?

Learnability analysis provides a quantitative way to compare competing knowledge representations (Pearl 2011, Legate & Yang 2012)

Working premise: Rational learners

A learner trying to learn which grammar is the right one for the language will choose the grammar perceived to be the best.

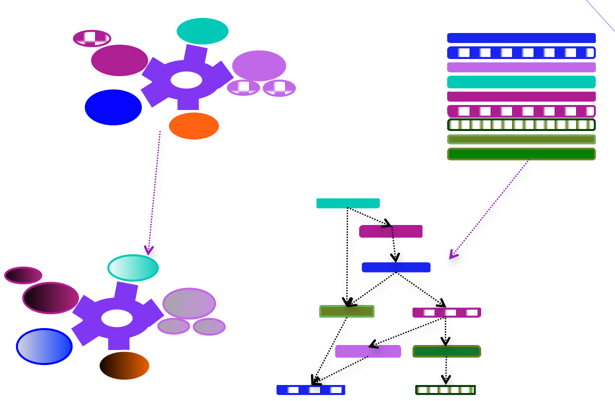
able to account for the most data perceived as relevant = most useful to have



To empirically ground a learnability analysis, we need to draw on a variety of methods.

To empirically ground a learnability analysis, we need to draw on a variety of methods.

Theoretical methods will define the knowledge representations, the set of grammars defined by a knowledge representation, and the language-specific grammar for a knowledge representation.

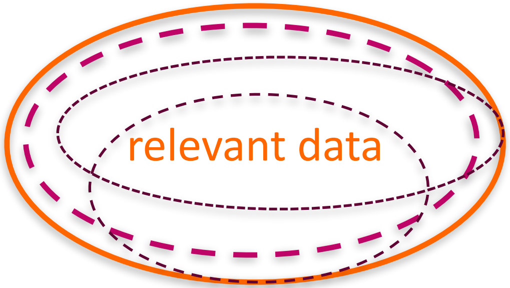


To empirically ground a learnability analysis, we need to draw on a variety of methods.

Experimental methods can define the data children are learning from.

To empirically ground a learnability analysis, we need to draw on a variety of methods.

Computational methods can analyze how much data any grammar defined by a knowledge representation can account for, including the one that's intended to be that language's grammar.



Quantifying learnability

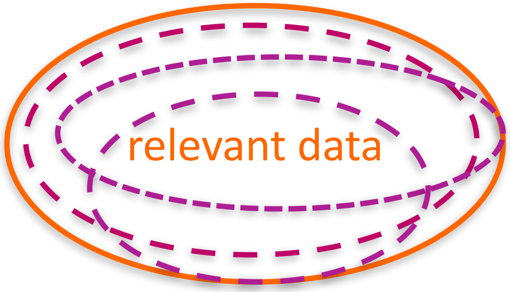
Once we define the data set the child is learning from, we can then ask which grammar in the hypothesis space defined by the knowledge representation is best, assuming a rational learner that will choose the grammar compatible with the most data.

Quantifying learnability

Once we define the data set the child is learning from, we can then ask which grammar in the hypothesis space defined by the knowledge representation is best, assuming a rational learner that will choose the grammar compatible with the most data.

Compatibility with a data point: A grammar is compatible with a data point if the grammar can account for that data point.

A grammar that can account for 70% of the data is better than a grammar that can only account for 55% of the data.

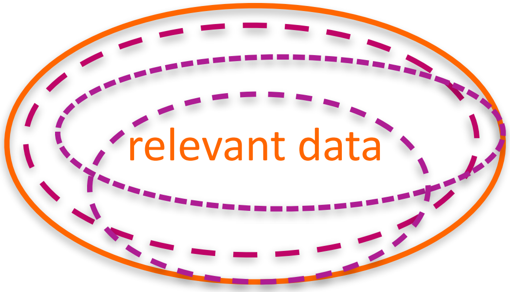


Quantifying learnability

Once we define the data set the child is learning from, we can then ask which grammar in the hypothesis space defined by the knowledge representation is best, assuming a rational learner that will choose the grammar compatible with the most data.

Raw compatibility for a grammar: The amount of data that grammar can account for.

Example: A grammar that can account for 70% of the data has an raw compatibility of 0.70.

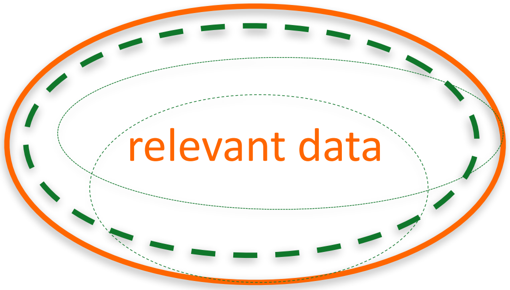


Quantifying learnability

Once we define the data set the child is learning from, we can then ask which grammar in the hypothesis space defined by the knowledge representation is best, assuming a rational learner that will choose the grammar compatible with the most data.

Relative compatibility for a grammar: The proportion of other grammars that this grammar is better than. This indicates how easy it would be for a rational learner looking for the best grammar to choose it.

Example: A grammar with ~1.00 relative compatibility is better than all other grammars defined by the knowledge representation.

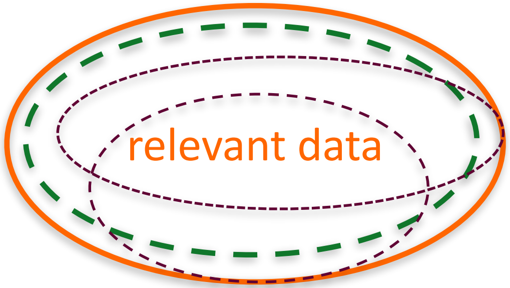


Quantifying learnability

Once we define the data set the child is learning from, we can then ask which grammar in the hypothesis space defined by the knowledge representation is best, assuming a rational learner that will choose the grammar compatible with the most data.

Learnability potential for a knowledge representation: The amount of data the best grammar (relative compatibility ≈ 1.00) is compatible with. This is how much of the data that knowledge representation is capable of accounting for.

Example: If the best grammar can account for 70% of the data, this knowledge representation has a learnability potential of 0.70.

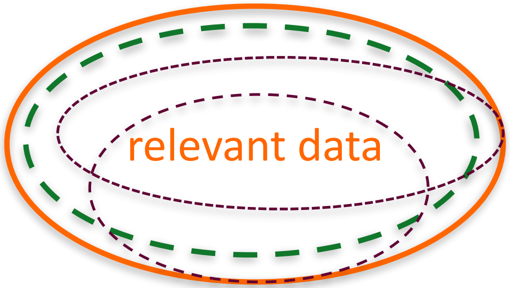


Quantifying learnability

Once we define the data set the child is learning from, we can then ask which grammar in the hypothesis space defined by the knowledge representation is best, assuming a rational learner that will choose the grammar compatible with the most data.

Working assumption:
The language-specific grammar should be the best grammar (relative compatibility ≈ 1.00) for the data of that language, assuming a rational learner that's looking for the best grammar.

It would be good if this grammar also had a high raw compatibility so that it would be useful to have, once learned.



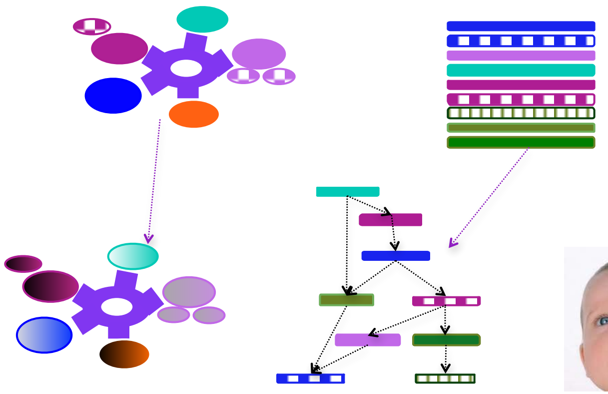
Road map

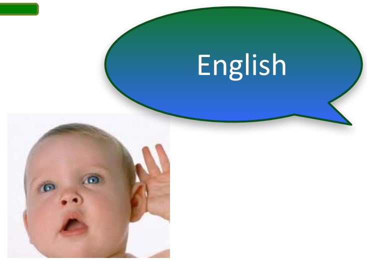
Empirically grounding & quantifying learnability

Case study:

Knowledge representations in metrical phonology

- ❖ Knowledge representation comparison
- ❖ English as a tricky learning scenario
- ❖ Learnability results & implications





Case study:
A generative system of metrical phonology

Observable data: stress contour

OCtopus

Underlying representation determined by grammar?

Case study:
A generative system of metrical phonology

Observable data: stress contour

OCtopus

Underlying representation determined by grammar?

? ? ? ?

(H L) H
OC to pus

(S S) S
OC to pus

(S S S)
OC to pus

(H L L)
OC to pus

Involves metrical feet:
Units larger than syllables
but (often) smaller than words

Three knowledge representations

Parametric systems

Correct grammar builds compatible contour

OCtopus

Three knowledge representations

Parametric systems

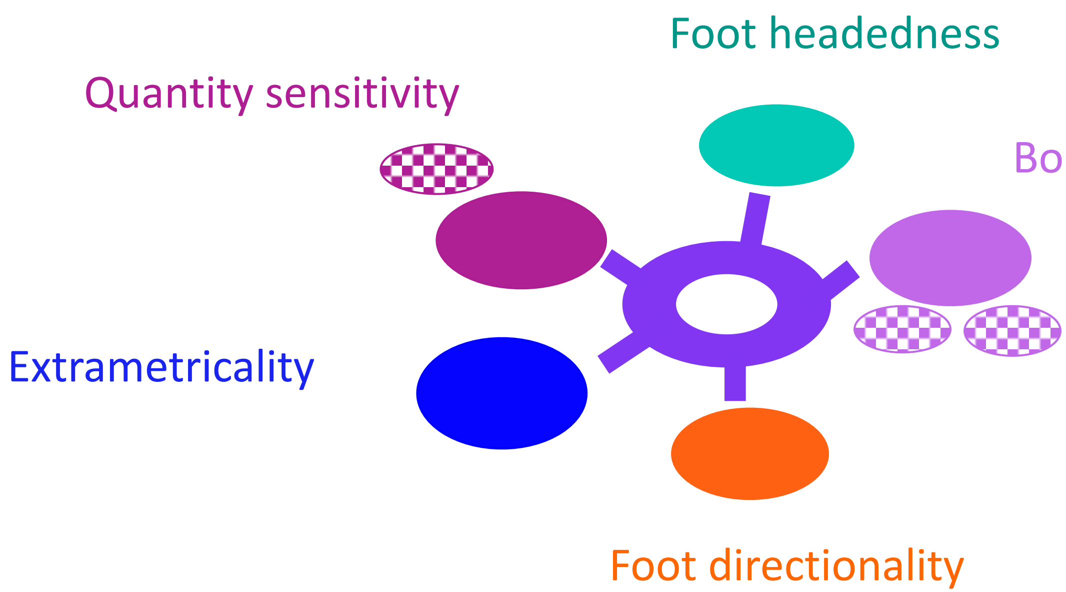
Correct grammar builds compatible contour

OCtopus

HV: Halle & Vergnaud 1987, Dresher 1999, Pearl 2011

5 parameters & 3 sub-parameters

Hypothesis space: 156 grammars



Grammar = Set of parameter & sub-parameter values

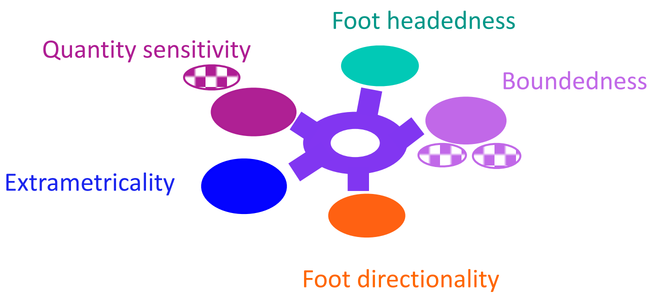
Three knowledge representations

Parametric systems

HV: Halle & Vergnaud 1987, Dresher 1999, Pearl 2011

5 parameters & 3 sub-parameters

Hypothesis space: 156 grammars



Correct grammar builds compatible contour

OCtopus

oc to pus

Three knowledge representations

Parametric systems

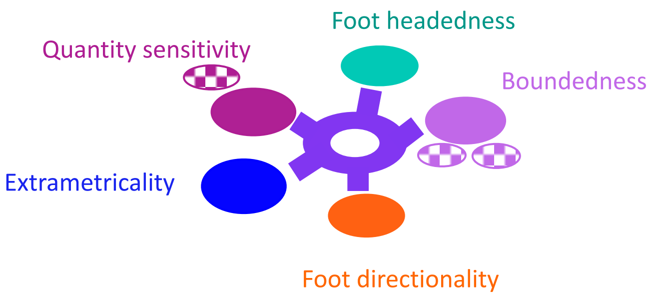
Correct grammar builds compatible contour

OCtopus

HV: Halle & Vergnaud 1987, Dresher 1999, Pearl 2011

5 parameters & 3 sub-parameters

Hypothesis space: 156 grammars



H L H
oc to pus

Quantity sensitivity
Are syllables all identical, or are they differentiated by syllable weight (into Heavy and Light syllables)?

Three knowledge representations

Parametric systems

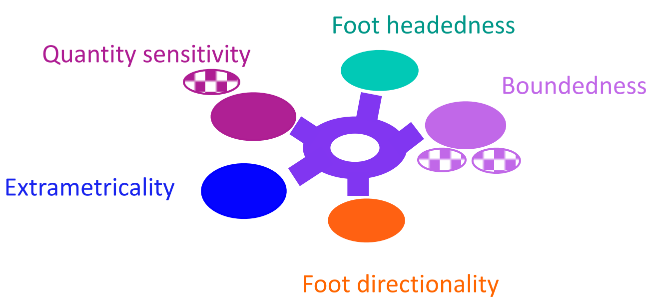
Correct grammar builds compatible contour

OCtopus

HV: Halle & Vergnaud 1987, Dresher 1999, Pearl 2011

5 parameters & 3 sub-parameters

Hypothesis space: 156 grammars



H L H

oc to pus

Extrametricality

Are all syllables included in the larger units of metrical feet, or are some excluded?

Three knowledge representations

Parametric systems

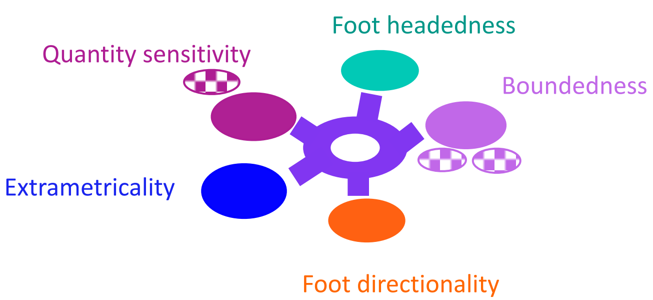
Correct grammar **builds** compatible contour

OCtopus

HV: Halle & Vergnaud 1987, Dresher 1999, Pearl 2011

5 parameters & 3 sub-parameters

Hypothesis space: 156 grammars



H L) H

oc to pus

Foot directionality

Are feet constructed from the left or from the right?

Three knowledge representations

Parametric systems

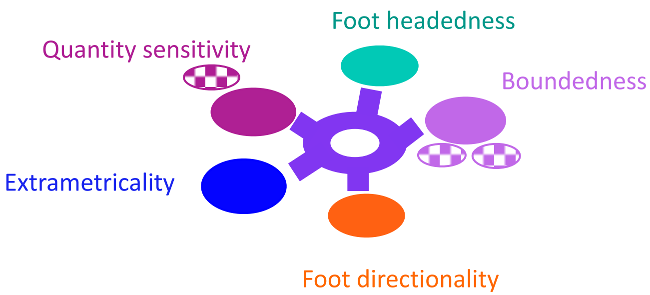
Correct grammar **builds** compatible contour

OCtopus

HV: Halle & Vergnaud 1987, Dresher 1999, Pearl 2011

5 parameters & 3 sub-parameters

Hypothesis space: 156 grammars



(H L) H
oc to pus

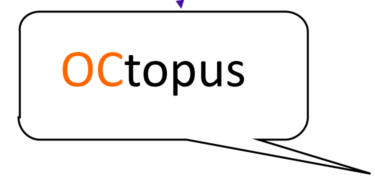
Boundedness

How big are metrical feet?

Three knowledge representations

Parametric systems

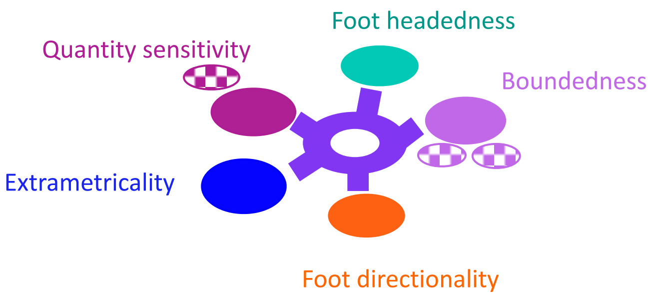
Correct grammar builds compatible contour

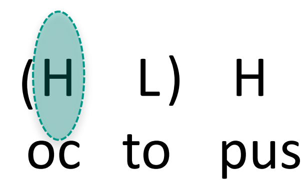


HV: Halle & Vergnaud 1987, Dresher 1999, Pearl 2011

5 parameters & 3 sub-parameters

Hypothesis space: 156 grammars





Foot headedness

Which syllable in a foot is stressed?

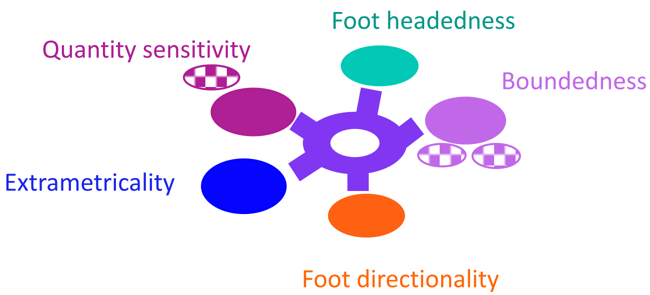
Three knowledge representations

Parametric systems

HV: Halle & Vergnaud 1987, Dresher 1999, Pearl 2011

5 parameters & 3 sub-parameters

Hypothesis space: 156 grammars



Correct grammar builds compatible contour

OCtopus

This grammar, comprised of particular parameter values, generates the correct stress contour.

(H L) H
OC to pus

Parameter values used:
Quantity sensitive, VC syllables = Heavy, Extrametricality on rightmost syllable, Feet built from the right, Foot = 2 syllables, Leftmost syllable in foot stressed

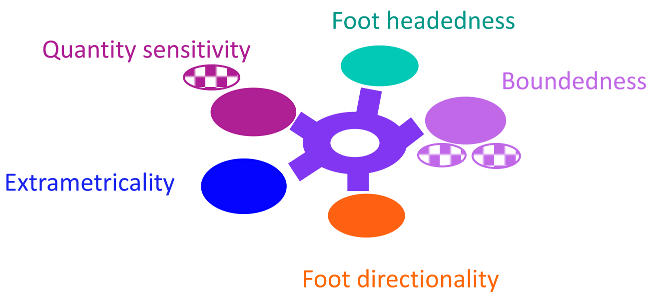
Three knowledge representations

Parametric systems

HV: Halle & Vergnaud 1987, Dresher 1999, Pearl 2011

5 parameters & 3 sub-parameters

Hypothesis space: 156 grammars



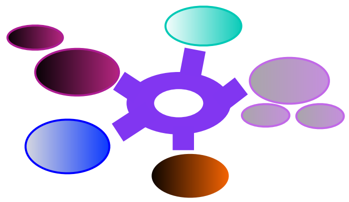
Correct grammar builds compatible contour

OCtopus

This grammar, comprised of particular parameter values, generates the correct stress contour.

(H L) H
OC to pus

Parameter values used:
QS-VC-H, Em-Rt, FtDir-Rt, B-2-Syl, FtHd-Left



...which are the values of the English grammar.

Three knowledge representations

Parametric systems

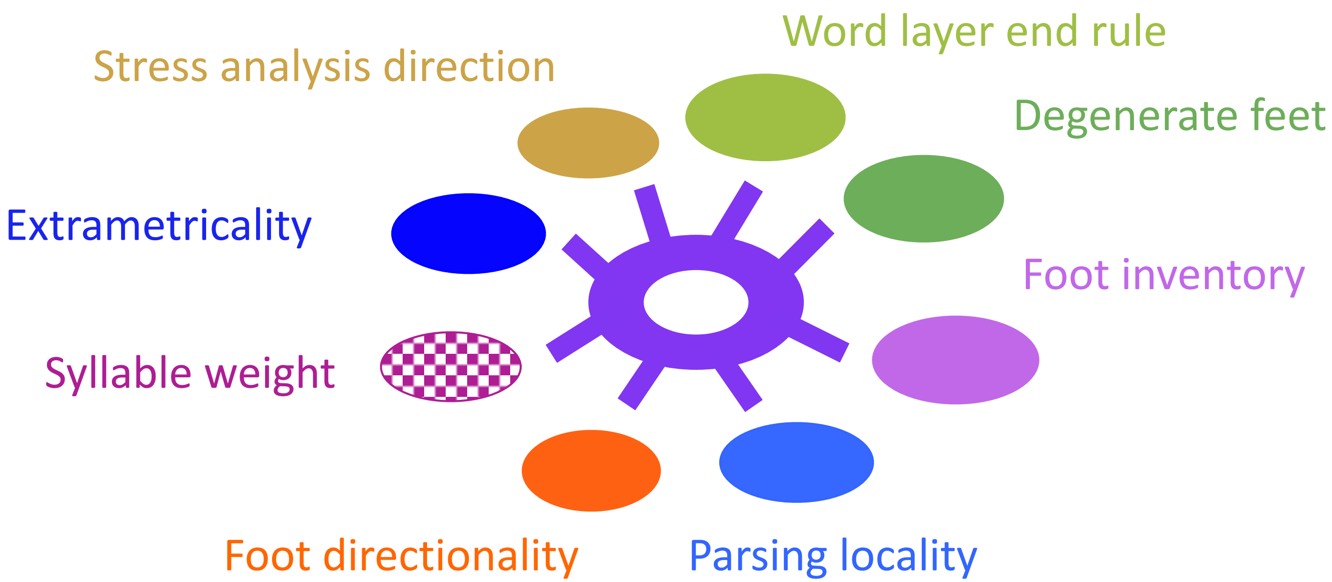
Correct grammar builds compatible contour

OCtopus

Hayes: Hayes 1995

8 parameters

Hypothesis space: 768 grammars



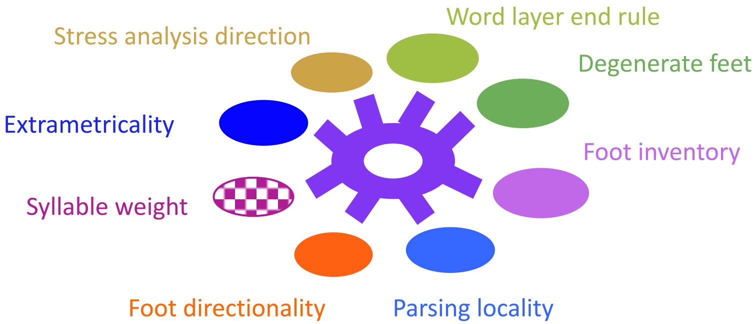
Three knowledge representations

Parametric systems

Hayes: Hayes 1995

8 parameters

Hypothesis space: 768 grammars



Correct grammar builds compatible contour

OCtopus

oc to pus

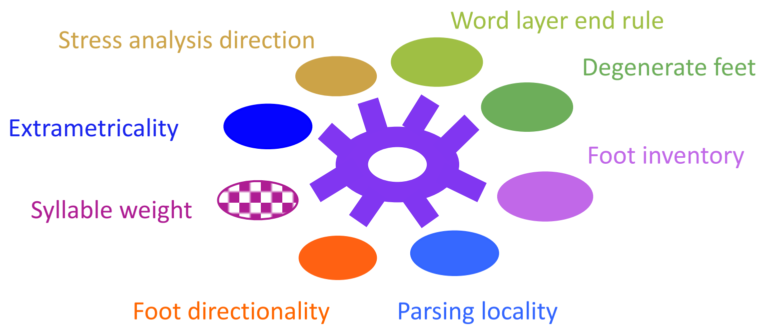
Three knowledge representations

Parametric systems

Hayes: Hayes 1995

8 parameters

Hypothesis space: 768 grammars



Stress analysis direction
Are metrical feet created before word-level stress is assigned to the edge syllables or after?

