Why sentences are more complex than words

Jeffrey Heinz[1]   William Idsardi[2]

[1]heinz@udel.edu
University of Delaware

[2]idsardi@umd.edu
University of Maryland

Parallel Domains
University of Southern California
May 6, 2011

Is phonology different from syntax?

Jean-Roger Vergnaud

No

Is phonology different from syntax?

Jean-Roger Vergnaud

No

Morris Halle

Yes (Bromberger and Halle 1989)

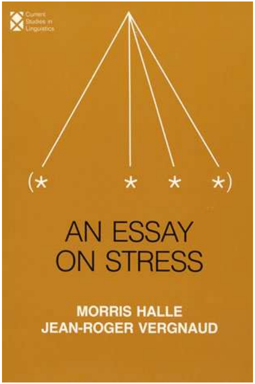
Is phonology different from syntax?

Jean-Roger Vergnaud

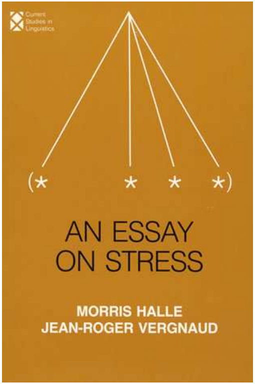
No

Morris Halle

Yes (Bromberger and Halle 1989)



Is phonology different from syntax?



Jean-Roger Vergnaud

No

Morris Halle

Yes (Bromberger and Halle 1989)

Elan Dresher, p.c.

> *If two things are different, make them similar. If they are similar make them the same.*

This talk

There is an important **computational** difference between phonology and syntax that requires explanation.

Hypothesis

Humans make different kinds of generalizations over words than they do over sentences and this explains this difference.

Linguistics and Cognitive Science

We suggest this difference can play a key role in larger debates in cognitive science between domain-general and domain-specific learning.

Strings

Strings are sequences of more basic units.

Sentences are sequences of morphemes.

John laugh ed while Mary talk ed.

Words are sequences of sounds.

b l i ŋ

Language Patterns

Language patterns are sets of strings,
or relations among strings.

No coda: *Coda

- {a, ka, ta, pi.koʊ, ba.du.pi} $\subset$ *Coda
- {bliŋ, mɛlp.ka, karp} $\cap$ *Coda $= \emptyset$

Language Patterns

Language patterns are sets of strings,
or relations among strings.

Word final obstruent devoicing: R=[-son]→[-voice]/____#

- {pad→pat, pat→pat, pabaɣ→pabax} ⊂ R
- {pad→pad, pad→dap} ∩ R = ∅

Language Patterns

Language patterns are sets of strings,
or relations among strings.

Conjunction: S $\rightarrow$ S and S

- {John swam and Mary laughed, They talked and they talked and they talked} $\subset$ S
- {John swam and Mary, They talked and they} $\cap$ S $= \emptyset$

Language Patterns

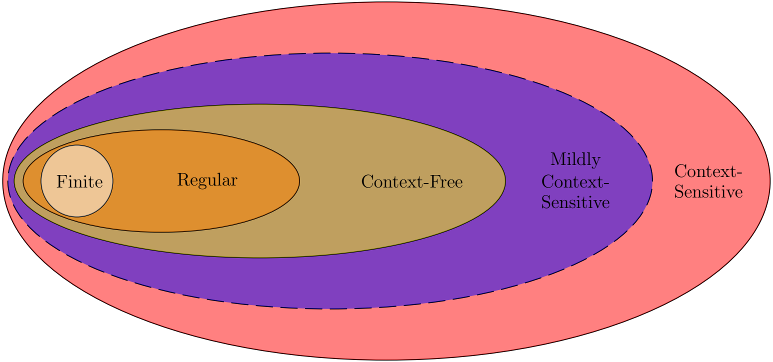
Language patterns are sets of strings,
or relations among strings.