Correct grammar builds compatible contour

OCtopus

(…feet first…)

oc to pus

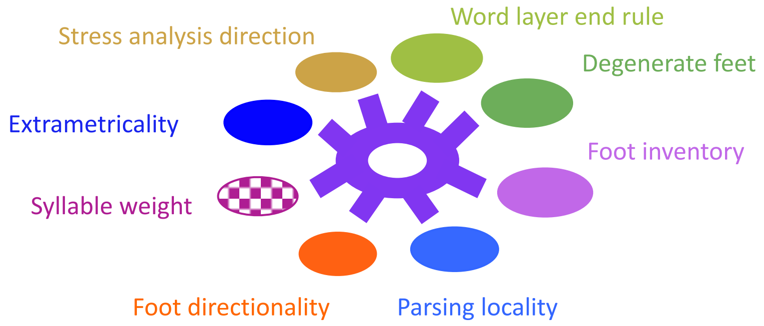
Three knowledge representations

Parametric systems

Hayes: Hayes 1995

8 parameters

Hypothesis space: 768 grammars



Correct grammar builds compatible contour

OCtopus

oc to pus

Extrametricality
Are syllables on the edge (or parts of syllables) excluded from metrical feet?

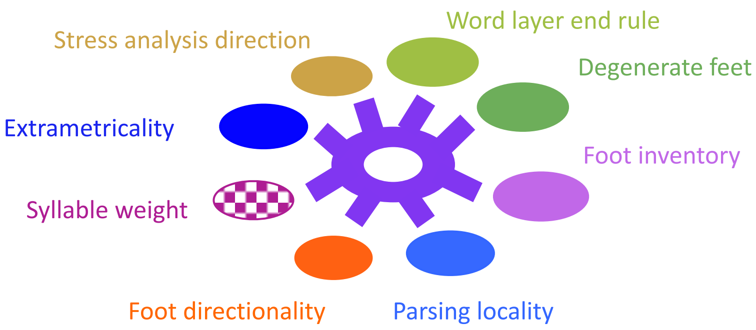
Three knowledge representations

Parametric systems

Hayes: Hayes 1995

8 parameters

Hypothesis space: 768 grammars



Correct grammar builds compatible contour

OCtopus

H L L

oc to pus

Syllable weight

Syllables are distinguished into Heavy and Light. Are syllables ending in VC (like *oc*) Heavy or Light?

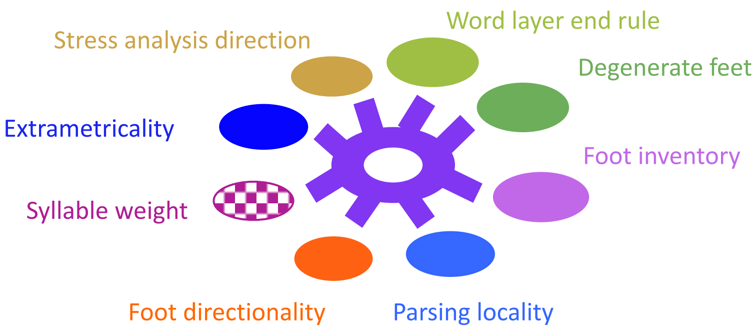
Three knowledge representations

Parametric systems

Hayes: Hayes 1995

8 parameters

Hypothesis space: 768 grammars



Correct grammar builds compatible contour

OCtopus

H L L)

oc to pus

Foot directionality

Are metrical feet constructed from the left or the right?

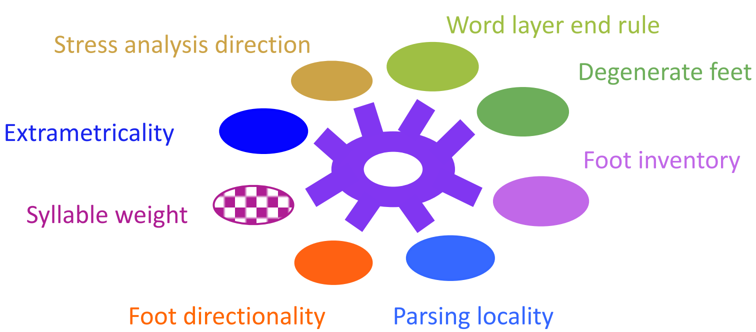
Three knowledge representations

Parametric systems

Hayes: Hayes 1995

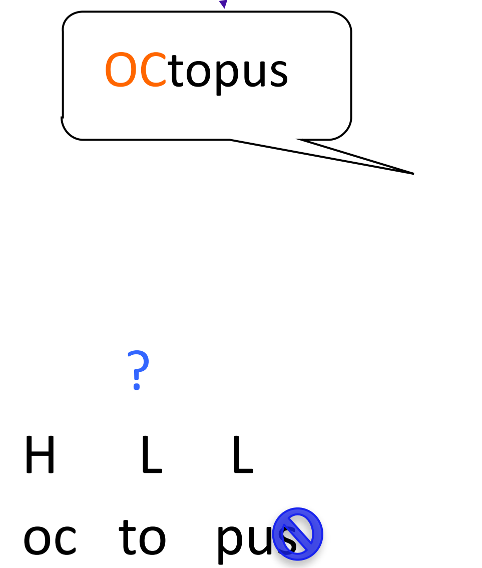
8 parameters

Hypothesis space: 768 grammars



Parsing locality
Is one Light syllable skipped between metrical feet?

Correct grammar builds compatible contour



Three knowledge representations

Parametric systems

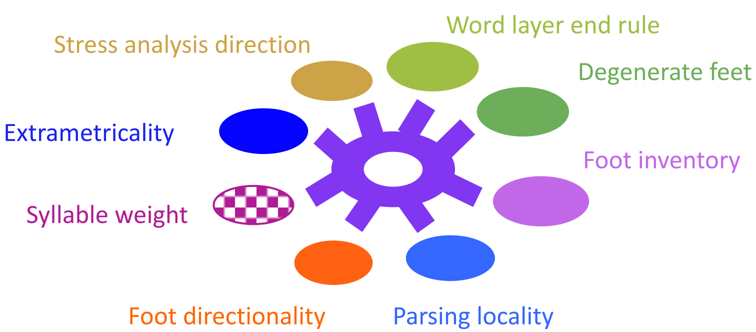
Correct grammar builds compatible contour

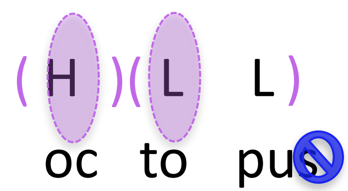
OCtopus

Hayes: Hayes 1995

8 parameters

Hypothesis space: 768 grammars





Foot inventory

How big are metrical feet?

Where does the stress fall within them?

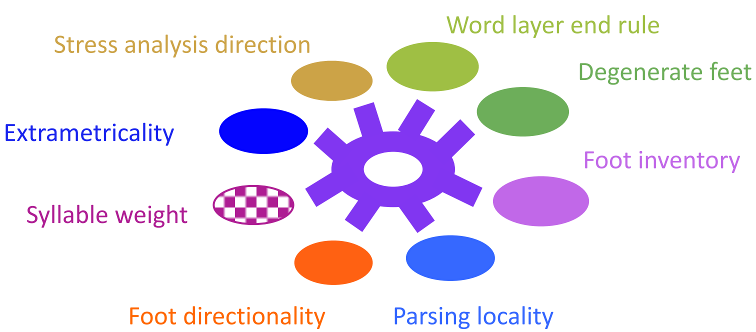
Three knowledge representations

Parametric systems

Hayes: Hayes 1995

8 parameters

Hypothesis space: 768 grammars



Correct grammar builds compatible contour

OCtopus

(H)(L L)

oc to pus

Degenerate feet

What do you do with leftover Light syllables if you have any?

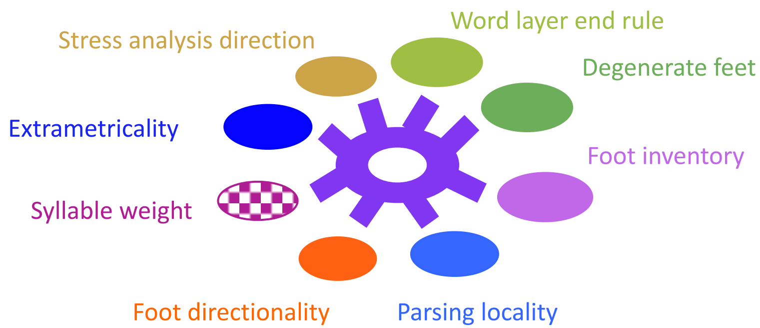
Three knowledge representations

Parametric systems

Hayes: Hayes 1995

8 parameters

Hypothesis space: 768 grammars



Correct grammar builds compatible contour

OCtopus

(H)(L L)

oc to pus

Word layer end rule

Where does word-level stress go if there are multiple stressed syllables? Can leftover Light syllables have word-level stress?

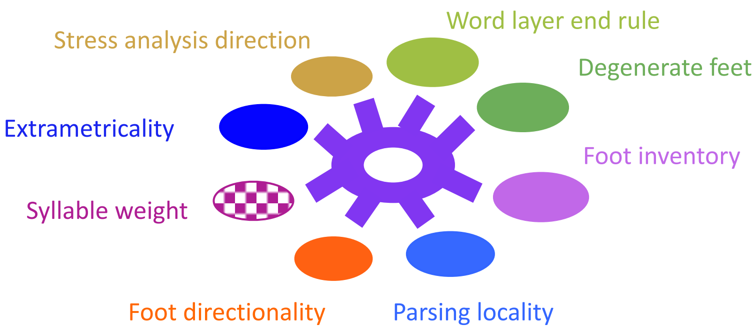
Three knowledge representations

Parametric systems

Hayes: Hayes 1995

8 parameters

Hypothesis space: 768 grammars



Correct grammar builds compatible contour

OCtopus

This grammar, comprised of particular parameter values, generates an incorrect stress contour.

(H)(L L)

OC TÓ pus

Parameter values used:

Bottom-up, Extrametricality on rightmost consonant, VC syllables = Heavy, Feet built from the right, Light syllables not skipped in between feet, Foot = Moraic trochee (2 moras with stress on leftmost), Single Light edge syllables not allowed to have stress, Rightmost syllable gets main stress

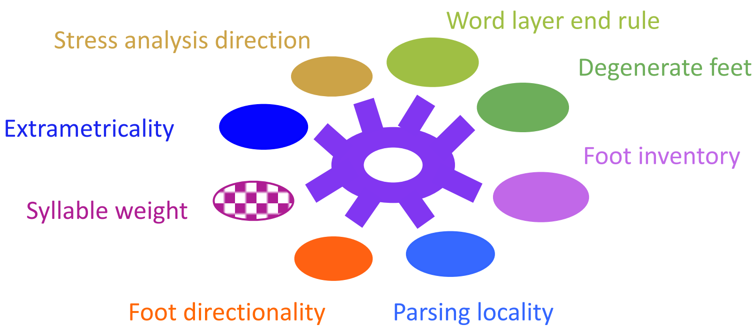
Three knowledge representations

Parametric systems

Hayes: Hayes 1995

8 parameters

Hypothesis space: 768 grammars



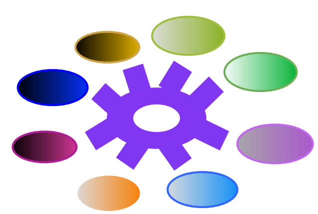
Parameter values used:
Bot, Em-RtCons, VC-H, FtDir-Rt, PL-Strong, MorTro, DF-Strong, WLER-Rt

Correct grammar builds compatible contour

OCtopus

This grammar, comprised of particular parameter values, generates an incorrect stress contour.

(H)(L L)
OC TÓ pus



...which are the values of the English grammar.

Three knowledge representations

Constraint-ranking systems

OT: Hammond 1999, Pater 2000, Tesar & Smolensky 2000

9 violable constraints

Three knowledge representations

Constraint-ranking systems

Best candidate for the correct grammar has a compatible contour

OCtopus

OT: Hammond 1999, Pater 2000, Tesar & Smolensky 2000

9 violable constraints

Premise: Many different candidates for a word's stress representation and contour are generated and then ranked according to which constraints are violated. Violating higher-ranked constraints is worse than violating lower-ranked constraints.

	C1	C2	C3	C4
(OC to) pus			*	*
oc (TO pus)	*		*	
(oc TO) pus		*	*	

Three knowledge representations

Constraint-ranking systems

Best candidate for the correct grammar has a compatible contour

OCtopus

OT: Hammond 1999, Pater 2000, Tesar & Smolensky 2000

9 violable constraints

Hypothesis space: 9! rankings = 362,880 grammars

Grammar = ranked ordering of all constraints

Three knowledge representations

Constraint-ranking systems

Best candidate for the correct grammar has a compatible contour

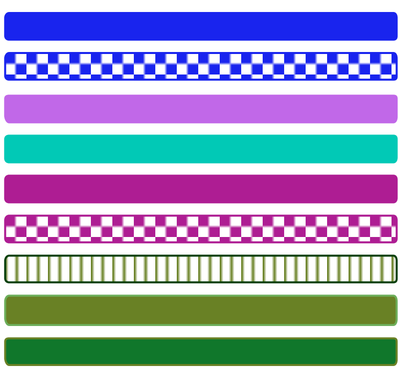
OCtopus

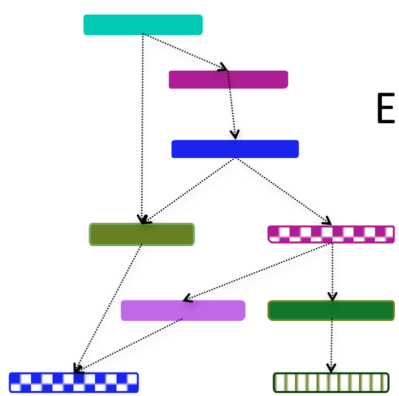
OT: Hammond 1999, Pater 2000, Tesar & Smolensky 2000

9 violable constraints

Hypothesis space: 9! rankings = 362,880 grammars

Official grammars for languages are often described as partial orderings of constraints.





English grammar

Three knowledge representations

Best candidate for the correct grammar has a compatible contour

OCtopus

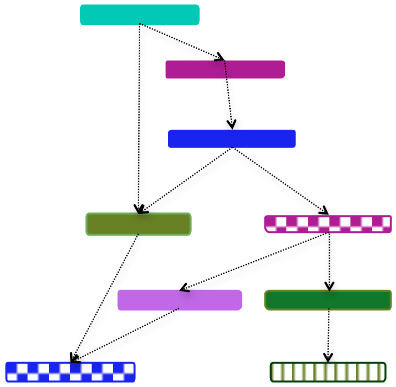
Constraint-ranking systems

OT: Hammond 1999, Pater 2000, Tesar & Smolensky 2000

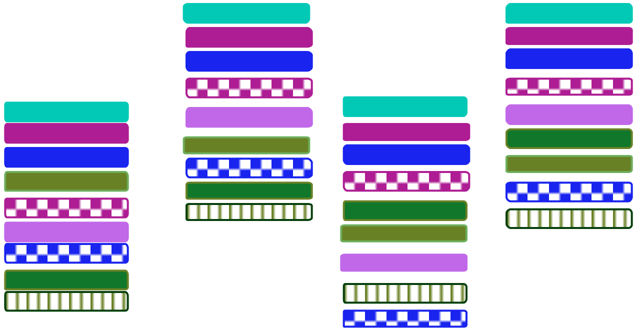
9 violable constraints

Hypothesis space: 9! rankings = 362,880 grammars

This means the "grammar" for a language is often a set of the possible rankings (grammars) that obey those orderings.



Ex: The English "grammar" is compatible with 26 rankings.



Three knowledge representations

Constraint-ranking systems

Best candidate for the correct grammar has a compatible contour

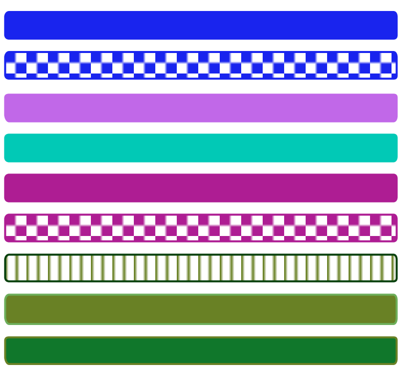
OCtopus

OT: Hammond 1999, Pater 2000, Tesar & Smolensky 2000

9 violable constraints

Hypothesis space: 9! rankings = 362,880 grammars

Principle (Rooting): All words must have stress



Three knowledge representations

Constraint-ranking systems

Best candidate for the correct grammar has a compatible contour

OCtopus

OT: Hammond 1999, Pater 2000, Tesar & Smolensky 2000

9 violable constraints

Hypothesis space: 9! rankings = 362,880 grammars

Principle (Rooting): All words must have stress

Nonfinality

Should the final syllable not be in a metrical foot?

(OC to) (PUS)

✓ (OC to) pus

(oc TO) (PUS)

oc (TO pus)

Three knowledge representations

Constraint-ranking systems

Best candidate for the correct grammar has a compatible contour

OCtopus

OT: Hammond 1999, Pater 2000, Tesar & Smolensky 2000

9 violable constraints

Hypothesis space: 9! rankings = 362,880 grammars

Principle (Rooting): All words must have stress

Parse-σ

Should all syllables be in metrical feet?

✓ (OC to) (PUS) — (OC to) pus

✓ (oc TO) (PUS) — oc (TO pus)

Three knowledge representations

Constraint-ranking systems

Best candidate for the correct grammar has a compatible contour

OCtopus

OT: Hammond 1999, Pater 2000, Tesar & Smolensky 2000

9 violable constraints

Hypothesis space: 9! rankings = 362,880 grammars

Principle (Rooting): All words must have stress

Foot binarity

Should all metrical feet consist of two units?

(OC to) (PUS)

✓ (OC to) pus

(oc TO) (PUS)

✓ oc (TO pus)

Three knowledge representations

Constraint-ranking systems

Best candidate for the correct grammar has a compatible contour

OCtopus

OT: Hammond 1999, Pater 2000, Tesar & Smolensky 2000

9 violable constraints

Hypothesis space: 9! rankings = 362,880 grammars

Principle (Rooting): All words must have stress

Trochaic

Should metrical feet have stress on the leftmost syllable?

✓ (OC to) (PUS)

✓ (OC to) pus

(oc TO) (PUS)

✓ oc (TO pus)

Three knowledge representations

Constraint-ranking systems

Best candidate for the correct grammar has a compatible contour

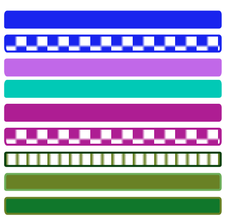
BAby

OT: Hammond 1999, Pater 2000, Tesar & Smolensky 2000

9 violable constraints

Hypothesis space: 9! rankings = 362,880 grammars

Principle (Rooting): All words must have stress



Weight-to-Stress (VV)

Should all VV syllables be stressed?

(ba BY)	✓ (BA) (BY)
(BA) by	(BA by)

Three knowledge representations

Constraint-ranking systems

Best candidate for the correct grammar has a compatible contour

OCtopus

OT: Hammond 1999, Pater 2000, Tesar & Smolensky 2000

9 violable constraints

Hypothesis space: 9! rankings = 362,880 grammars

Principle (Rooting): All words must have stress

Weight-to-Stress (VC)

Should all VC syllables be stressed?

✓ (OC to) (PUS)

(OC to) pus

(oc TO) (PUS)

oc (TO pus)

Three knowledge representations

Constraint-ranking systems

Best candidate for the correct grammar has a compatible contour

OCtopus

OT: Hammond 1999, Pater 2000, Tesar & Smolensky 2000

9 violable constraints

Hypothesis space: 9! rankings = 362,880 grammars

Principle (Rooting): All words must have stress

Align left

≈ Should metrical feet include the leftmost syllable?

✓ (OC to) (PUS)

✓ (OC to) pus

✓ (oc TO) (PUS)

oc (TO pus)

Three knowledge representations

Constraint-ranking systems

Best candidate for the correct grammar has a compatible contour

OCtopus

OT: Hammond 1999, Pater 2000, Tesar & Smolensky 2000

9 violable constraints

Hypothesis space: 9! rankings = 362,880 grammars

Principle (Rooting): All words must have stress

Align right
≈ Should metrical feet include the rightmost syllable?

✓ (OC to) (PUS)

(OC to) pus

✓ (oc TO) (PUS)

✓ oc (TO pus)

Three knowledge representations

Constraint-ranking systems

Best candidate for the correct grammar has a compatible contour

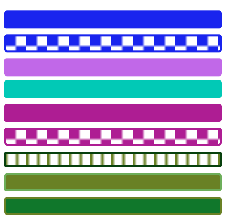
yourSELF

OT: Hammond 1999, Pater 2000, Tesar & Smolensky 2000

9 violable constraints

Hypothesis space: 9! rankings = 362,880 grammars

Principle (Rooting): All words must have stress



Nonfinality, Parse-σ
Foot binarity
Trochaic
Weight-to-Stress
Align left, Align right
*Sonorant nucleus

***Sonorant nucleus**

Should syllables not have sonorants (m, n, ŋ, l, r) as the nucleus?

✓ your (SELF)	(yr SELF)
✓ (YOUR) (SELF)	(YOUR slf)

Three knowledge representations

Constraint-ranking systems

Best candidate for the correct grammar has a compatible contour

OCtopus

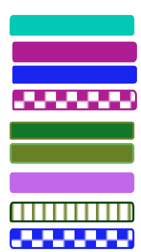
OT: Hammond 1999, Pater 2000, Tesar & Smolensky 2000

9 violable constraints

Hypothesis space: 9! rankings = 362,880 grammars

Principle (Rooting): All words must have stress

A sample grammar that is a version of the English "grammar":



Sample candidates

(OC to) (PUS)

(OC to) pus

(oc TO) (PUS)

oc (TO pus)

Three knowledge representations

Constraint-ranking systems

Best candidate for the correct grammar has a compatible contour

OCtopus

OT: Hammond 1999, Pater 2000, Tesar & Smolensky 2000

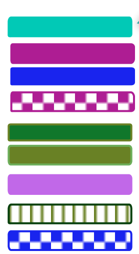
9 violable constraints

Hypothesis space: 9! rankings = 362,880 grammars

Principle (Rooting): All words must have stress

Most important: Metrical feet have stress on the leftmost syllable.

A sample grammar that is a version of the English “grammar”:



Sample candidates

(OC to) (PUS)	(OC to) pus
(oc TO) (PUS)	oc (TO pus)

Three knowledge representations

Constraint-ranking systems

Best candidate for the correct grammar has a compatible contour

OCtopus

OT: Hammond 1999, Pater 2000, Tesar & Smolensky 2000

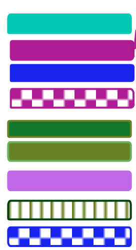
9 violable constraints

Hypothesis space: 9! rankings = 362,880 grammars

Principle (Rooting): All words must have stress

Next important: VV syllables are stressed.

A sample grammar that is a version of the English "grammar":



Sample candidates

(OC to) (PUS) (OC to) pus

(oc TO) (PUS) oc (TO pus)

Three knowledge representations

Constraint-ranking systems

OT: Hammond 1999, Pater 2000, Tesar & Smolensky 2000

9 violable constraints

Hypothesis space: 9! rankings = 362,880 grammars

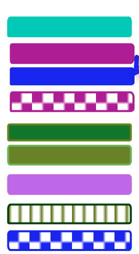
Principle (Rooting): All words must have stress

Best candidate for the correct grammar has a compatible contour

OCtopus

Next important: The final syllable is not included in a foot.

A sample grammar that is a version of the English “grammar”:



Sample candidates

(OC to) (PUS)

(OC to) pus

(oc TO) (PUS)

oc (TO pus)

Three knowledge representations

Constraint-ranking systems

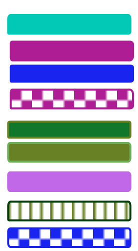
OT: Hammond 1999, Pater 2000, Tesar & Smolensky 2000

9 violable constraints

Hypothesis space: 9! rankings = 362,880 grammars

Principle (Rooting): All words must have stress

A sample grammar that is a version of the English "grammar":



Best candidate for the correct grammar has a compatible contour

OCtopus

Only one candidate left, and it has a compatible contour.

Sample candidates

~~(OC to) (PUS)~~

(OC to) pus

~~(oc TO) (PUS)~~

~~oc (TO pus)~~

Three knowledge representations

Constraint-ranking systems

Best candidate for the correct grammar has a compatible contour

OCtopus

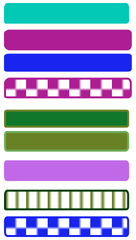
OT: Hammond 1999, Pater 2000, Tesar & Smolensky 2000

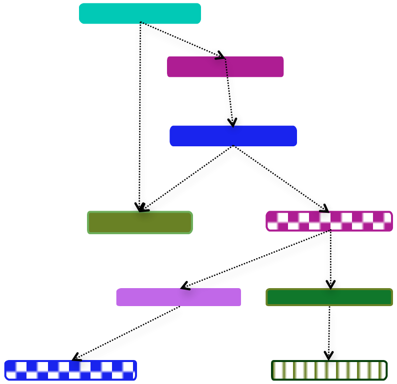
9 violable constraints

Hypothesis space: 9! rankings = 362,880 grammars

Principle (Rooting): All words must have stress

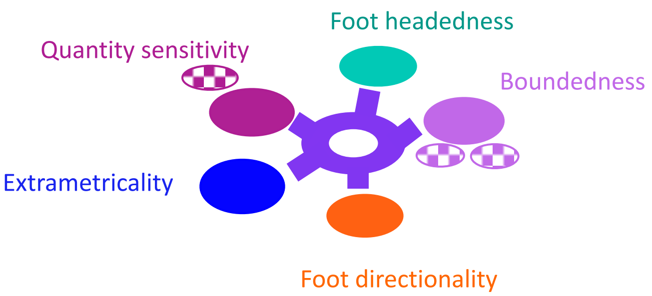
A sample grammar that is a version of the English "grammar":





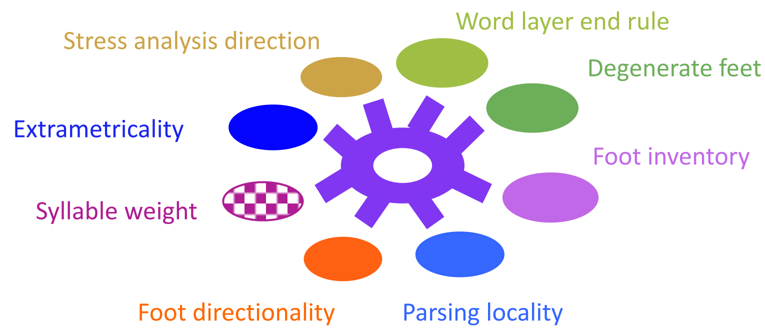
English "grammar"

Knowledge representation comparison



HV: 5 parameters & 3 sub-parameters

Hypothesis space: 156 grammars



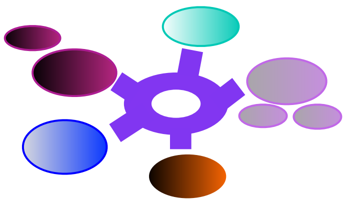
Hayes: 8 parameters

Hypothesis space: 768 grammars

OT: 9 violable constraints

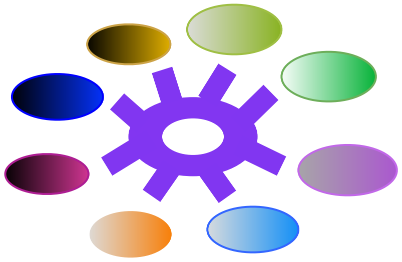
Hypothesis space: 362,880 grammars

English instantiations



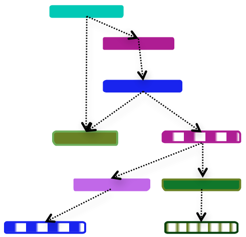
HV: 5 parameters & 4 sub-parameters

Hypothesis space: 156 grammars



Hayes: 8 parameters

Hypothesis space: 768 grammars



OT: 9 violable constraints

Hypothesis space: 362,880 grammars

(English = 26 grammars)

Learning English metrical phonology: Non-trivial

Non-trivial because there are many data that are ambiguous for which parameter value or constraint ranking they implicate

OCtopus ?

This is generally a problem for acquisition (poverty of the stimulus = the data are compatible with many hypotheses).

Learning English metrical phonology: Non-trivial

Non-trivial because there are many irregularities. This is less common for acquisition – usually there aren't a lot of exceptions to the system being acquired.

Learning English metrical phonology: Non-trivial

Non-trivial because there are many irregularities. This is less common for acquisition – usually there aren't a lot of exceptions to the system being acquired.

Some causes of irregularity:

Interactions with morphology (Chomsky & Halle 1968, Hayes 1982, Kiparsky 1979)

Example: Adding productive morphology doesn't change the stress pattern, even though all grammars base their stress patterns on the syllables present in the word.

EARly	PREtty	senSAtion
EARlier	PREttiest	senSAtional
		senSAtionally

Learning English metrical phonology: Non-trivial

Non-trivial because there are many irregularities. This is less common for acquisition – usually there aren't a lot of exceptions to the system being acquired.

Some causes of irregularity:

Interactions with grammatical category (Hammond 1999, Hayes 1982, Cassidy & Kelly 2001, Christiansen & Monaghan 2006)

Stress contours may be different across grammatical categories, even though the syllabic word form doesn't change.

NOUNS	VERBS
CONduct	conDUCT
DEsert	deSERT
SUspect	suSPECT

Learning English metrical phonology: Non-trivial

These irregularities can cause multiple stress contours to be associated with a syllabic word form. This is problematic for the grammars in these knowledge representations…

Syllabic word form: V VV

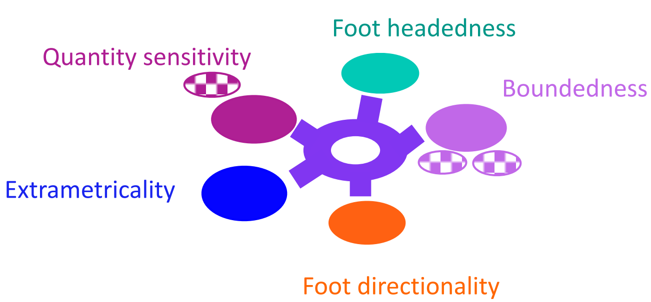
KI tty	a WAY	UH OH
V vv	v VV	V VV

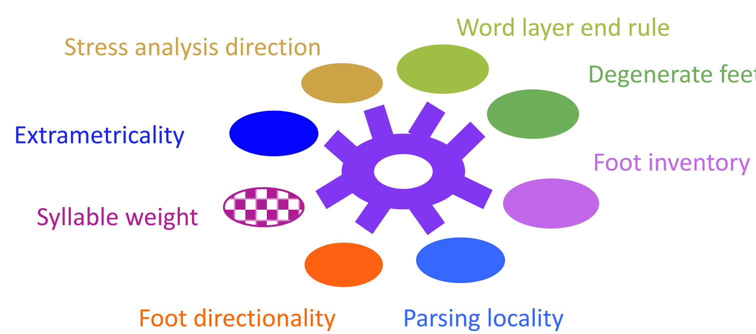
Learning English metrical phonology: Non-trivial

These irregularities can cause multiple stress contours to be associated with a syllabic word form. This is problematic for the grammars in these knowledge representations, since a grammar can only generate a single stress contour per syllabic word form…

Syllabic word form: V VV

Generate one of these…	KI tty	a WAY	UH OH
	V vv	v VV	V VV





Learning English metrical phonology: Non-trivial

These irregularities can cause multiple stress contours to be associated with a syllabic word form. This is problematic for the grammars in these knowledge representations, since a grammar can only generate a single stress contour per syllabic word form or select a single stressed syllabic word form as the best candidate.

Syllabic word form: V VV

Select one of these…	KI tty	a WAY	UH OH
	V vv	v VV	V VV

Learning English metrical phonology: Non-trivial

Upshot of multiple stress contours: No one grammar can account for all the stressed words in the input.

But how big of a problem is this in English child-directed speech?

Syllabic word form: V VV

KI tty	a WAY	UH OH
V vv	v VV	V VV

Learning English metrical phonology: Non-trivial

Analysis of Brent corpus (CHILDES database): 4780 word types (99,968 tokens) of American English speech directed at children between the ages of 6 and 12 months

Syllabic word form: V VV

KI tty	a WAY	UH OH
V vv	v VV	V VV

Multiple stress contours

HV: 73 of 123 syllabic word forms

Hayes: 86 of 149 syllabic word forms

OT: 166 of 452 syllabic word forms

This occurs a lot!

Learning English metrical phonology

So what's the best any grammar in a given knowledge representation actually does, given these data?

Learnability potential = proportion of data the best grammar (relative compatibility ≈ 1.00) can account for

Learning English metrical phonology

So what's the best any grammar in a given knowledge representation actually does, given these data?

Learnability potential = proportion of data the best grammar (relative compatibility ≈ 1.00) can account for

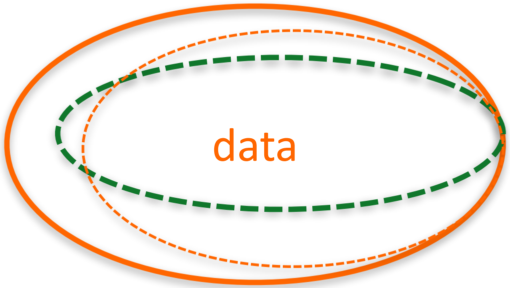
Raw compatibility of best grammar

HV: 0.668 types (0.739 tokens)

Hayes: 0.683 types (0.750 tokens)

OT: 0.657 types (0.729 tokens)

Around 2/3 of the word types



Learning English metrical phonology

Implication:

The best grammar is pretty useful to have. It allows a learner to account for a good proportion of the input, even if there's a significant chunk that can't be accounted for.

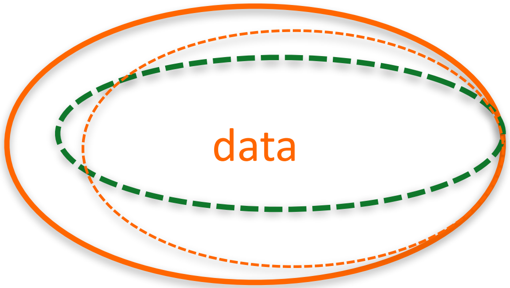
Raw compatibility of best grammar

HV: 0.668 types (0.739 tokens)

Hayes: 0.683 types (0.750 tokens)

OT: 0.657 types (0.729 tokens)

Around 2/3 of the word types



Learning English metrical phonology

So how does the (best) English grammar in a given knowledge representation do, given these data?

Raw compatibility of the English grammar = proportion of data the (best) English grammar can account for

Learning English metrical phonology

So how does the (best) English grammar in a given knowledge representation do, given these data?

Raw compatibility of the English grammar = proportion of data the (best) English grammar can account for

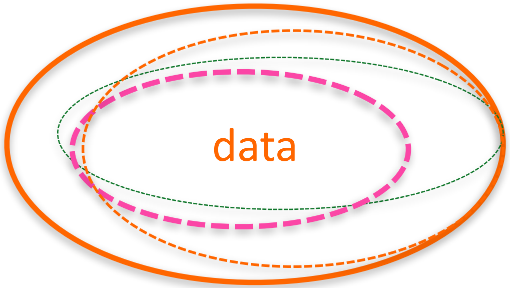
Raw compatibility of English grammar

HV: 0.593 types (0.716 tokens)

Hayes: 0.485 types (0.531 tokens)

OT: 0.573 types (0.574 tokens)

Significantly less than the best grammar



Learning English metrical phonology

So how does the (best) English grammar in a given knowledge representation do, given these data?

Raw compatibility of the English grammar = proportion of data the (best) English grammar can account for

Raw compatibility of English grammar

HV: 0.593 types (0.716 tokens)

Hayes: 0.485 types (0.531 tokens)

OT: 0.573 types (0.574 tokens)

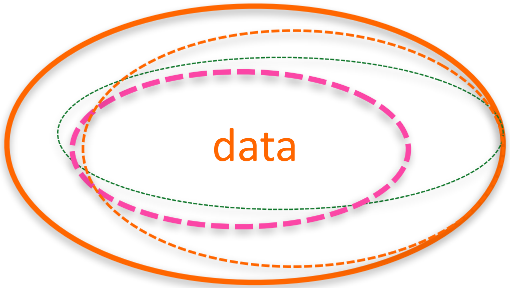
Significantly less than the best grammar

Raw compatibility of best grammar

HV: 0.668 types (0.739 tokens)

Hayes: 0.683 types (0.750 tokens)

OT: 0.657 types (0.729 tokens)



Learning English metrical phonology

Implication:

A rational learner would not pick the English grammar for any of these knowledge representations. It would pick the best grammar instead.

Raw compatibility of English grammar

HV: 0.593 types (0.716 tokens)

Hayes: 0.485 types (0.531 tokens)

OT: 0.573 types (0.574 tokens)

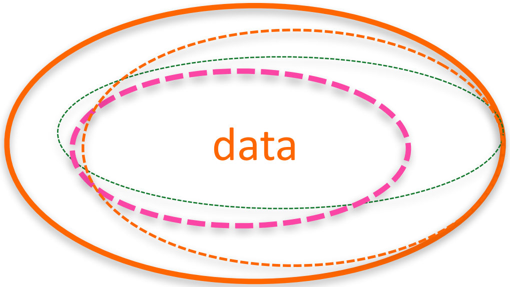
Significantly less than the best grammar

Raw compatibility of best grammar

HV: 0.668 types (0.739 tokens)

Hayes: 0.683 types (0.750 tokens)

OT: 0.657 types (0.729 tokens)



Learning English metrical phonology

So how does the (best) English grammar compare to the other grammars defined by the knowledge representation?

Relative compatibility of the English grammar = proportion of grammars in the hypothesis space the (best) English grammar is better than

Learning English metrical phonology

So how does the (best) English grammar compare to the other grammars defined by the knowledge representation?

Relative compatibility of the English grammar = proportion of grammars in the hypothesis space the (best) English grammar is better than

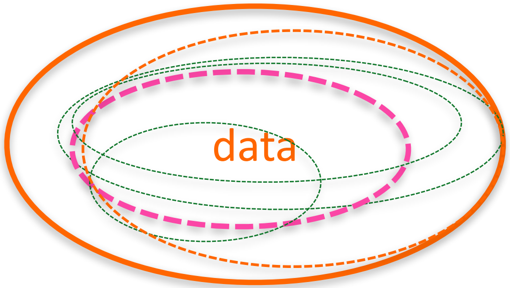
Relative compatibility of English grammar

HV: 0.673 by types (0.673 by tokens) out of 156 grammars

Hayes: 0.676 by types (0.685 by tokens) out of 768 grammars

OT: 0.817 by types (0.785 by tokens) out of 362,880 grammars

Better than many…but many are still better



Learning English metrical phonology

Implication:

There are many other grammars in the hypothesis space that are more compatible with the data. Even if children aren't optimal learners, it would be easier to pick one of these other more compatible grammars.

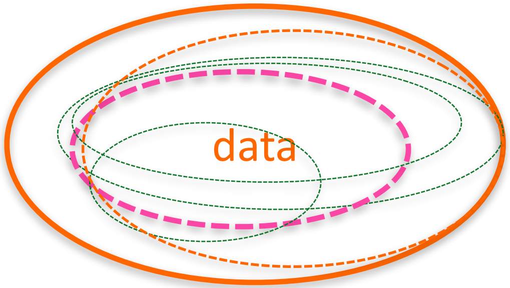
Relative compatibility of English grammar

HV: 0.673 by types (0.673 by tokens) out of 156 grammars

Hayes: 0.676 by types (0.685 by tokens) out of 768 grammars

OT: 0.817 by types (0.785 by tokens) out of 362,880 grammars

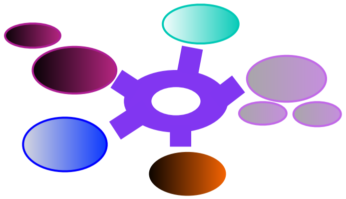
Better than many…but many are still better



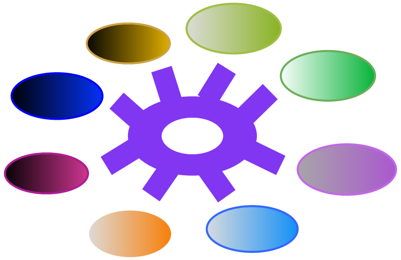
Learning English metrical phonology

Interim conclusion:

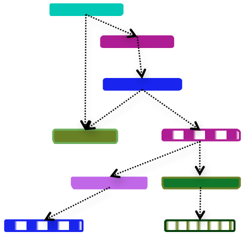
Learnability issues exist for the English grammar in all three knowledge representations.



Parametric: HV

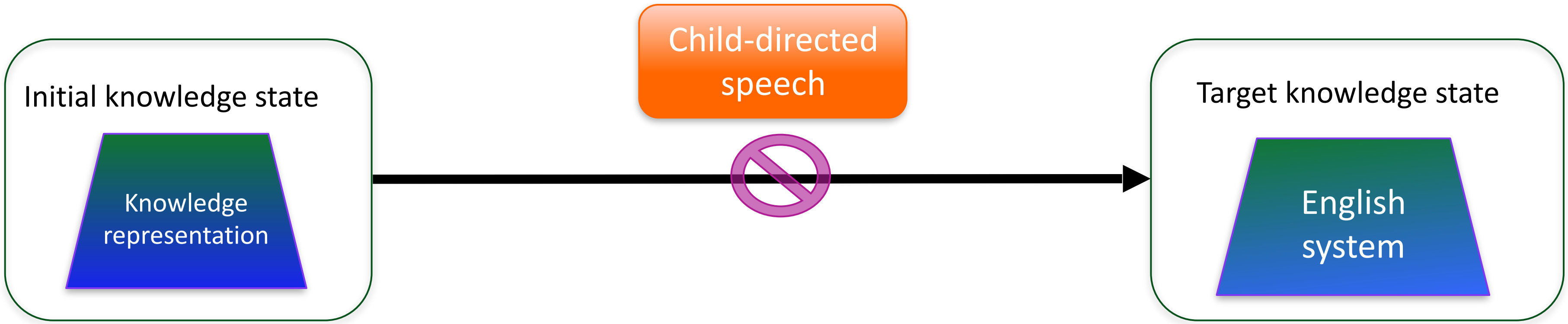


Parametric: Hayes

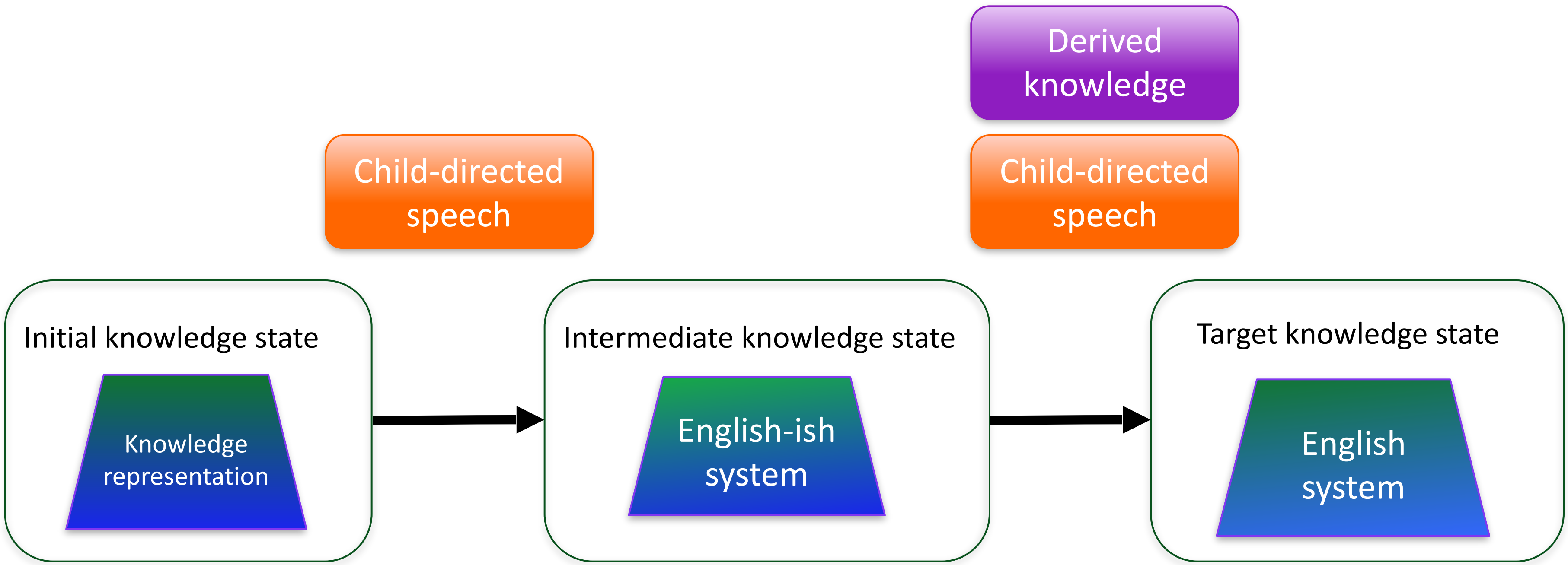


Constraint-based: OT

The learnability problem



The learnability problem: One option



Change the (immediate) target state. Assume there is a transitory state in learning that the learner reaches and then leaves once additional knowledge is acquired.