Conjunction: S $\rightarrow$ S and S

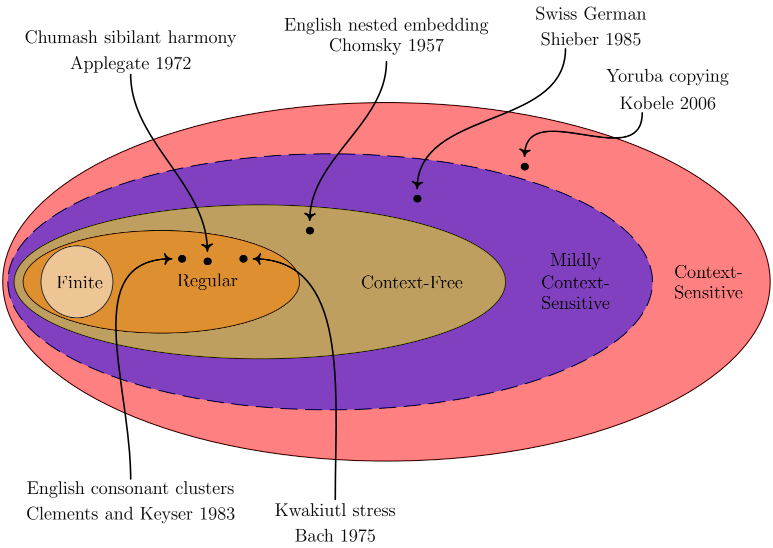
- {John swam and Mary laughed, They talked and they talked and they talked} $\subset$ S
- {John swam and Mary, They talked and they} $\cap$ S $= \emptyset$

What kinds of sets and relations are natural language patterns?

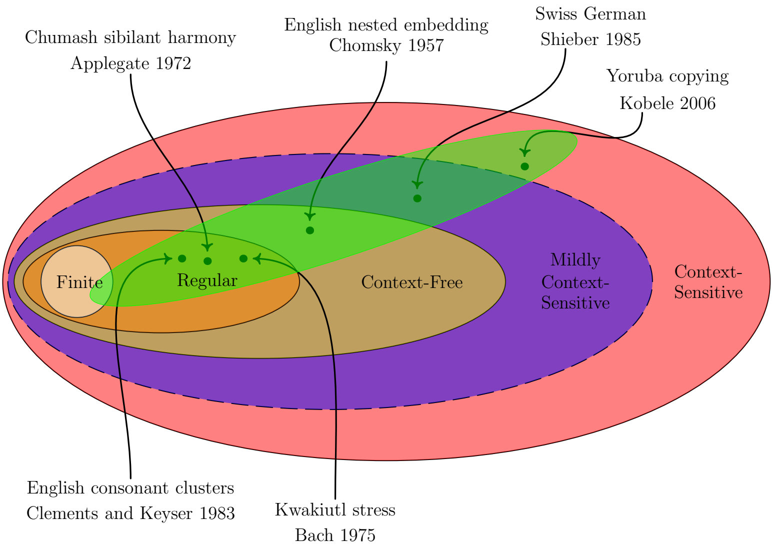
The Chomsky Hierarchy



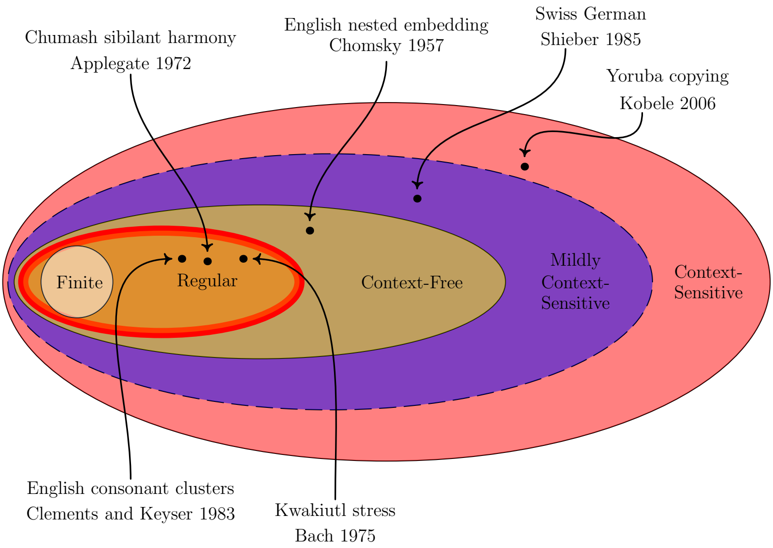
The Chomsky Hierarchy and natural language patterns



The Chomsky Hierarchy and natural language patterns



The Chomsky Hierarchy and natural language patterns



Phonology is regular (Kaplan and Kay 1994)

$$F_1 \times F_2 \times \cdots \times F_n = P$$

1. Optional, left-to-right, right-to-left, and simultaneous application of rules A ⟶ B / C ___ D (where A,B,C,D are regular expressions) *describe regular relations*, provided the rule cannot reapply to the locus of its structural change.
2. Rule ordering is functional composition (finite-state transducer composition).
3. Regular relations are closed under composition.
4. SPE grammars (finitely many ordered rewrite rules of the above type) can describe virtually all phonological patterns.
5. Therefore, phonology is regular (both F_i and P).