Learning English metrical phonology

One solution: The learner has derived additional knowledge that helps guide learning.

General knowledge: Interactions with morphology

(Chomsky & Halle 1968, Hayes 1982, Kiparsky 1979)

Specific knowledge: Adding productive morphology doesn't change the stress pattern, even though all grammars base their stress patterns on the syllables present in the word.

EARly	PREtty	senSAtion
EARlier	PREttiest	senSAtional
		senSAtionally

Learning English metrical phonology

One solution: The learner has derived additional knowledge that helps guide learning.

English children seem to use inflectional morphology productively around 3 (Brown 1973) – so they may be aware it doesn't get stressed, based on their prior linguistic experience.

EARly

EARlier

PREtty

PREttiest

senSAtion

senSAtional

senSAtionally

Learning English metrical phonology

So what's the best any grammar in a given knowledge representation actually does, given these data and the knowledge that inflectional morphology is stressless?

Learnability potential = proportion of data the best grammar (relative compatibility ≈ 1.00) can account for

Learning English metrical phonology

So what's the best any grammar in a given knowledge representation actually does, given these data and the knowledge that inflectional morphology is stressless?

Learnability potential = proportion of data the best grammar (relative compatibility ≈ 1.00) can account for

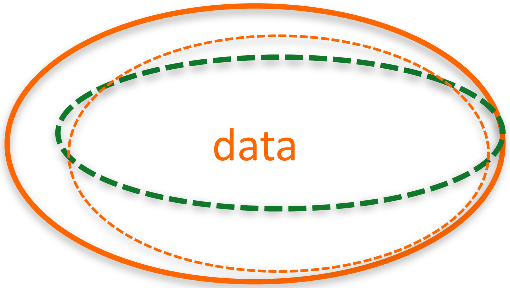
Raw compatibility of best grammar

HV: 0.662 types (0.738 tokens)

Hayes: 0.683 types (0.750 tokens)

OT: 0.677 types (0.749 tokens)

Still around 2/3 of the word types…



Learning English metrical phonology

Implication:

The best grammar is still pretty useful to have. It allows a learner to account for a good proportion of the input, even if there's a significant chunk that can't be accounted for. However, knowing inflectional morphology is stressless doesn't seem to help it account for any more than it could before…

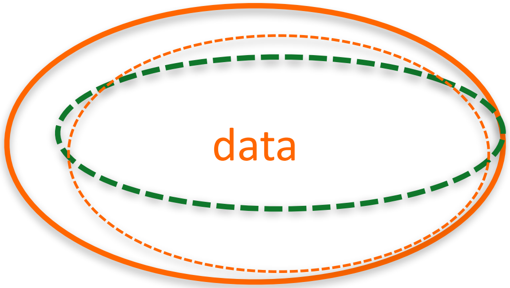
Raw compatibility of best grammar

HV: 0.662 types (0.738 tokens)

Hayes: 0.683 types (0.750 tokens)

OT: 0.677 types (0.749 tokens)

Still around 2/3 of the word types…



Learning English metrical phonology

So how does the (best) English grammar in a given knowledge representation do, given these data and the knowledge that inflectional morphology is stressless?

Raw compatibility of the English grammar = proportion of data the (best) English grammar can account for

Learning English metrical phonology

So how does the (best) English grammar in a given knowledge representation do, given these data and the knowledge that inflectional morphology is stressless?

Raw compatibility of the English grammar = proportion of data the (best) English grammar can account for

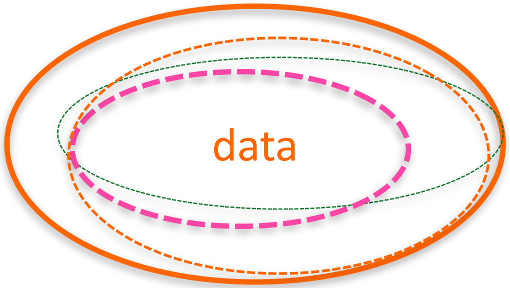
Raw compatibility of English grammar

HV: 0.605 types (0.719 tokens)

Hayes: 0.550 types (0.552 tokens)

OT: 0.578 types (0.575 tokens)

Still significantly less than the best grammar



Learning English metrical phonology

So how does the (best) English grammar in a given knowledge representation do, given these data and the knowledge that inflectional morphology is stressless?

Raw compatibility of the English grammar = proportion of data the (best) English grammar can account for

Raw compatibility of English grammar

HV: 0.605 types (0.719 tokens)

Hayes: 0.550 types (0.552 tokens)

OT: 0.578 types (0.575 tokens)

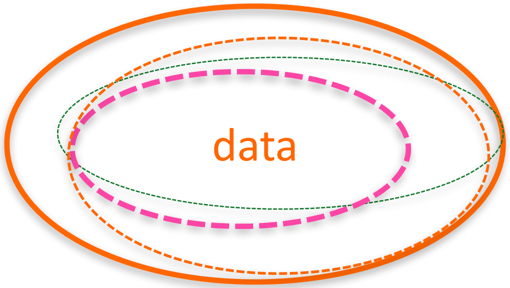
Still significantly less than the best grammar

Raw compatibility of best grammar

HV: 0.662 types (0.738 tokens)

Hayes: 0.683 types (0.750 tokens)

OT: 0.677 types (0.749 tokens)



Learning English metrical phonology

Implication:

A rational learner would still not pick the English grammar for any of these knowledge representations, even with knowledge that inflectional morphology is stressless. It would pick the best grammar instead.

Raw compatibility of English grammar

HV: 0.605 types (0.719 tokens)

Hayes: 0.550 types (0.552 tokens)

OT: 0.578 types (0.575 tokens)

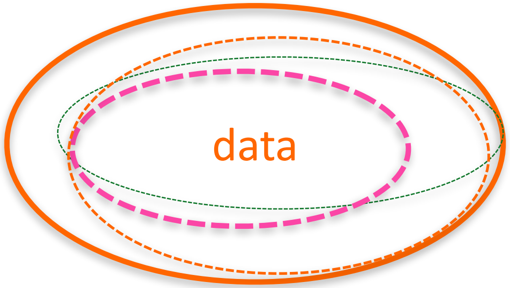
Still significantly less than the best grammar

Raw compatibility of best grammar

HV: 0.662 types (0.738 tokens)

Hayes: 0.683 types (0.750 tokens)

OT: 0.677 types (0.749 tokens)



Learning English metrical phonology

So how does the (best) English grammar compare to the other grammars defined by the knowledge representation, once the learner knows inflectional morphology is stressless?

Relative compatibility of the English grammar = proportion of grammars in the hypothesis space the (best) English grammar is better than

Learning English metrical phonology

So how does the (best) English grammar compare to the other grammars defined by the knowledge representation, once the learner knows inflectional morphology is stressless?

Relative compatibility of the English grammar = proportion of grammars in the hypothesis space the (best) English grammar is better than

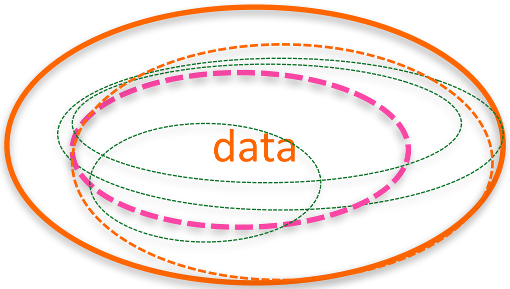
Relative compatibility of English grammar

HV: 0.712 by types (0.673 by tokens) out of 156 grammars

Hayes: 0.704 by types (0.685 by tokens) out of 768 grammars

OT: 0.786 by types (0.777 by tokens) out of 362,880 grammars

Better than many…but many are still better



Learning English metrical phonology

Implication:

There remain many other grammars in the hypothesis space that are more compatible with the data, even though the learner knows inflectional morphology is stressless. Even if children aren't optimal learners, it would be easier to pick one of these other more compatible grammars.

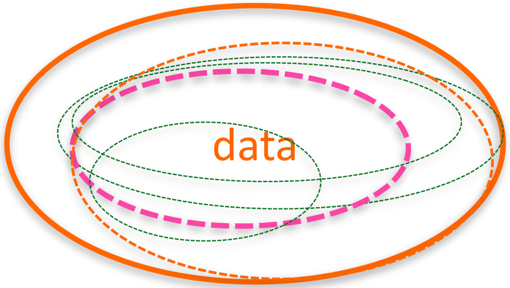
Relative compatibility of English grammar

HV: 0.712 by types (0.673 by tokens) out of 156 grammars

Hayes: 0.704 by types (0.685 by tokens) out of 768 grammars

OT: 0.786 by types (0.777 by tokens) out of 362,880 grammars

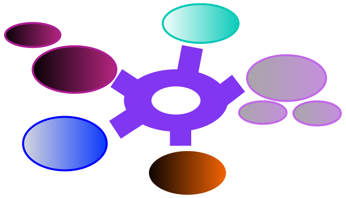
Better than many…but many are still better



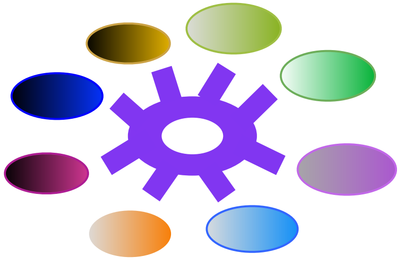
Learning English metrical phonology

Continuing conclusion:

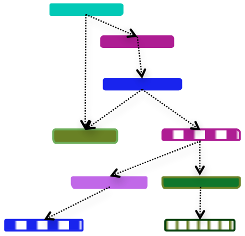
The same learnability issues persist for the English grammar in all three knowledge representations, even when the learner has some knowledge of the interactions between morphology and metrical phonology.



Parametric: HV

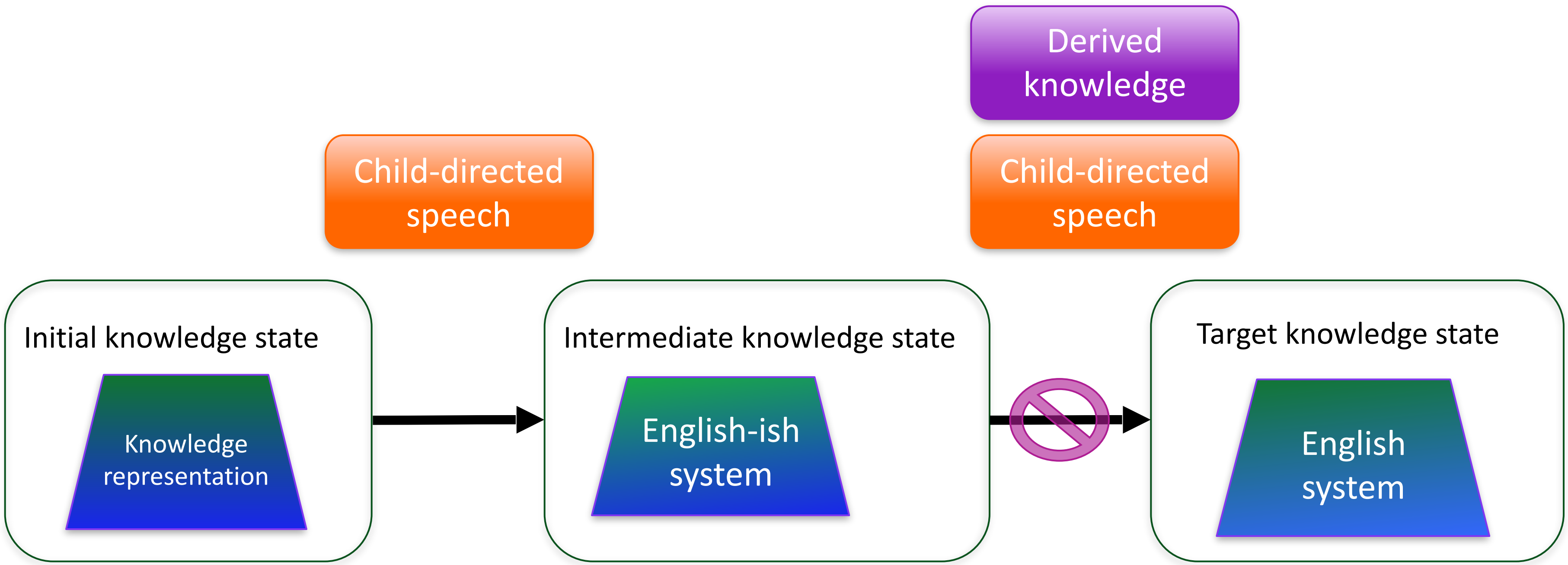


Parametric: Hayes



Constraint-based: OT

The learnability problem: One option that didn't work



Additional knowledge that inflectional morphology is stressless in English didn't seem to help. Why not?

The learnability problem: One option that didn't work

One problem:

All English grammars generally want long syllables (VV nucleus) to be stressed (though the HV parametric grammar allows some exceptions). However, many English words have long syllables that aren't stressed. These remain problematic even with knowledge about inflectional morphology.

proper names	**diminuitives**	
EL mo	KI tty	SWEE tie
MAN dy	DA ddy	DO ggie
	BLAN kie	SO ckie

The learnability problem: One option that didn't work

One problem:

All English grammars generally want long syllables (VV nucleus) to be stressed (though the HV parametric grammar allows some exceptions). However, many English words have long syllables that aren't stressed. These remain problematic even with knowledge about inflectional morphology.

proper names

EL mo

MAN dy

diminuitives

KI tty

DA ddy

BLAN kie

SWEE tie

DO ggie

SO ckie

unstressed long syllables

The learnability problem: One option that didn't work

…yet

One solution: Additional knowledge

Perhaps children learn that the /i/ diminuitive affix behaves like inflectional morphology. Then, syllables containing this ending are expected to be stressless.

✓

proper names	**diminuitives**	
EL mo	KI tty	SWEE tie
MAN dy	DA ddy	DO ggie
	BLAN kie	SO ckie

unstressed long syllables

The learnability problem: One option that didn't work

...yet

One solution: Additional knowledge

Perhaps children learn that proper names are a coherent (semantic) class that may have different stress properties. This is similar to recognizing that grammatical categories may have different effects on stress.

✓ **proper names**

EL mo

MAN dy

✓ **diminuitives**

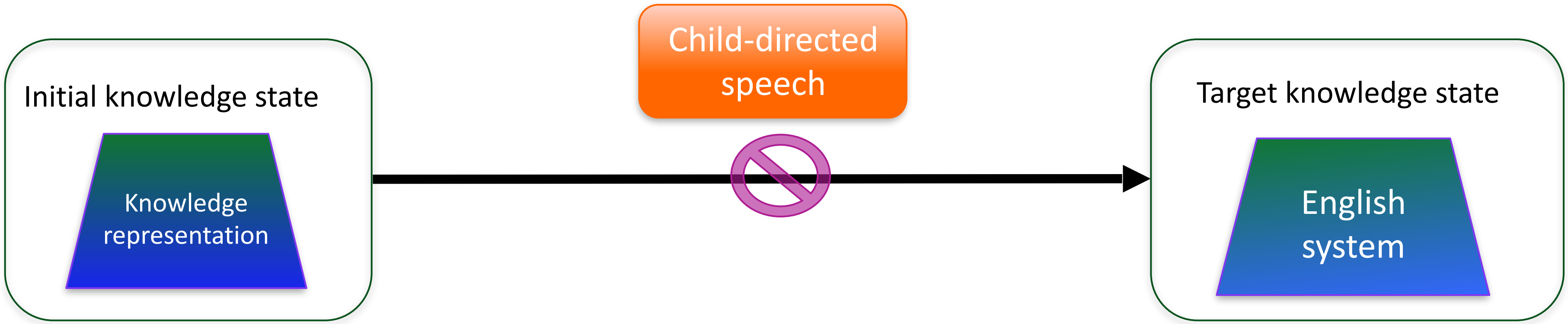
KI tty SWEE tie

DA ddy DO ggie

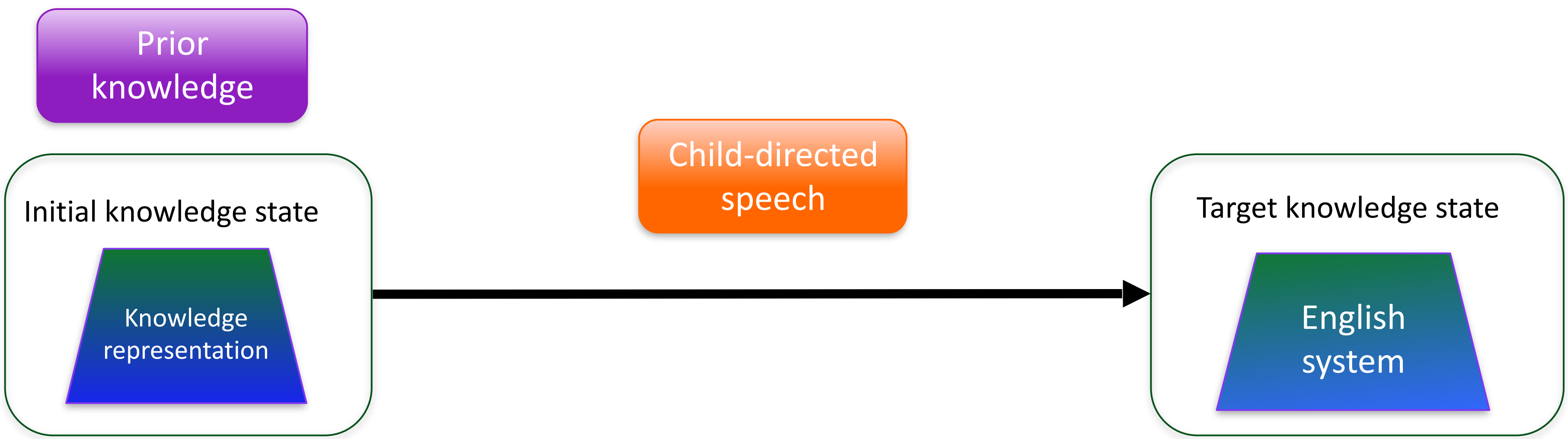
BLAN kie SO ckie

unstressed long syllables

The learnability problem: Another option



The learnability problem: Another option

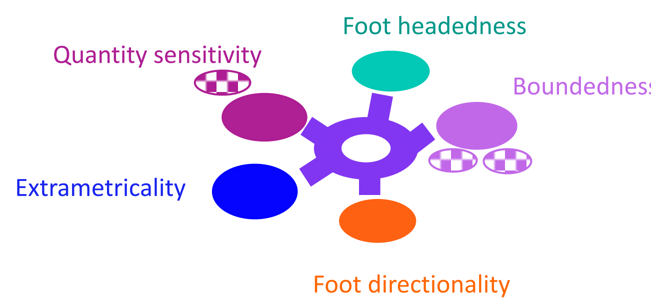


The initial state of the learner includes prior knowledge that helps the learner learn in a more sophisticated way.

What kind of prior knowledge?

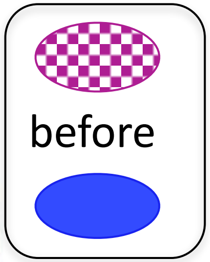
Helpful prior knowledge: Learning biases

Pearl 2008: The parametric HV English grammar can be learned from child-directed speech if children are biased to learn only from data perceived as unambiguous for a particular parameter value.



In addition, children must learn the parameter values in particular orders (obeying certain order constraints).

OCtopus

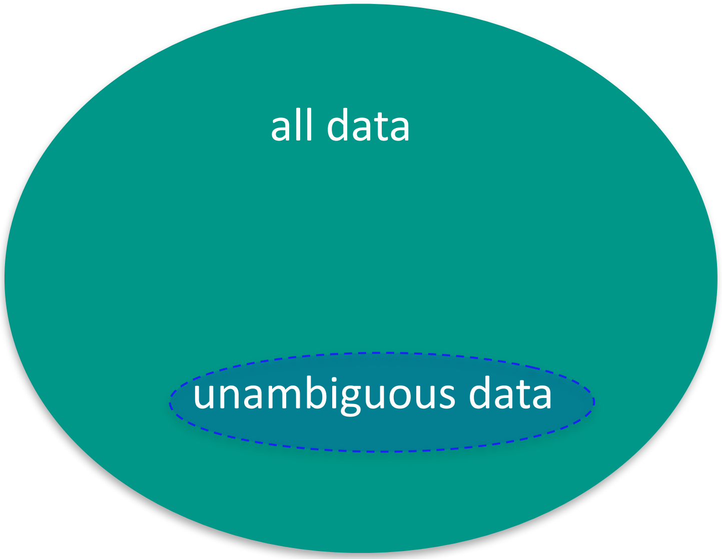


Unambiguous data filter

Previous working assumption: The learner will try to learn a grammar that can account for all the data encountered.

Unambiguous data filter

Updated working assumption: The learner will try to learn a grammar that can account for all the unambiguous data encountered.



This is a small subset of the available data which can be viewed as maximally informative.

Unambiguous data filter

Updated working assumption: The learner will try to learn a grammar that can account for all the unambiguous data encountered.

Why would this occur?

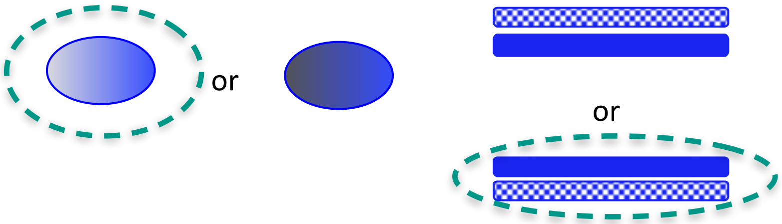
Perhaps the learner prioritizes data that are viewed as highly informative. The goal then becomes to learn a system that can account for all these data.

Unambiguous data filter

Updated working assumption: The learner will try to learn a grammar that can account for all the unambiguous data encountered.

How would this occur?

The learner may look for cues that signal a data point is unambiguous for a particular parameter value or constraint ordering (Pearl 2008, Pearl 2011). These cues may be derived from attempting to analyze a data point with the existing parametric/constraint-ordering options (Fodor 1998, Pearl 2007) – if only one parameter value or constraint ordering is present in successful analyses, this is a cue.



What kind of prior knowledge?

Helpful prior knowledge: Learning biases

Potentially helpful: A bias to learn only from data viewed as productive (Legate & Yang 2012).

✓

COO kie

DA ddy

FU nny

✗

a WAY

be LOW

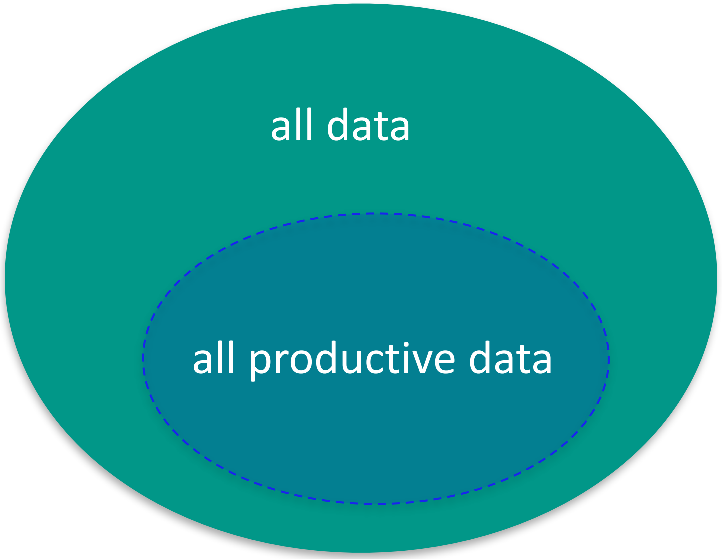
to DAY

Productive data filter

Previous working assumption: The learner will try to learn a grammar that can account for all the data encountered.

Productive data filter

Updated working assumption: The learner will try to learn a grammar that can account for all the productive data encountered.



Productive data filter

Updated working assumption: The learner will try to learn a grammar that can account for all the productive data encountered.

Why would this occur?

Perhaps the learner realizes that some data are unproductive, and therefore likely irregular and unpredictable. The goal then becomes to learn a grammar that can account for all the data that are predictable.

Productive data filter

Updated working assumption: The learner will try to learn a grammar that can account for all the productive data encountered.

How would this occur?

For every syllable word form (ex: V VV) that has multiple stress contours associated with it, the learner assumes that one of these patterns may be the productive contour and the others are exceptions to this general “rule”.

Productive data filter

Updated working assumption: The learner will try to learn a grammar that can account for all the productive data encountered.

How would this occur?

A formal way for identifying if there is a dominant rule for a set of items is the Tolerance Principle (Yang 2005, Legate & Yang 2012). This is used to estimate how many exceptions a rule can tolerate in a set before it's no longer useful for the learner to have the rule. If there are too many exceptions, it's better not to have a rule and learn patterns on an individual item basis instead of having a rule that keeps getting violated.

Productive data filter

Updated working assumption: The learner will try to learn a grammar that can account for all the productive data encountered.

How would this occur?

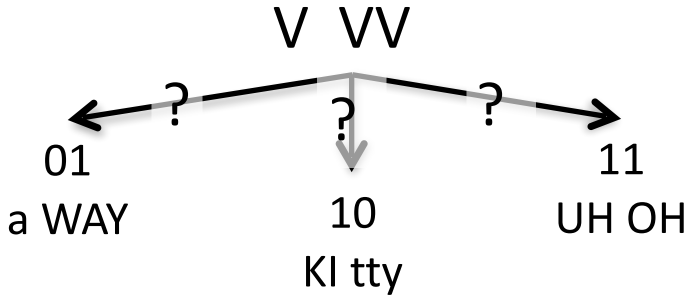
The number of exceptions a rule can tolerate for a set of N items is

$$\frac{N}{ln(N)}$$

(Yang 2005, Legate & Yang 2012)

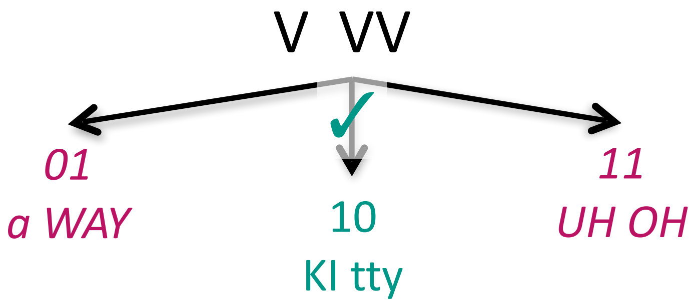
The Tolerance Principle in action

For every syllable word form with multiple stress contours, the learner could assess whether any of those contours is the dominant one (the "rule" for that syllable word form), using the Tolerance Principle.



The Tolerance Principle in action

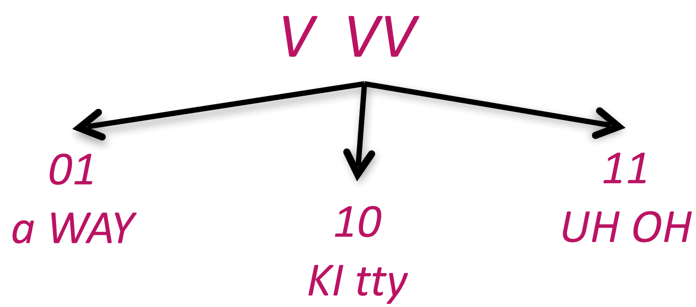
For every syllable word form with multiple stress contours, the learner could assess whether any of those contours is the dominant one (the "rule" for that syllable word form), using the Tolerance Principle.



If one contour is dominant, the learner should focus on accounting for that pattern, since it's regular and productive. The grammar should be able to generate it. The other contours can be ignored for purposes of learning the grammar.

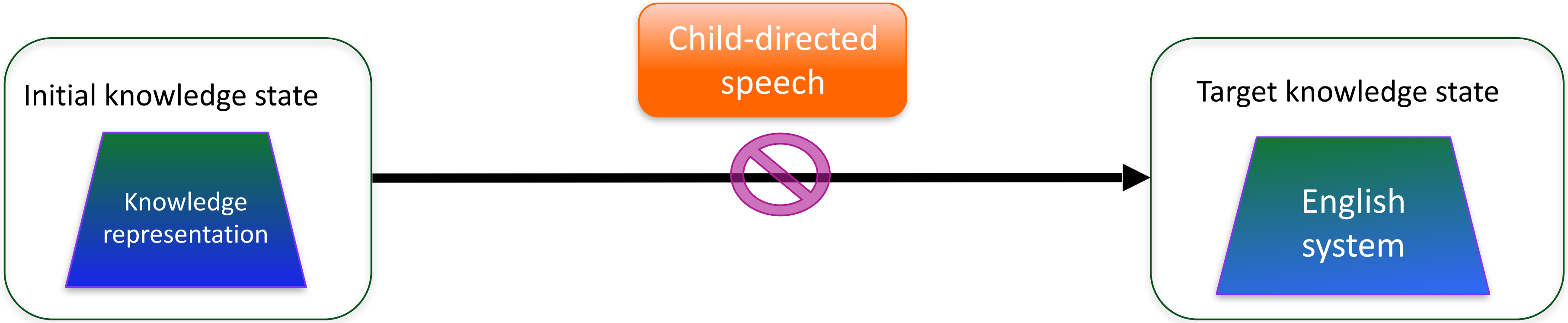
The Tolerance Principle in action

For every syllable word form with multiple stress contours, the learner could assess whether any of those contours is the dominant one (the “rule” for that syllable word form), using the Tolerance Principle.



If no contour is dominant, the learner should ignore this syllable word form for the purposes of learning the grammar since there is no obvious regularity to account for.

The learnability problem: A third option

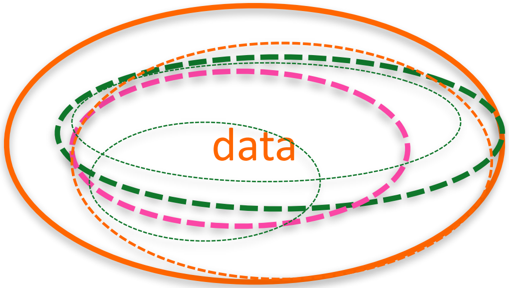


The learnability problem: A third option

The target grammar is different than we think, and we should update our definition of the English grammar.

What should the target grammar be?

One approach: What values/constraint rankings do the grammars have that are more compatible with the data than the official English grammar?

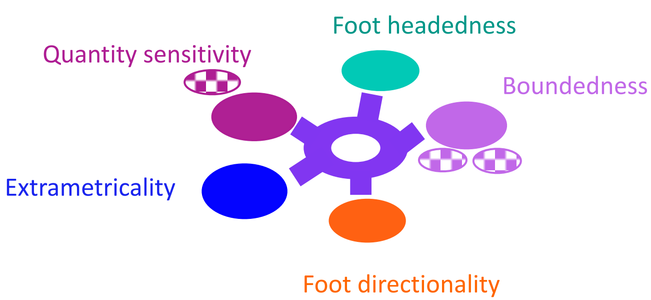


What should the target grammar be?

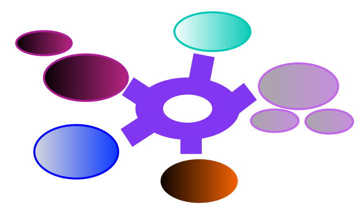
English system

One approach: What values/constraint rankings do the grammars have that are more compatible with the data than the official English grammar?

Parametric: HV



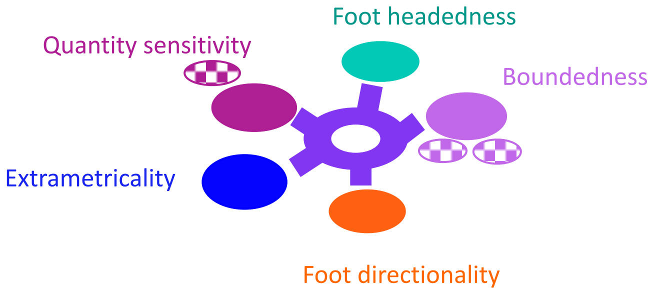
English grammar



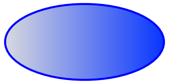
What should the target grammar be?

One approach: What values/constraint rankings do the grammars have that are more compatible with the data than the official English grammar?

Parametric: HV



If we examine the grammars with high compatibility, it turns out that the values used by the English grammar are the values used by the majority of these grammars.

Example: 

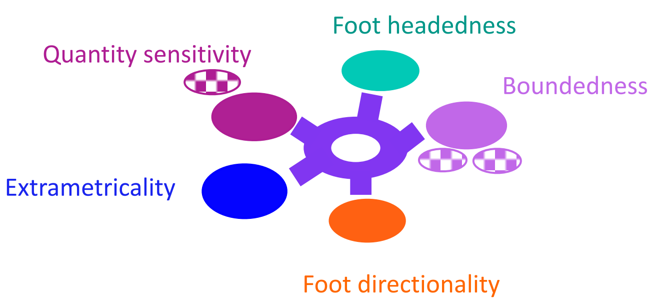
Extrametricality on the rightmost syllable is used by 53 of 58 high compatibility grammars.

What should the target grammar be?

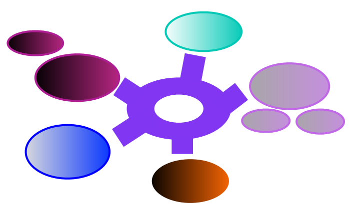
English system

One approach: What values/constraint rankings do the grammars have that are more compatible with the data than the official English grammar?

Parametric: HV



English grammar



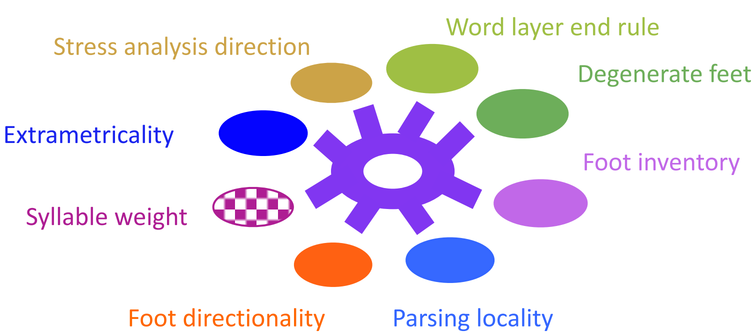
Upshot: Unclear for the HV knowledge representation that the learning problem can be fixed by simply switching one parameter value here or there.

What should the target grammar be?

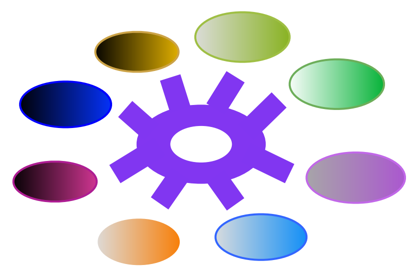
English system

One approach: What values/constraint rankings do the grammars have that are more compatible with the data than the official English grammar?

Parametric: Hayes



English grammar

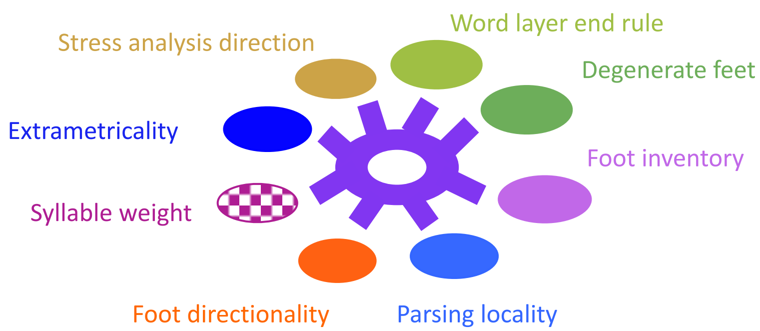


What should the target grammar be?

English system

One approach: What values/constraint rankings do the grammars have that are more compatible with the data than the official English grammar?

Parametric: Hayes

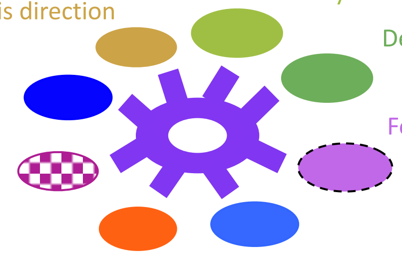


If we examine the grammars with high compatibility, it turns out that there are some parameter values that the majority of high compatibility grammars use, but which the English grammar does not use.

What should the target grammar be?

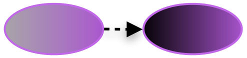
One approach: What values/constraint rankings do the grammars have that are more compatible with the data than the official English grammar?

Parametric: Hayes



Optimal: 0.683 types (0.750 tokens)

If we examine the grammars with high compatibility, it turns out that there are some parameter values that the majority of high compatibility grammars use, but which the English grammar does not use.

(1) Change the Foot inventory value. 

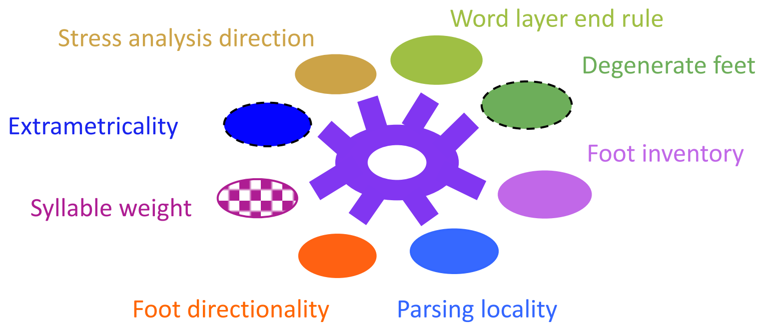
This boosts raw compatibility from 0.485 types (0.531 tokens) to 0.644 types (0.733 tokens).

Relative compatibility = 0.910

What should the target grammar be?

One approach: What values/constraint rankings do the grammars have that are more compatible with the data than the official English grammar?

Parametric: Hayes

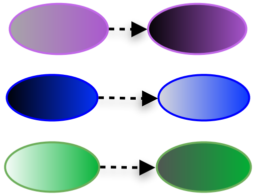


Optimal: 0.683 types (0.750 tokens)

If we examine the grammars with high compatibility, it turns out that there are some parameter values that the majority of high compatibility grammars use, but which the English grammar does not use.

(1) Change the Foot inventory value.

(2) Change the Extrametricality and Degenerate feet values.



This boosts raw compatibility from 0.485 types (0.531 tokens) to 0.652 types (0.729 tokens).

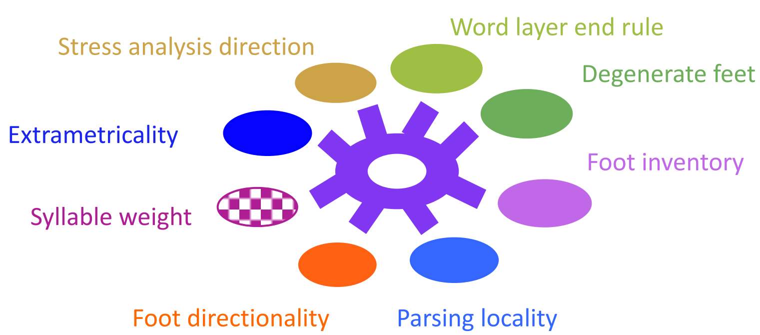
Relative compatibility = 0.923

What should the target grammar be?

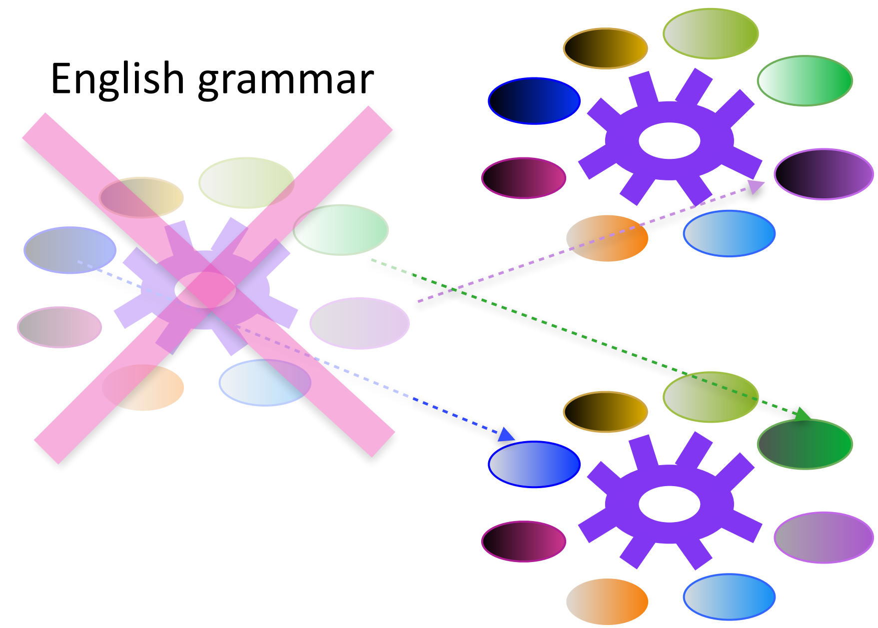
English system

One approach: What values/constraint rankings do the grammars have that are more compatible with the data than the official English grammar?

Parametric: Hayes



English grammar



Upshot: For the Hayes knowledge representation, the learning problem could be ameliorated by simply switching a small number of parameter values.

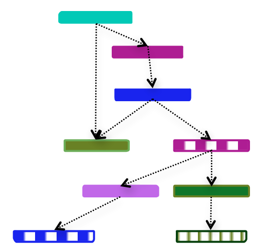
What should the target grammar be?

English system

One approach: What values/constraint rankings do the grammars have that are more compatible with the data than the official English grammar?

Constraint-based: OT

English grammar obeys this ordering



What should the target grammar be?

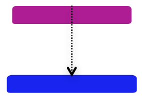
English system

One approach: What values/constraint rankings do the grammars have that are more compatible with the data than the official English grammar?

Constraint-based: OT

If we examine the grammars with high compatibility, it turns out that there is one constraint ordering English uses which none of these grammars use.

Weight-to-Stress VV >> Nonfinality



(Effect: Prefer long syllables to be stressed, even if they're at the right edge of the word)

BAby ← problematic

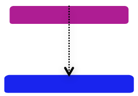
What should the target grammar be?

English system

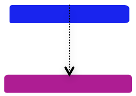
One approach: What values/constraint rankings do the grammars have that are more compatible with the data than the official English grammar?

Constraint-based: OT

If we examine the grammars with high compatibility, it turns out that there is one constraint ordering English uses which none of these grammars use.



Implication: This ranking may be better for English data.



What should the target grammar be?

English system

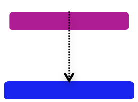
One approach: What values/constraint rankings do the grammars have that are more compatible with the data than the official English grammar?

Constraint-based: OT

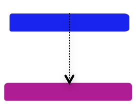
Optimal: 0.657 types (0.729 tokens)

If we examine the grammars with high compatibility, it turns out that there is one constraint ordering English uses which none of these grammars use.

Best English grammar raw compatibility with the original ranking is 0.574 types (0.573 tokens).



Best English grammar raw compatibility with this swapped ranking is 0.655 types (0.729 tokens).



Relative compatibility = 0.988

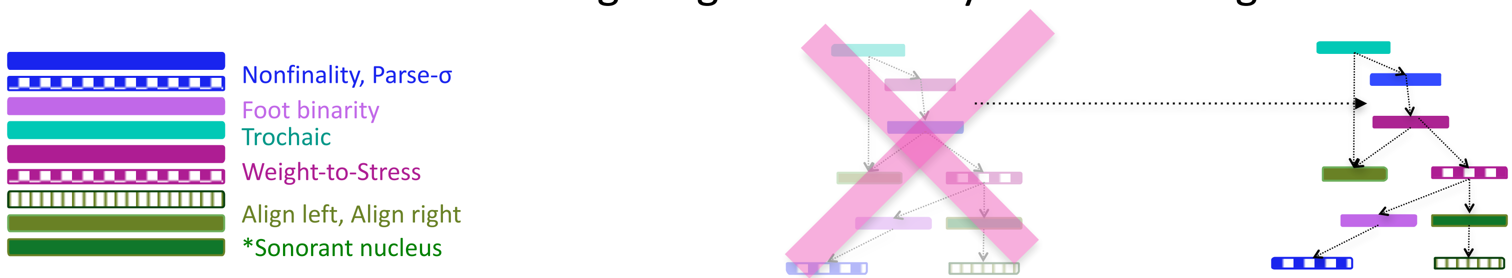
What should the target grammar be?

English system

One approach: What values/constraint rankings do the grammars have that are more compatible with the data than the official English grammar?

Constraint-based: OT

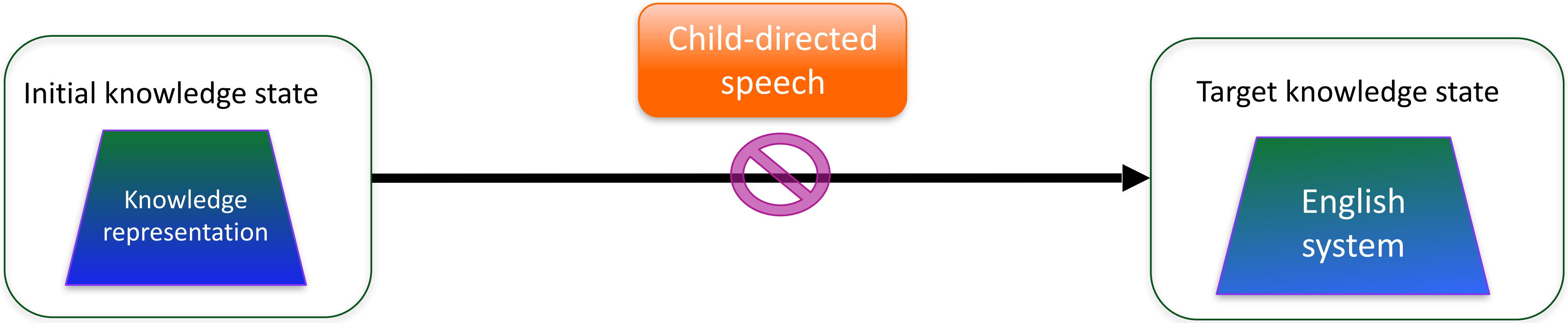
English grammar obeys this ordering



Upshot: For the OT knowledge representation, the learning problem could be alleviated by simply switching one constraint ordering.