Phonology is regular (Kaplan and Kay 1994)

$$F_1 \times F_2 \times \cdots \times F_n = P$$

1. Optional, left-to-right, right-to-left, and simultaneous application of rules A $\longrightarrow$ B / C ____ D (where A,B,C,D are regular expressions) *describe regular relations*, provided the rule cannot reapply to the locus of its structural change.
2. Rule ordering is functional composition (finite-state transducer composition).
3. Regular relations are closed under composition.
4. SPE grammars (finitely many ordered rewrite rules of the above type) can describe virtually all phonological patterns.
5. Therefore, phonology is regular (both F_i and P).

Phonology is regular (Kaplan and Kay 1994)

$$F_1 \times F_2 \times \cdots \times F_n = P$$

1. Optional, left-to-right, right-to-left, and simultaneous application of rules A $\longrightarrow$ B / C ___ D (where A,B,C,D are regular expressions) *describe regular relations*, provided the rule cannot reapply to the locus of its structural change.
2. Rule ordering is functional composition (finite-state transducer composition).
3. Regular relations are closed under composition.
4. SPE grammars (finitely many ordered rewrite rules of the above type) can describe virtually all phonological patterns.
5. Therefore, phonology is regular (both F_i and P).

Phonology is regular (Kaplan and Kay 1994)

$$F_1 \times F_2 \times \cdots \times F_n = P$$

1. Optional, left-to-right, right-to-left, and simultaneous application of rules A ⟶ B / C ___ D (where A,B,C,D are regular expressions) *describe regular relations*, provided the rule cannot reapply to the locus of its structural change.
2. Rule ordering is functional composition (finite-state transducer composition).
3. Regular relations are closed under composition.
4. SPE grammars (finitely many ordered rewrite rules of the above type) can describe virtually all phonological patterns.
5. Therefore, phonology is regular (both F_i and P).

Phonology is regular (Kaplan and Kay 1994)

$$F_1 \times F_2 \times \cdots \times F_n = P$$

1. Optional, left-to-right, right-to-left, and simultaneous application of rules $\mathrm{A} \longrightarrow \mathrm{B}$ / C ____ D (where A,B,C,D are regular expressions) *describe regular relations*, provided the rule cannot reapply to the locus of its structural change.
2. Rule ordering is functional composition (finite-state transducer composition).
3. Regular relations are closed under composition.
4. SPE grammars (finitely many ordered rewrite rules of the above type) can describe virtually all phonological patterns.
5. Therefore, phonology is regular (both F_i and P).

Phonology is regular (Kaplan and Kay 1994)

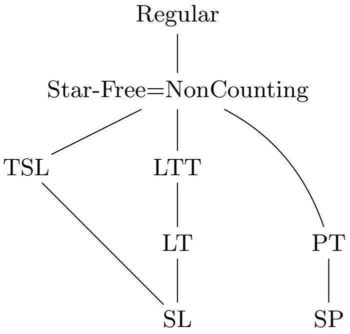
$$F_1 \times F_2 \times \cdots \times F_n = P$$

1. Optional, left-to-right, right-to-left, and simultaneous application of rules A $\longrightarrow$ B / C ___ D (where A,B,C,D are regular expressions) *describe regular relations*, provided the rule cannot reapply to the locus of its structural change.
2. Rule ordering is functional composition (finite-state transducer composition).
3. Regular relations are closed under composition.
4. SPE grammars (finitely many ordered rewrite rules of the above type) can describe virtually all phonological patterns.
5. Therefore, phonology is regular (both F_i and P).

What about reduplication?

- It's morpho-syntax (Inkelas and Zoll 2000, Roark and Sproat 2007).

Phonology is subregular

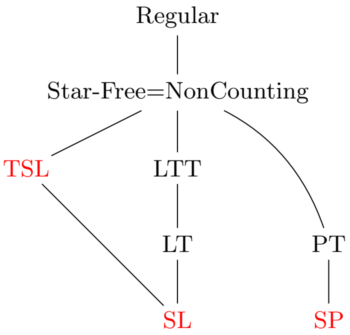


Proper inclusion relationships among subregular language classes (indicated from top to bottom).