Learnability implication recap

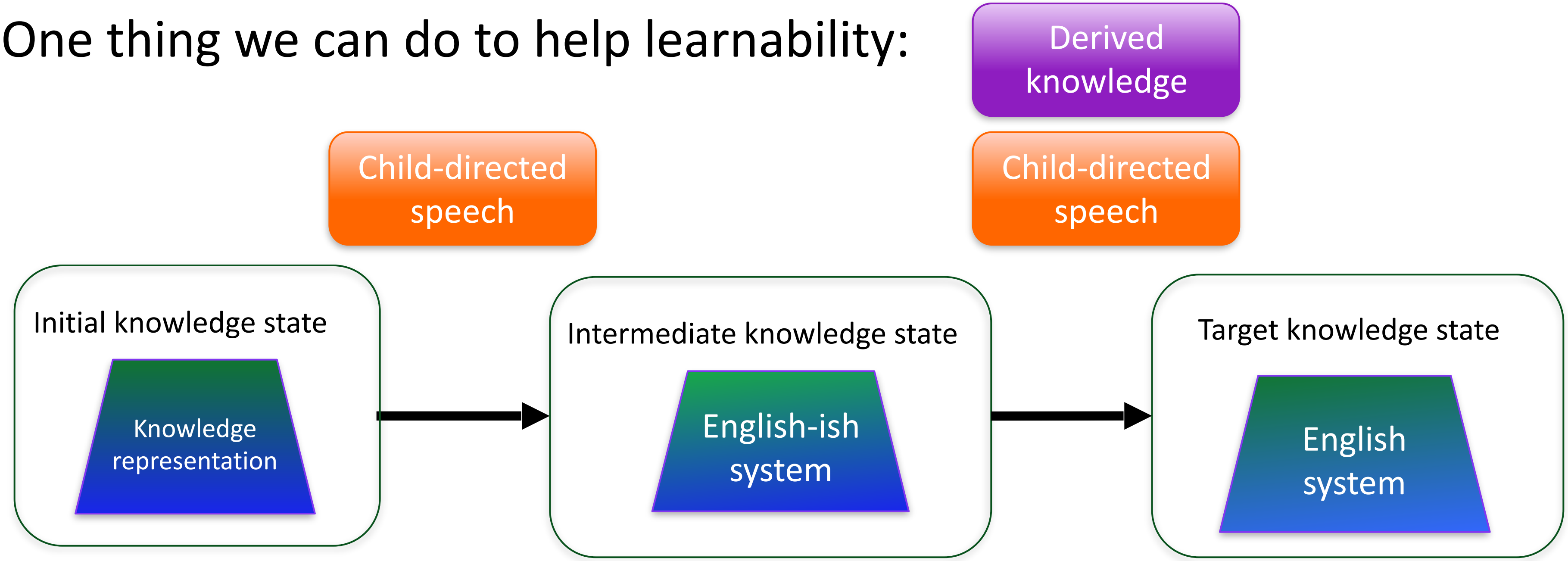
Since learnability issues exist for all three knowledge representations, something else must be going on.



As it stands, they can explain cross-linguistic variation, but the English grammars don't seem to be learnable from English data.

Learnability implication recap

One thing we can do to help learnability:

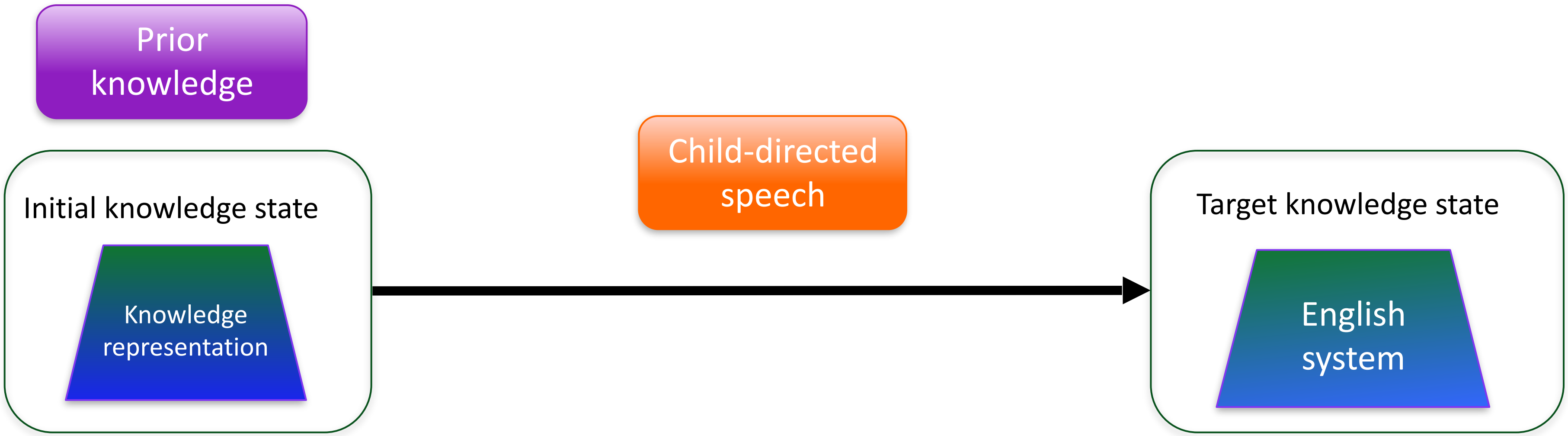


Assume there is at least one transitory state in learning that the learner reaches and then leaves once additional knowledge is acquired.

Adding some knowledge about the interaction of stress with inflectional morphology is insufficient on its own, however.

Learnability implication recap

Another thing we can do to help learnability:



Add in prior knowledge that helps the child perceive the input in a helpful way. Two potentially useful learning biases involve learning a grammar that accounts for a subset of the available data, rather than all of it. One parametric system (HV) has been shown to be learnable this way.

Learnability implication recap

A third thing we can do to help learnability:

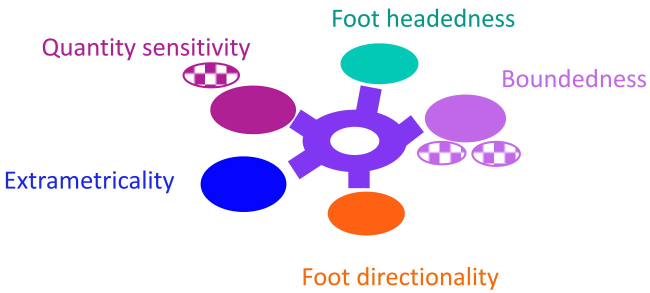
Update our ideas about the target grammar slightly: alter certain parameter values or constraint rankings. (These could also be reasonable definitions of transitory grammars for children.)

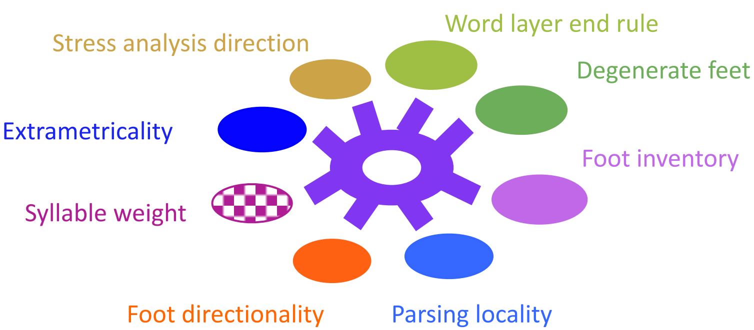
Big picture

Big picture

Establishing a methodology for quantitatively evaluating competing linguistic knowledge representations

- based on an argument from acquisition (how learnable are they from realistic data?)





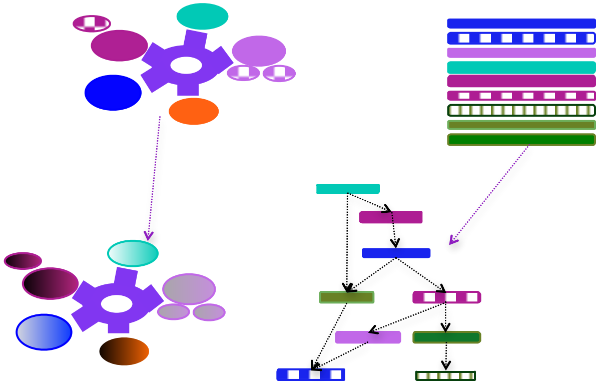
Big picture

Establishing a methodology for quantitatively evaluating competing linguistic knowledge representations

- based on an argument from acquisition (how learnable are they from realistic data?)

Testing against hard cases, like learning English

Idea: If a representation can handle the hard cases, it's really useful



Big picture

Establishing a methodology for quantitatively evaluating competing linguistic knowledge representations

- based on an argument from acquisition (how learnable are they from realistic data?)

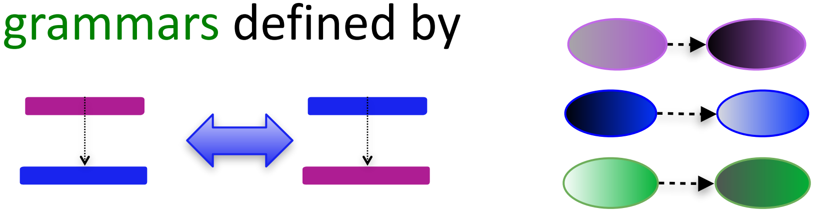
Testing against hard cases, like learning English

Idea: If a representation can handle the hard cases, it's really useful

Provide insight on why current instantiations fail and what can be done about it

- alter theory about how learning proceeds

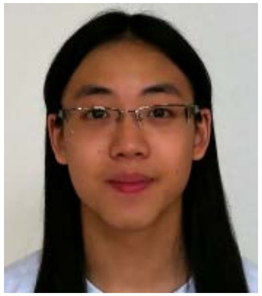
- alter theory of language-specific grammars defined by knowledge representations



Thank you!

Zephyr Detrano

Tim Ho

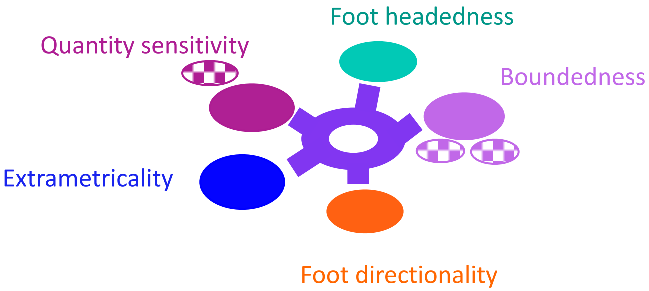


Computation of
Language
Laboratory

UC Irvine

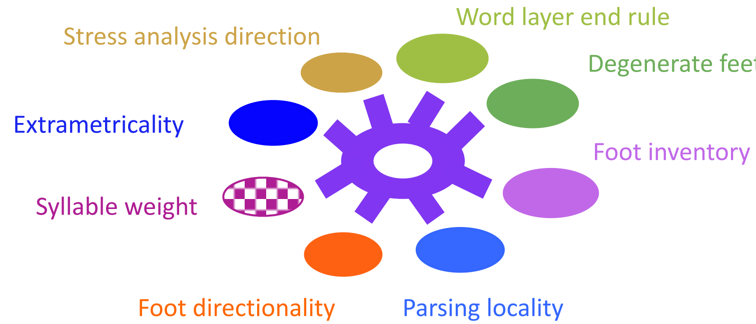
Extra material

Knowledge representation comparison



HV: 5 parameters & 3 sub-parameters

Hypothesis space: 156 grammars



Hayes: 8 parameters

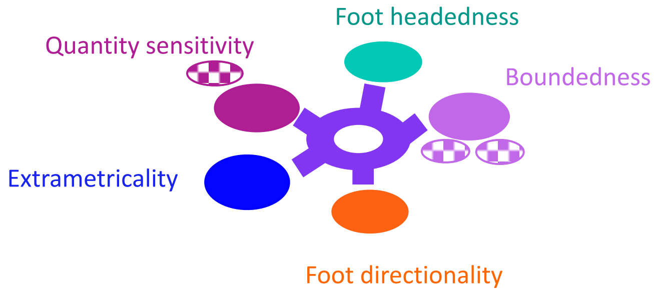
Hypothesis space: 768 grammars

Each representation assumes certain syllabic distinctions.

OT: 9 violable constraints

Hypothesis space: 362,880 grammars

Knowledge representation comparison

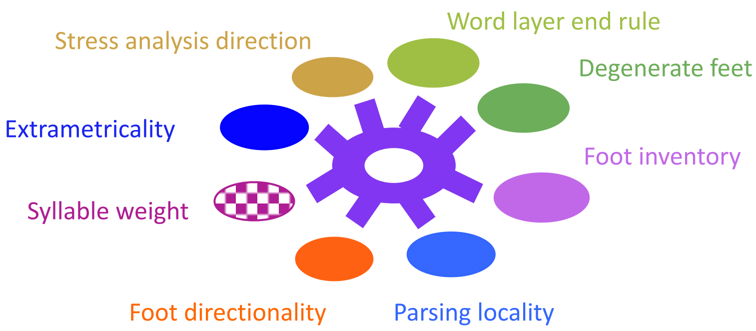


HV: 5 parameters & 3 sub-parameters

Hypothesis space: 156 grammars

Syllabic distinctions: 3

(short, closed, long)



Hayes: 8 parameters

Hypothesis space: 768 grammars

Syllabic distinctions: 4

(short, potentially short, closed, long)

OT: 9 violable constraints

Hypothesis space: 362,880 grammars

Syllabic distinctions: 8

(short, sonorant, 4 closed variants, long, super-long)

Learning English metrical phonology: Non-trivial

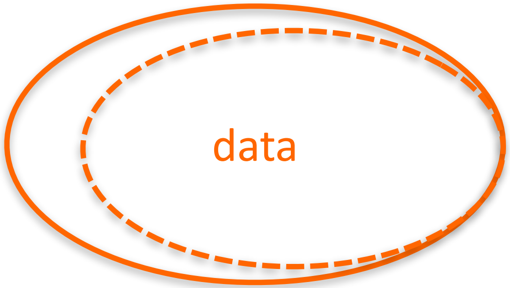
So what's the best any grammar could possibly do, given these data?

Answer: Syllabic learnability potential

Account for the most frequent stress pattern for each syllabic word form.

Syllabic word form: V VV

KI tty	a WAY	UH OH
V vv	v VV	V VV



Learning English metrical phonology: Non-trivial

So what's the best any grammar could possibly do, given these data?

Answer: Syllabic learnability potential

Account for the most frequent stress pattern for each syllabic word form.

Syllabic word form: V VV

KI tty	a WAY	UH OH
V vv	v VV	V VV

Syllabic learnability potential by knowledge representation (proportion accounted for)

HV: 0.711 types (0.766 tokens)

Hayes: 0.719 types (0.769 tokens)

OT: 0.795 types (0.829 tokens)

Pretty good potential coverage, even if it isn't perfect

Learning English metrical phonology

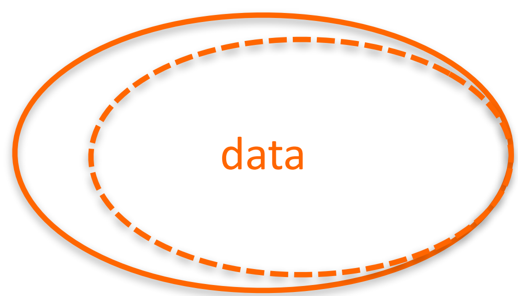
So what's the best any grammar could possibly do, given these data and the knowledge that inflectional morphology is stressless?

Syllabic learnability potential

Accounting for the most frequent stress pattern for each syllabic word form.

Syllabic word form: V VV

KI tty	a WAY	UH OH
V vv	v VV	V VV



Learning English metrical phonology

So what's the best any grammar could possibly do, given these data and the knowledge that inflectional morphology is stressless?

Syllabic learnability potential

Accounting for the most frequent stress pattern for each syllabic word form.

Syllabic word form: V VV

KI tty	a WAY	UH OH
V vv	v VV	V VV

Syllabic learnability potential by knowledge representation (proportion accounted for)

HV: 0.708 types (0.766 tokens)

Hayes: 0.711 types (0.768 tokens)

OT: 0.820 types (0.852 tokens)

Still pretty good potential coverage…but it's also still not perfect.

Learning English metrical phonology

Why wouldn't the best grammar's compatibility be equivalent to the syllabic learnability potential? What's preventing it?

A grammar is constrained by the specific parameters or constraints defined by the KR. These parameters/constraints may not be compatible with the most frequent stress contour every time.

Syllabic word form: V VV

KI tty	a WAY
V vv	v VV
18	242

Syllabic word form: VV VV

BA by	o KAY
VV vv	vv VV
198	4

Syllabic learnability potential: Choose these stress contours (which are opposite)

Learning English metrical phonology

Why wouldn't the best grammar's compatibility be equivalent to the syllabic learnability potential? What's preventing it?

A grammar is constrained by the specific parameters or constraints defined by the KR. These parameters/constraints may not be compatible with the most frequent stress contour every time.

Syllabic word form: V VV

KI tty	a WAY
V vv	v VV
18	242

Syllabic word form: VV VV

BA by	o KAY
VV vv	vv VV
198	4

Grammar compatibility (preferring same contour): Choose these stress contours…

Learning English metrical phonology

Why wouldn't the best grammar's compatibility be equivalent to the syllabic learnability potential? What's preventing it?

A grammar is constrained by the specific parameters or constraints defined by the KR. These parameters/constraints may not be compatible with the most frequent stress contour every time.

Syllabic word form: V VV

KI tty	a WAY
V vv	v VV
18	242

Syllabic word form: VV VV

BA by	o KAY
VV vv	vv VV
198	4

Grammar compatibility (preferring same contour): …or these stress contours.

Parametric knowledge representation comparison

- **HV English grammar outperforms Hayes English grammar in overall compatibility**

Raw compatibilities by type for English grammar in parameter systems (with no knowledge of inflection):

HV		**Hayes**		
59.33%	**-**	**48.05%**	**=**	**11.28% difference**

Which common stressed wordforms are contributing to the relatively high performance of the HV English grammar?

The 10 most common stressed wordforms by type constitute 58.32% of total types in the input. (L = VVC*, X = V, A = VCC+, P = VC)

Stressed wordform	# Types	Examples
Lp	***592***	***water, doing, going***
Xp	***472***	***little, getting, coming***
Ll	***334***	***baby, sweetie, mommy***
Xl	***309***	***kitty, daddy, very***
Ap	***235***	***goodness, handsome, helper***
LL	***188***	***okay, byebye, TV***
Al	***172***	***window, birdie, only***
La	***171***	***peanuts, secrets, highest***
Xa	***170***	***biggest, buckets, hiccups***
xL	***145***	***below, today, hurray***

HV English grammar derives **8** of the 10 most common stressed wordforms.

Stressed wordform	# Types	Examples	HV
Lp	*592*	*water, doing, going*	*Yes*
Xp	*472*	*little, getting, coming*	*Yes*
Ll	*334*	*baby, sweetie, mommy*	*Yes*
Xl	*309*	*kitty, daddy, very*	*Yes*
Ap	*235*	*goodness, handsome, helper*	*Yes*
LL	*188*	*okay, byebye, TV*	*No*
Al	*172*	*window, birdie, only*	*Yes*
La	*171*	*peanuts, secrets, highest*	*Yes*
Xa	*170*	*biggest, buckets, hiccups*	*Yes*
xL	*145*	*below, today, hurray*	*No*

Hayes English grammar derives **5** of the 10 most common stressed wordforms.

Stressed wordform	# Types	Examples	Hayes
Lp	***592***	***water, doing, going***	***Yes***
Xp	***472***	***little, getting, coming***	***Yes***
Ll	*334*	*baby, sweetie, mommy*	**No**
Xl	*309*	*kitty, daddy, very*	**No**
Ap	***235***	***goodness, handsome, helper***	***Yes***
LL	***188***	***okay, byebye, TV***	***Yes***
Al	*172*	*window, birdie, only*	**No**
La	*171*	*peanuts, secrets, highest*	**No**
Xa	*170*	*biggest, buckets, hiccups*	**No**
xL	***145***	***below, today, hurray***	***Yes***

The **Hayes English grammar** misses **Ll and Xl,** two common patterns that together account for **13%** of the input by type.

However, it derives **LL and xL,** alternate contours for these wordforms that are also frequent, accounting for **7%** of input by type.

Stressed wordform	# Types	Examples	HV
Lp	***592***	***water, doing, going***	***Yes***
Xp	***472***	***little, getting, coming***	***Yes***
Ll	*334*	*baby, sweetie, mommy*	**No**
Xl	*309*	*kitty, daddy, very*	**No**
Ap	***235***	***goodness, handsome, helper***	***Yes***
LL	***188***	***okay, byebye, TV***	***Yes***
Al	*172*	*window, birdie, only*	**No**
La	*171*	*peanuts, secrets, highest*	**No**
Xa	*170*	*biggest, buckets, hiccups*	**No**
xL	***145***	***below, today, hurray***	***Yes***

HV vs. Hayes
on most frequent word forms

Stressed wordform	# Types	Examples	HV	Hayes
Lp	***592***	*water, doing, going*	***Yes***	***Yes***
Xp	***472***	*little, getting, coming*	***Yes***	***Yes***
Ll	***334***	*baby, sweetie, mommy*	***Yes***	***No***
Xl	***309***	*kitty, daddy, very*	***Yes***	***No***
Ap	***235***	*goodness, handsome, helper*	***Yes***	***Yes***
LL	***188***	*okay, byebye, TV*	***No***	***Yes***
Al	***172***	*window, birdie, only*	***Yes***	***No***
La	***171***	*peanuts, secrets, highest*	***Yes***	***No***
Xa	***170***	*biggest, buckets, hiccups*	***Yes***	***No***
xL	***145***	*below, today, hurray*	***No***	***Yes***

The impact of morphological knowledge

Example: What happens to words of the La stressed word form when the child gets morphological knowledge? (for the Hayes grammar, which can't account for it without morphological knowledge)

Stressed wordform	# Types	Examples	HV	Hayes
Lp	***592***	*water, doing, going*	***Yes***	***Yes***
Xp	***472***	*little, getting, coming*	***Yes***	***Yes***
Ll	***334***	*baby, sweetie, mommy*	***Yes***	***No***
Xl	***309***	*kitty, daddy, very*	***Yes***	***No***
Ap	***235***	*goodness, handsome, helper*	***Yes***	***Yes***
LL	***188***	*okay, byebye, TV*	***No***	***Yes***
Al	***172***	*window, birdie, only*	***Yes***	***No***
La	***171***	*peanuts, secrets, highest*	***Yes***	***No***
Xa	***170***	*biggest, buckets, hiccups*	***Yes***	***No***
xL	***145***	*below, today, hurray*	***No***	***Yes***

The impact of morphological knowledge

Example: What happens to words of the La stressed word form when the child gets morphological knowledge? (for the Hayes grammar, which can't account for it without morphological knowledge)

Before morphological knowledge

171 La (island, giant, moment)

After morphological knowledge

57 La (54 of the 171 + 3 added from Lp form)
– Hayes still can't account for these

100 Lp (father's→father pockets→pocket slobbered→slobber)
17 L (cutest→cute nicest→nice weirdest→weird)
- Hayes can now account for these

In this case, knowing inflectional morphology is stressless helps!

The impact of morphological knowledge

In general, the Hayes English grammars benefits from morphology knowledge (6.95% more types accounted for, due to 322 types), unlike the HV and OT English grammars.

Where are these changes happening?

- **28** types: incorrectly derived bisyllabics become monosyllabic
Examples: cleanest → clean (La→L); biggest → big (Xa→P); bestest → best (Aa→A)

- **100** types: incorrectly derived **La** becomes correctly-derived **Lp**
Examples: father's → father; pockets → pocket; slobbered → slobber

- **112** types: incorrectly derived **Xa** becomes correctly-derived **Xp**
Examples: sister's→ sister; apples→ apple; tickled→ tickle;

~ **92** types: Changes in less common wordforms
Examples: messages→ message; promises → promise; modeling → model

Productive data filter in action

Productive data filter in action

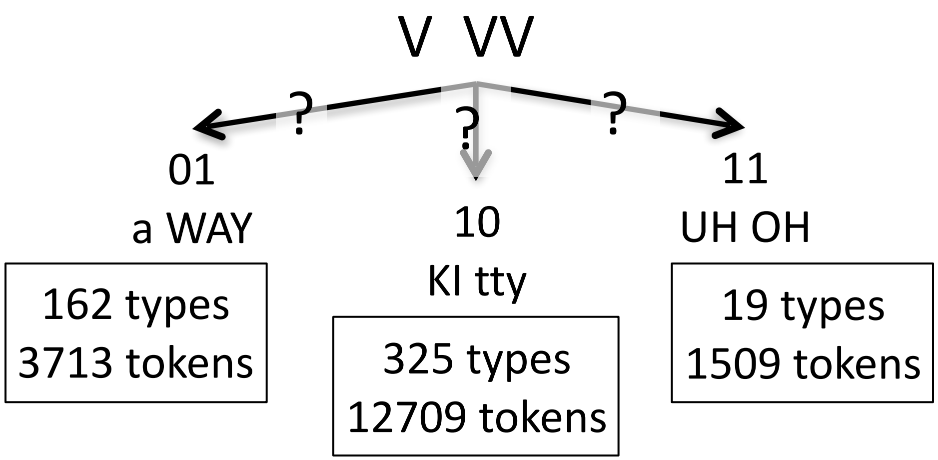
Parametric: HV & Hayes, with inflectional knowledge

HV: 123 syllable word forms

3 syllable distinctions

Hayes: 149 syllable word forms

4 syllable distinctions



Productive data filter in action

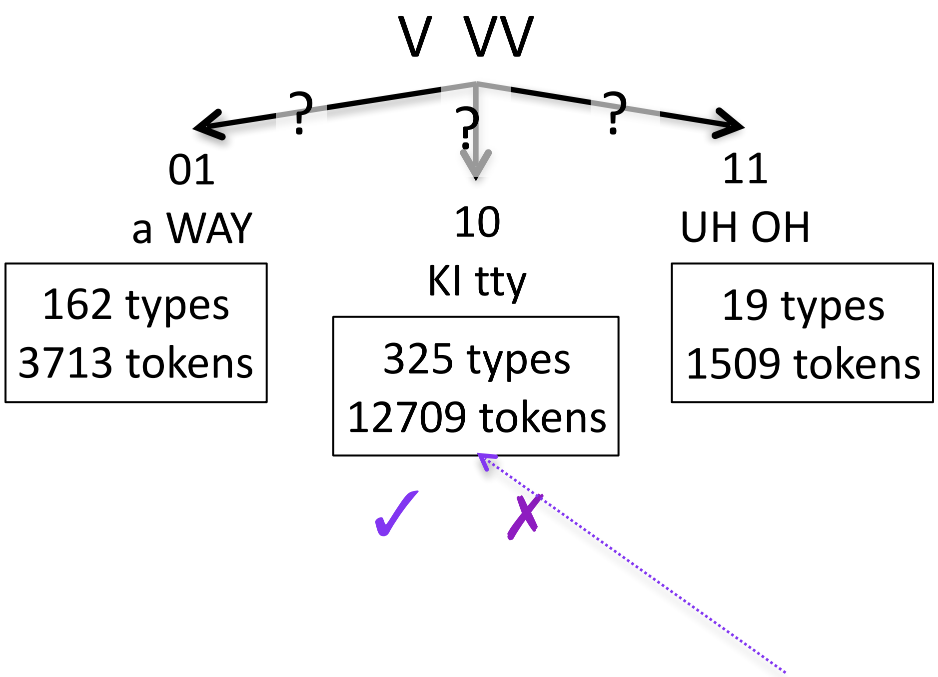
Parametric: HV & Hayes, with inflectional knowledge

HV: 123 syllable word forms

3 syllable distinctions

Hayes: 149 syllable word forms

4 syllable distinctions



These items are good for the HV English grammar.

Productive data filter in action

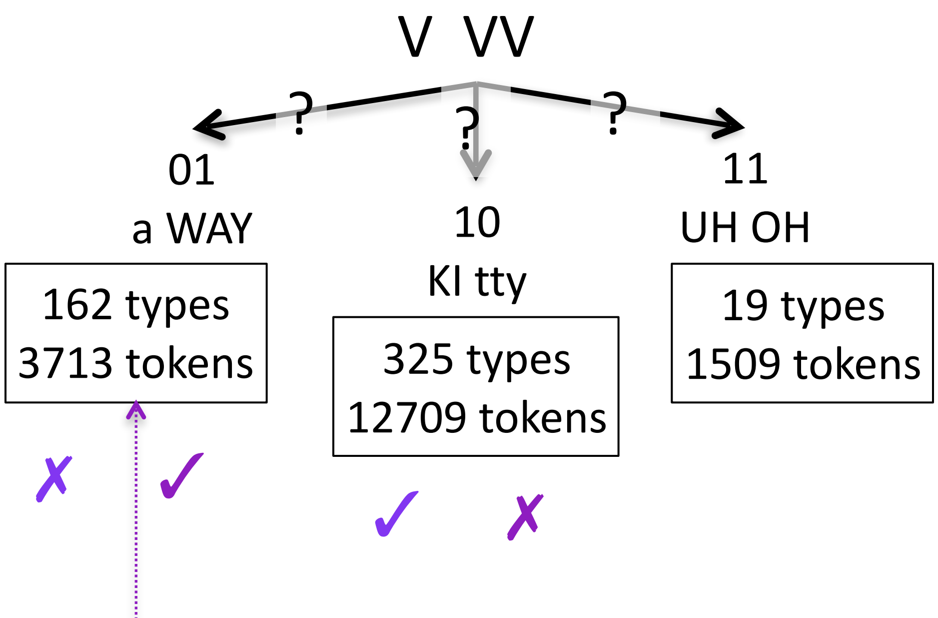
Parametric: HV & Hayes, with inflectional knowledge

HV: 123 syllable word forms

3 syllable distinctions

Hayes: 149 syllable word forms

4 syllable distinctions



These items are good for the Hayes English grammar.

Productive data filter in action

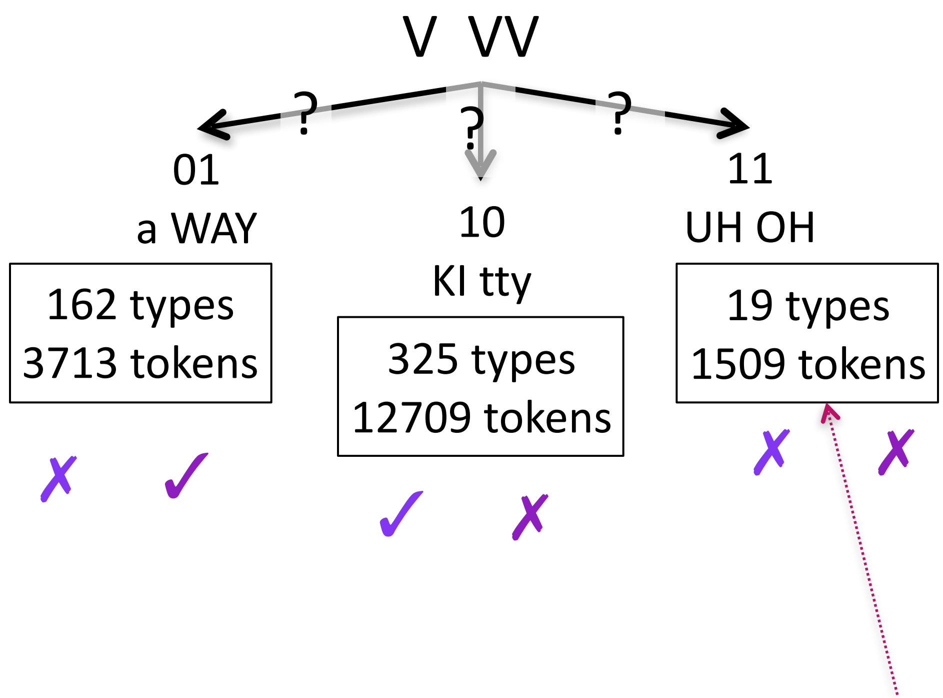
Parametric: HV & Hayes, with inflectional knowledge

HV: 123 syllable word forms

3 syllable distinctions

Hayes: 149 syllable word forms

4 syllable distinctions



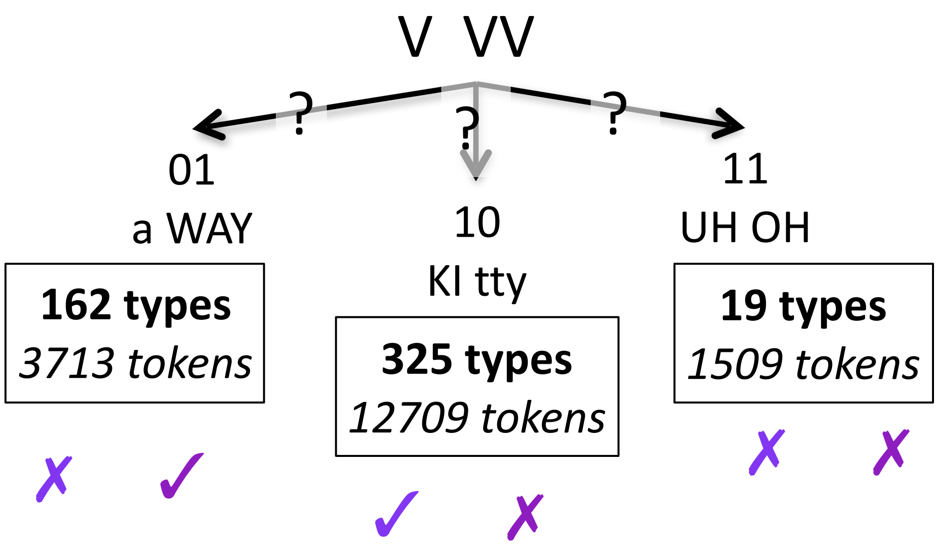
These items aren't good for either English grammar.

Productive data filter in action

Parametric: HV & Hayes, with inflectional knowledge

HV: 123 syllable word forms
3 syllable distinctions

Hayes: 149 syllable word forms
4 syllable distinctions



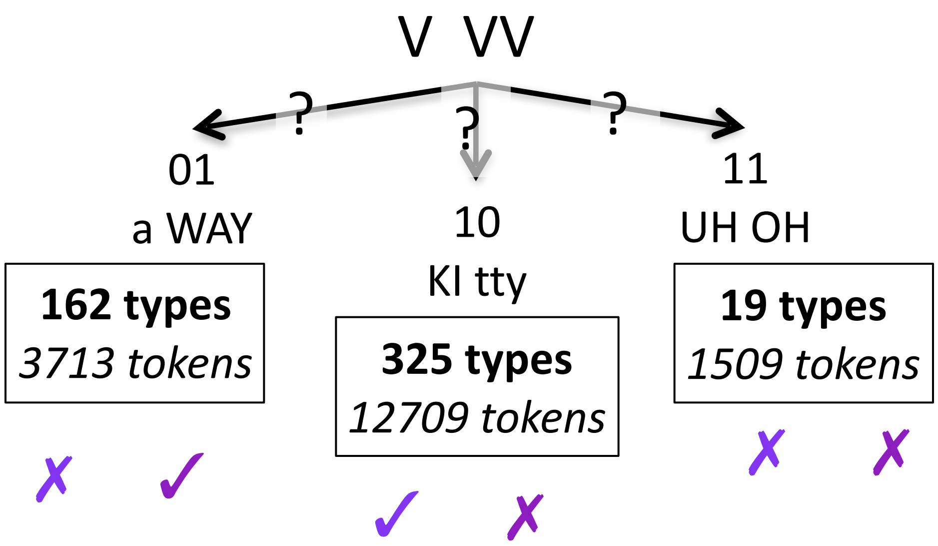
The Tolerance Principle looks at the **word types** with each stress pattern. Each represents an individual item that might follow the regular stress pattern rule (if there is one).

Productive data filter in action

Parametric: HV & Hayes, with inflectional knowledge

HV: 123 syllable word forms
3 syllable distinctions

Hayes: 149 syllable word forms
4 syllable distinctions



How many items should the stress "rule" apply to? N = 162 + 325 + 19 = 506

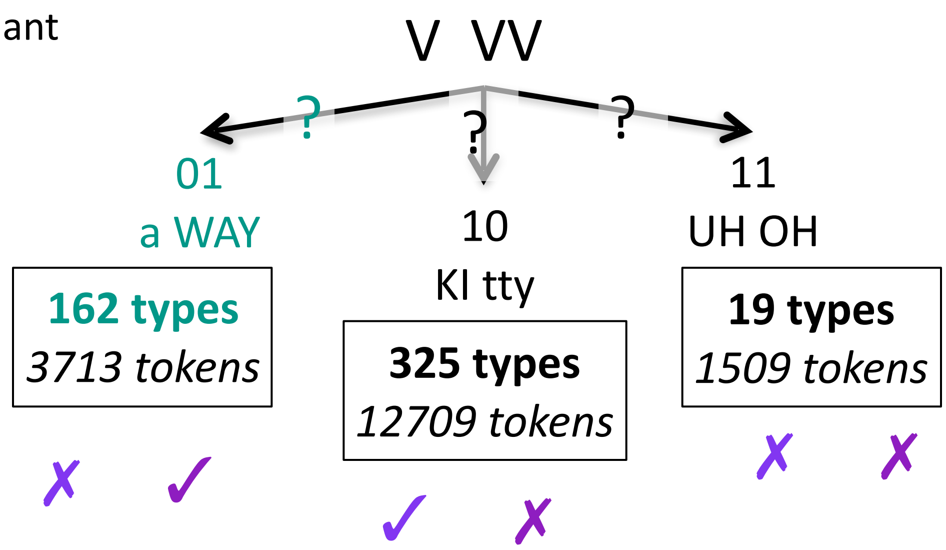
Productive data filter in action

Parametric: HV & Hayes, with inflectional knowledge

HV: 123 syllable word forms
3 syllable distinctions

Hayes: 149 syllable word forms
4 syllable distinctions

If this is the dominant pattern, too many exceptions:
325 + 19 > 81



How many exceptions are allowed? 506 / ln(506) = **81**

Productive data filter in action

Parametric: HV & Hayes, with inflectional knowledge

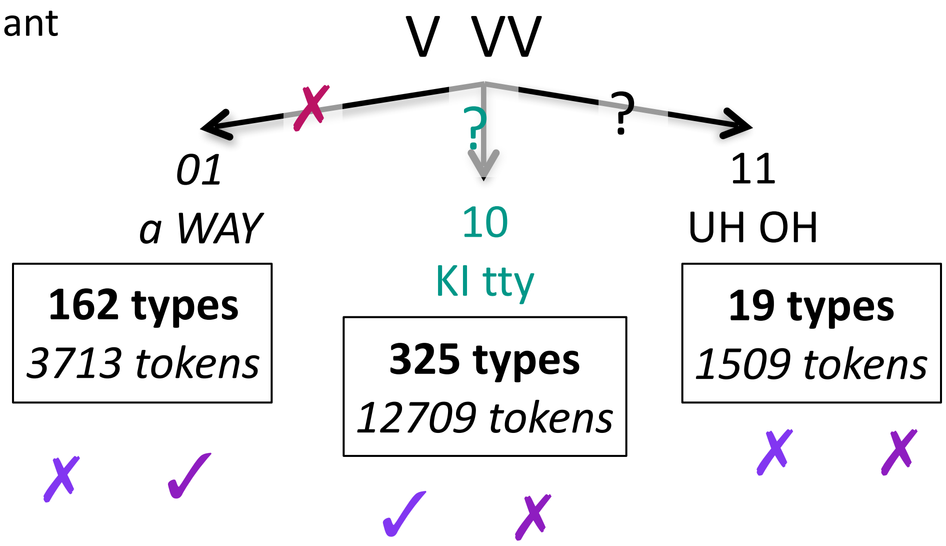
HV: 123 syllable word forms

3 syllable distinctions

Hayes: 149 syllable word forms

4 syllable distinctions

If this is the dominant pattern, too many exceptions:
162 + 19 > 81



How many exceptions are allowed? 506 / ln(506) = **81**

Productive data filter in action

Parametric: HV & Hayes, with inflectional knowledge

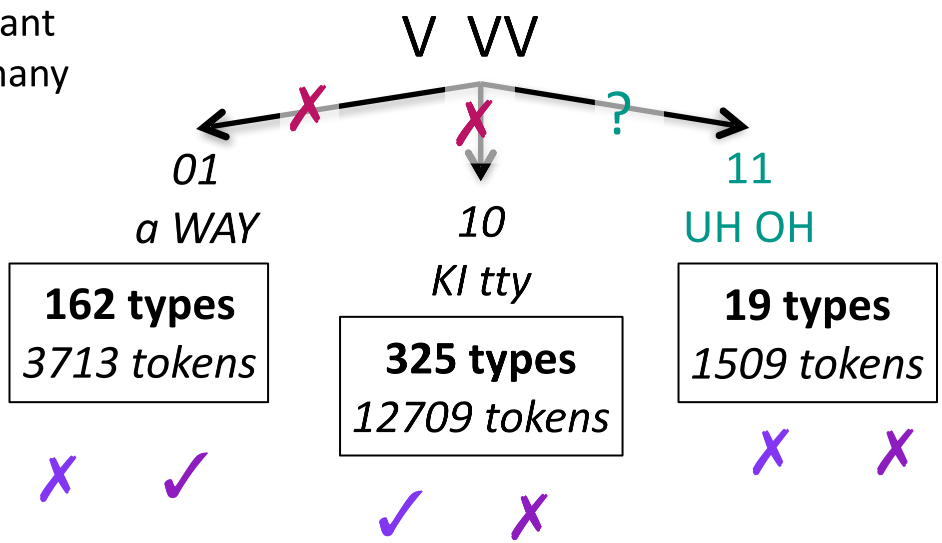
HV: 123 syllable word forms

3 syllable distinctions

Hayes: 149 syllable word forms

4 syllable distinctions

If this is the dominant pattern, way too many exceptions:
162 + 325 > 81



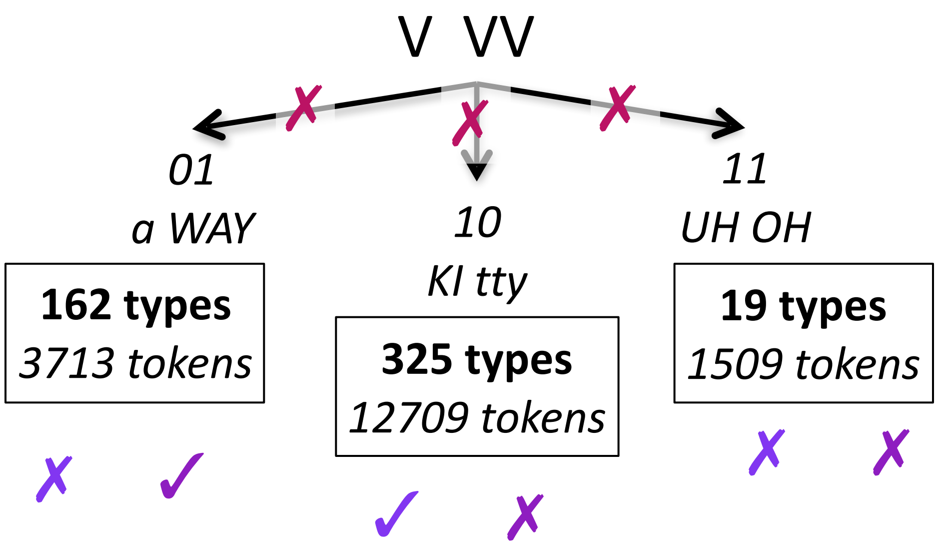
How many exceptions are allowed? 506 / ln(506) = **81**

Productive data filter in action

Parametric: HV & Hayes, with inflectional knowledge

HV: 123 syllable word forms
3 syllable distinctions

Hayes: 149 syllable word forms
4 syllable distinctions



Learner conclusion: No dominant stress pattern, so none of these syllable word form data should be used to learn the English grammar.

Productive data filter in action

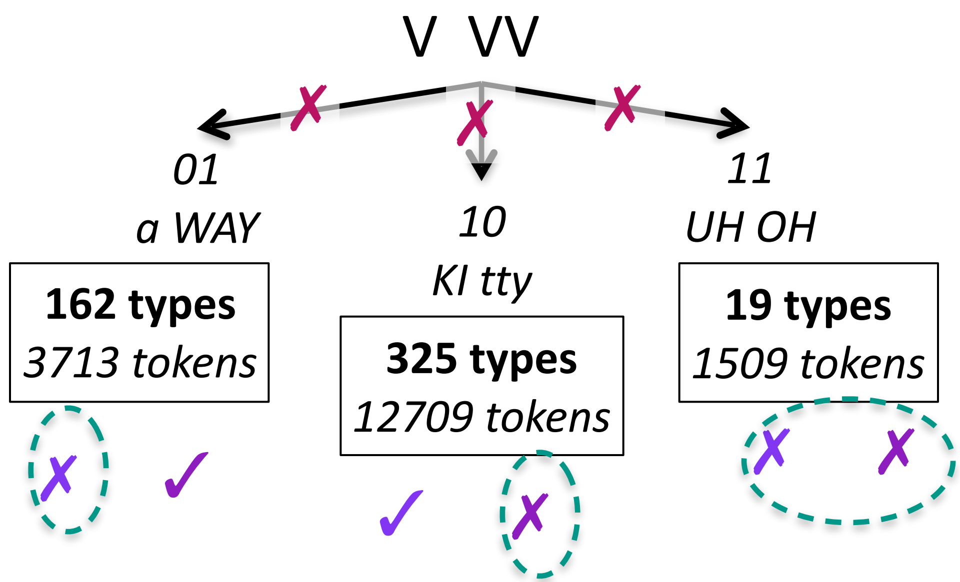
Parametric: HV & Hayes, with inflectional knowledge

HV: 123 syllable word forms

3 syllable distinctions

Hayes: 149 syllable word forms

4 syllable distinctions



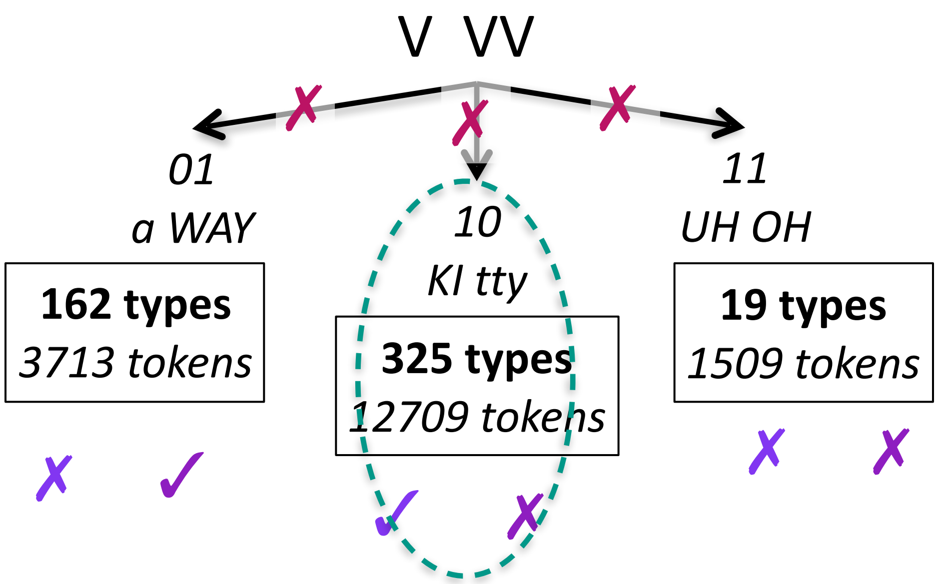
This will end up helping both grammars, since they won't be penalized for the patterns they can't account for.

Productive data filter in action

Parametric: HV & Hayes, with inflectional knowledge

HV: 123 syllable word forms
3 syllable distinctions

Hayes: 149 syllable word forms
4 syllable distinctions



However, the Hayes grammar is helped a little more, since it couldn't account for the most frequent stress pattern before, while the HV grammar could.

Productive data filter in action

Constraint-based: OT, with inflectional knowledge

452 syllable word forms

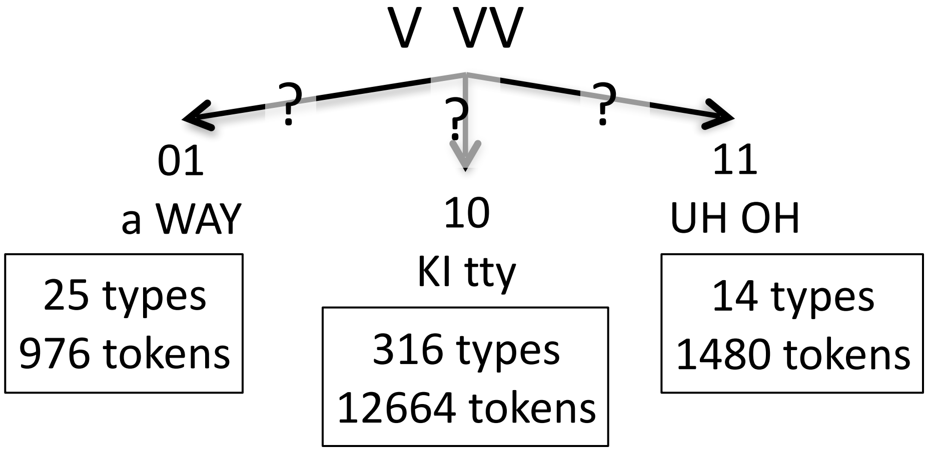
8 syllable distinctions

Productive data filter in action

Constraint-based: OT, with inflectional knowledge

452 syllable word forms

8 syllable distinctions

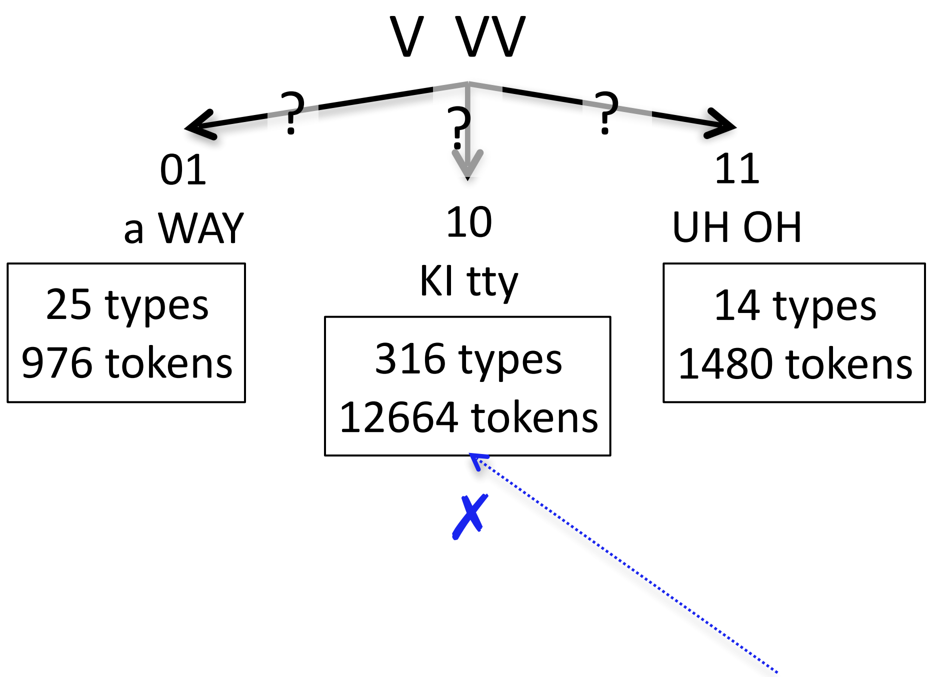


Productive data filter in action

Constraint-based: OT, with inflectional knowledge

452 syllable word forms

8 syllable distinctions



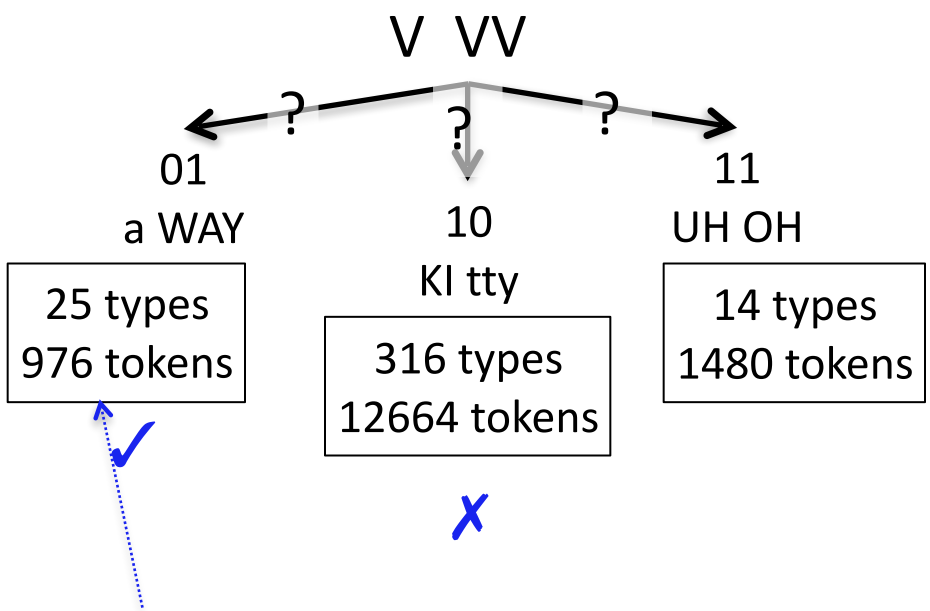
These items are bad for all English grammars.

Productive data filter in action

Constraint-based: OT, with inflectional knowledge

452 syllable word forms

8 syllable distinctions



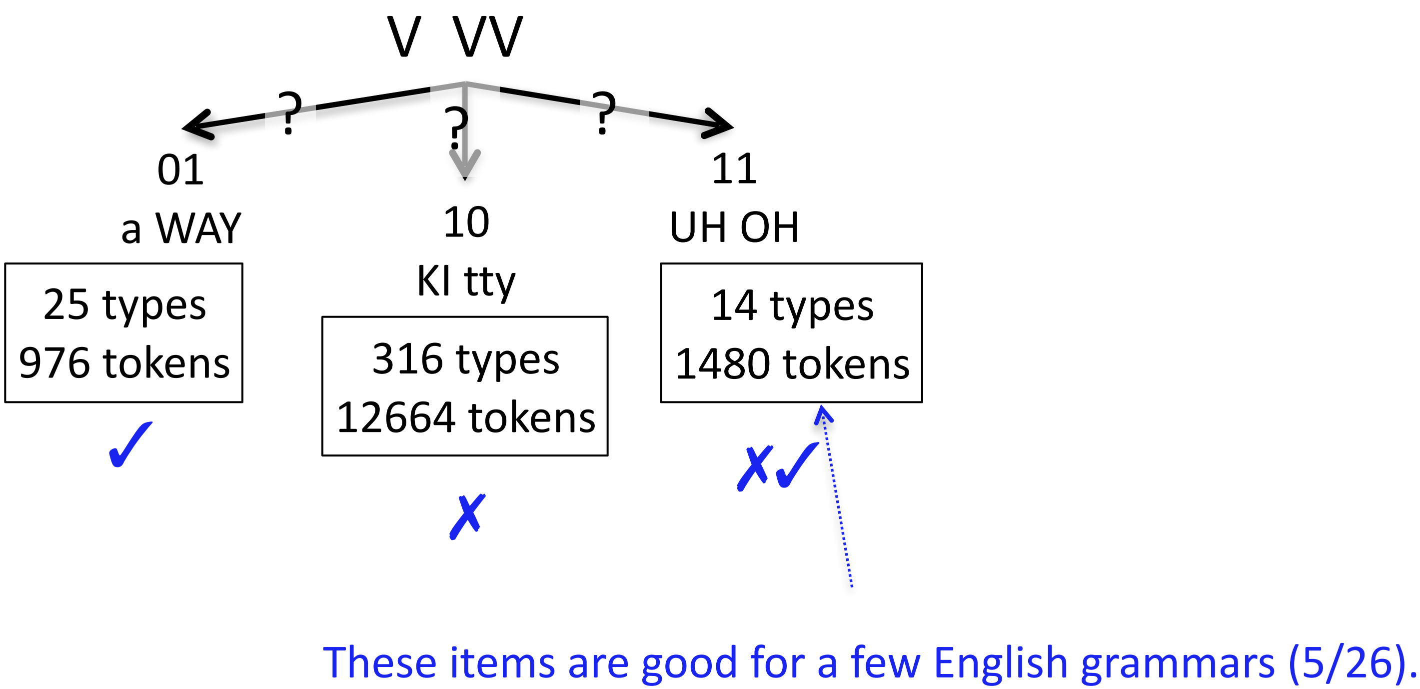
These items are good for most English grammars (21/26).

Productive data filter in action

Constraint-based: OT, with inflectional knowledge

452 syllable word forms

8 syllable distinctions

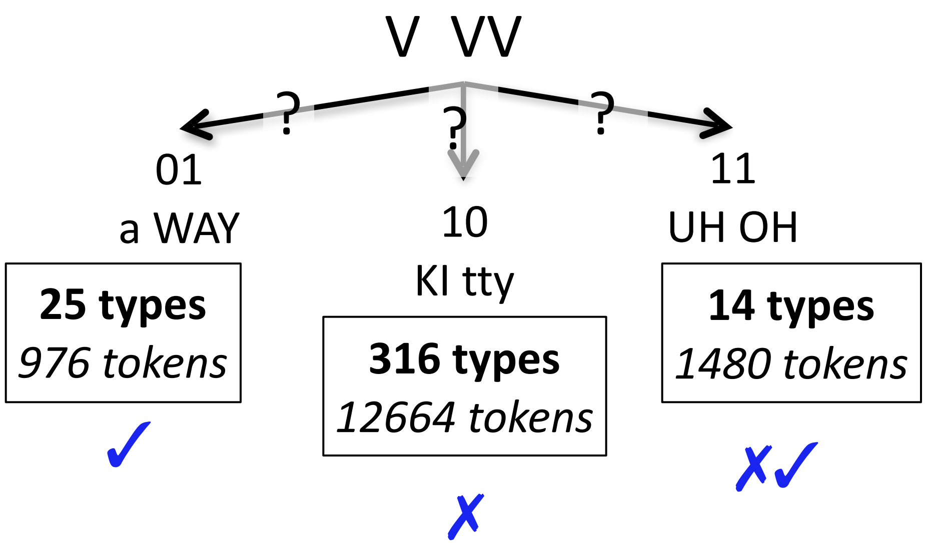


Productive data filter in action

Constraint-based: OT, with inflectional knowledge

452 syllable word forms

8 syllable distinctions



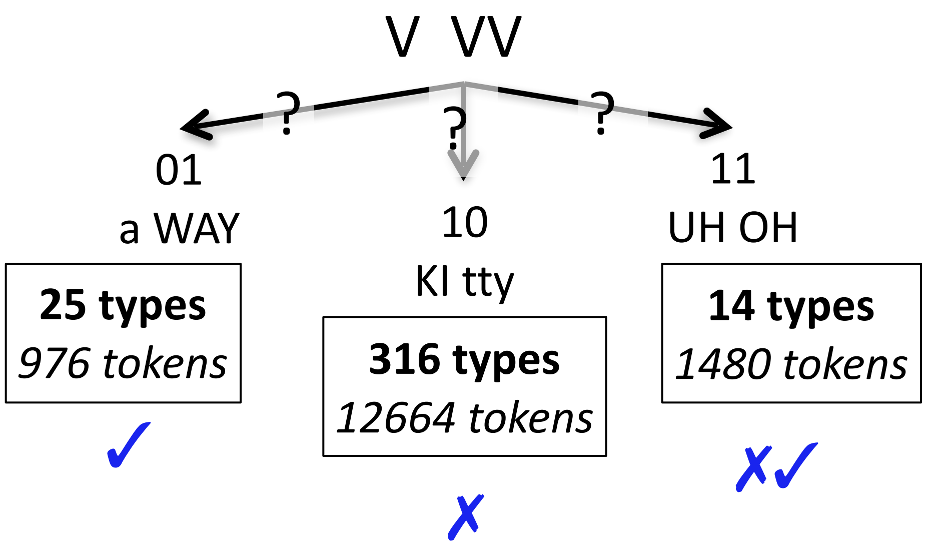
How many items should the stress “rule” apply to? N = 25 + 316 + 14 = 355

Productive data filter in action

Constraint-based: OT, with inflectional knowledge

452 syllable word forms

8 syllable distinctions



How many exceptions are allowed? 355 / ln(355) = **60**

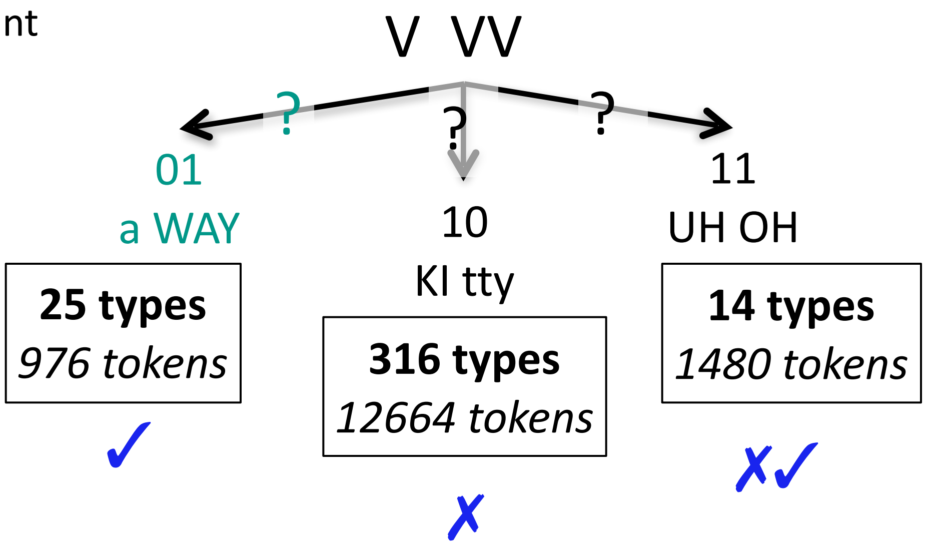
Productive data filter in action

Constraint-based: OT, with inflectional knowledge

452 syllable word forms

8 syllable distinctions

If this is the dominant pattern, too many exceptions:
316 + 14 > 60



How many exceptions are allowed? 355 / ln(355) = **60**

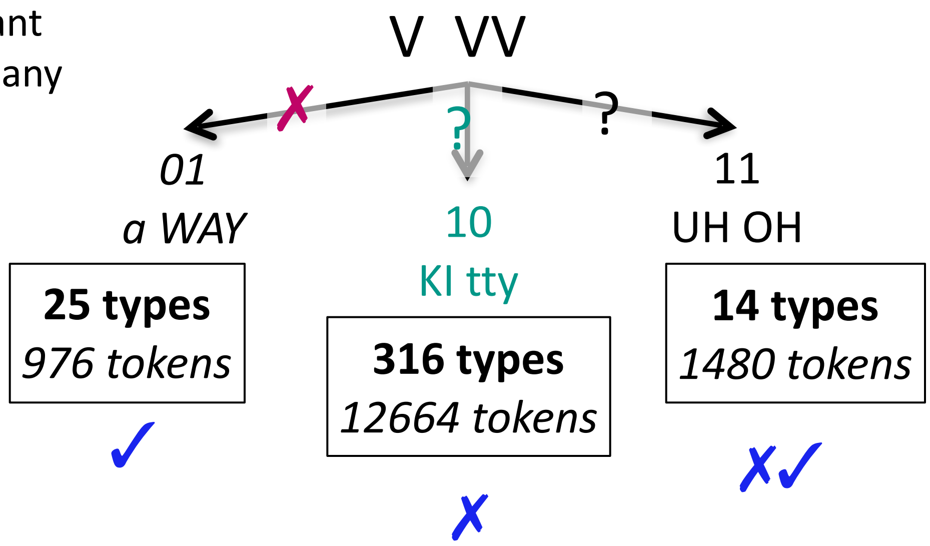
Productive data filter in action

Constraint-based: OT, with inflectional knowledge

452 syllable word forms

8 syllable distinctions

If this is the dominant pattern, NOT too many exceptions:
25 + 14 < 60



How many exceptions are allowed? 355 / ln(355) = **60**

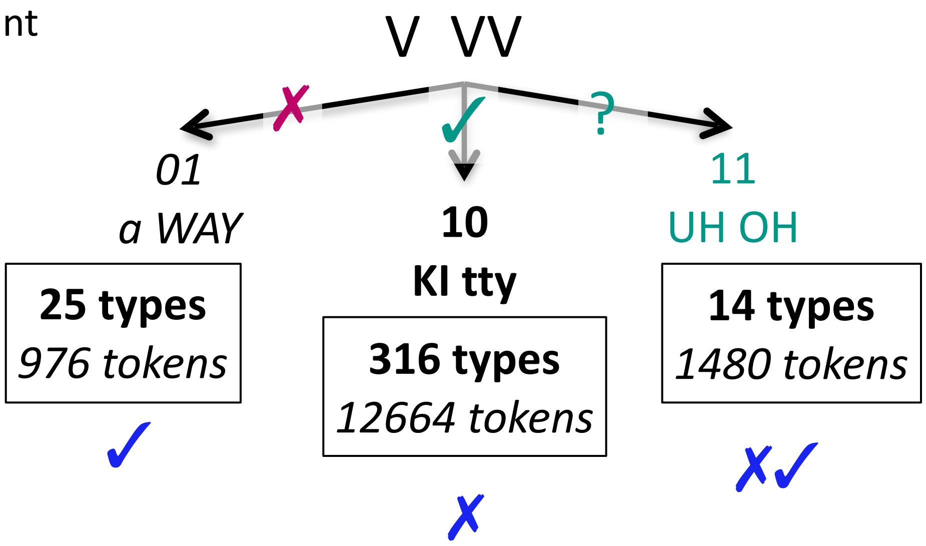
Productive data filter in action

Constraint-based: OT, with inflectional knowledge

452 syllable word forms

8 syllable distinctions

If this is the dominant pattern, too many exceptions:
25 + 316 > 60



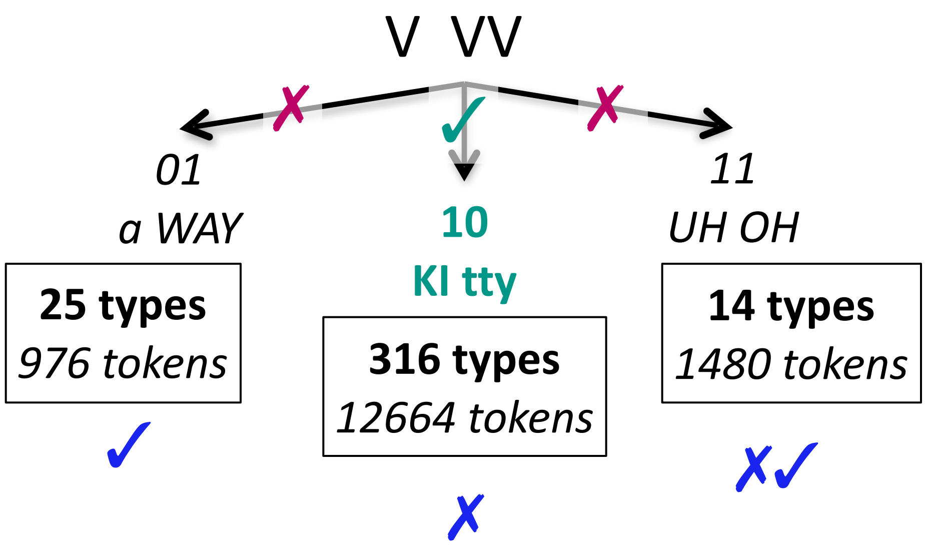
How many exceptions are allowed? 355 / ln(355) = **60**

Productive data filter in action

Constraint-based: OT, with inflectional knowledge

452 syllable word forms

8 syllable distinctions



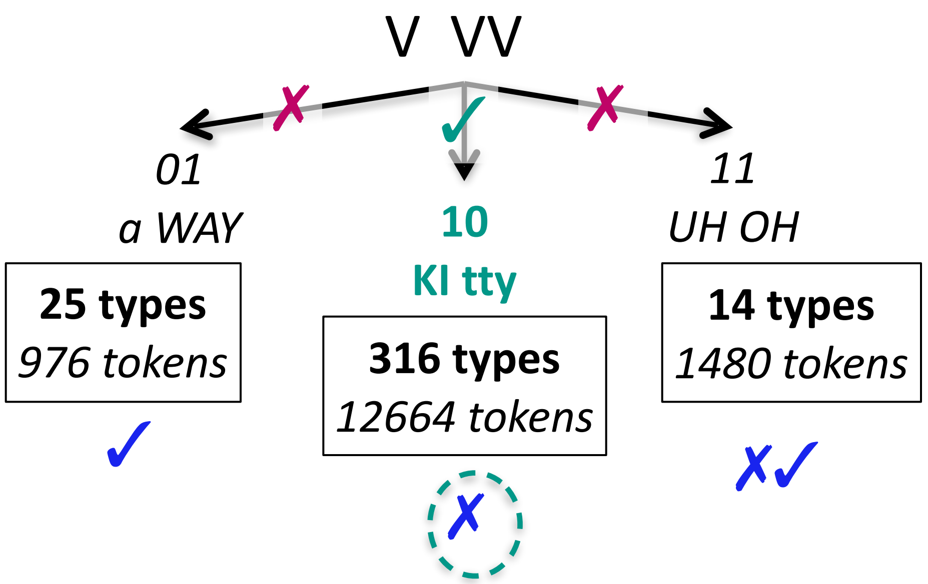
Under the OT syllable representation, there is a dominant stress pattern for this word form. Therefore, this pattern should be accounted for by the English grammar.

Productive data filter in action

Constraint-based: OT, with inflectional knowledge

452 syllable word forms

8 syllable distinctions



Unfortunately, this is the only pattern the English grammars cannot account for….this means a learner using the productivity filter would have even more trouble learning the current English OT grammar constraints.