TSL	Tier-based Strictly Local	PT	Piecewise Testable
LTT	Locally Threshold Testable	SL	Strictly Local
LT	Locally Testable	SP	Strictly Piecewise

(McNaughton and Papert 1971, Simon 1975, Rogers and Pullum in press, Rogers et al. 2010, Heinz 2010, Heinz et al. 2011)

Phonology is subregular

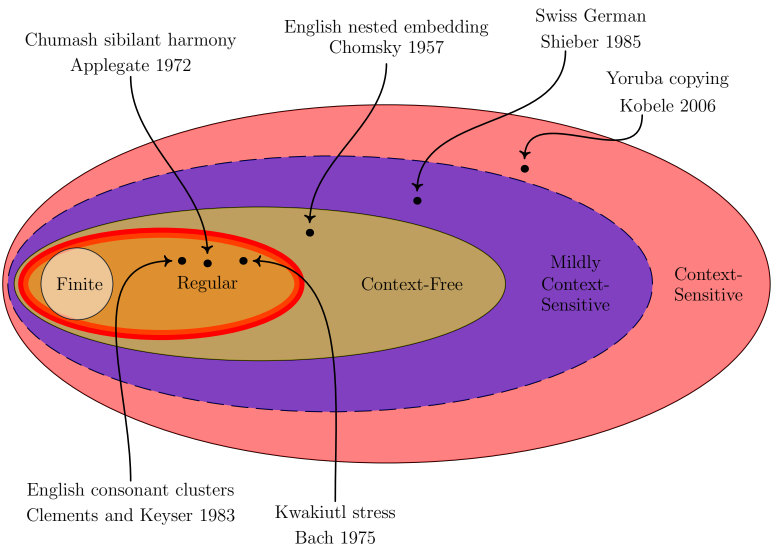


Proper inclusion relationships among subregular language classes (indicated from top to bottom).

TSL	Tier-based Strictly Local	PT	Piecewise Testable
LTT	Locally Threshold Testable	SL	Strictly Local
LT	Locally Testable	SP	Strictly Piecewise

(McNaughton and Papert 1971, Simon 1975, Rogers and Pullum in press, Rogers et al. 2010, Heinz 2010, Heinz et al. 2011)

The Chomsky Hierarchy and natural language patterns



So why the difference?

The problem of induction and generalization

Philosophy

(Plato, Aristotle, Hume, Mill, Russell, Carnap, Quine, Goodman, ...)

Linguistics

(Chomsky 1957, 1965, Wexler and Cullicover 1980, Piattelli-Palmarini 1980, Berwick 1985, Morgan 1986, Yang 2000, Niyogi 2006, ...)

Computer Science

(Gold 1967, Horning 1969, Angluin 1980, Valiant 1984, Osherson et al. 1984, Angluin 1988, Anthony and Biggs 1991, Kearns and Vazirani 1994, Vapnik 1994, 1998, Jain et al. 1999, Chater and Vitanyí 2007, de la Higuera 2010, Clark and Lappin 2011)

So how can language patterns be learned?

Define "Learning"

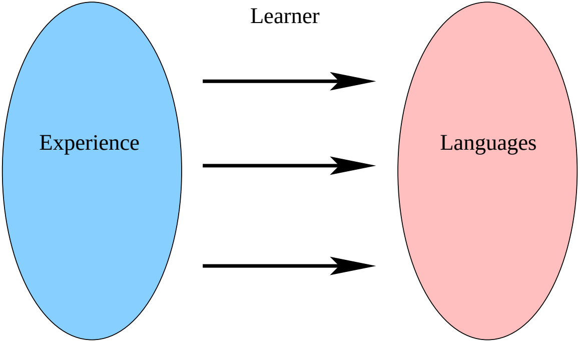
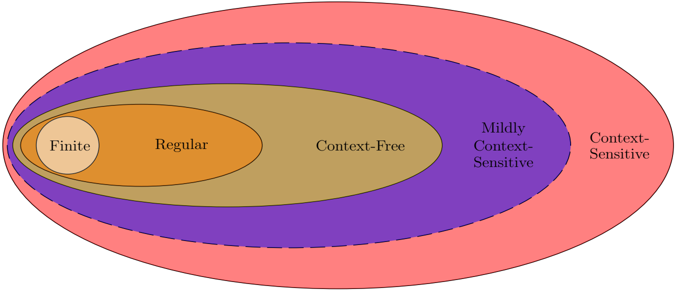


Figure: Learners are functions ϕ from experience to languages.

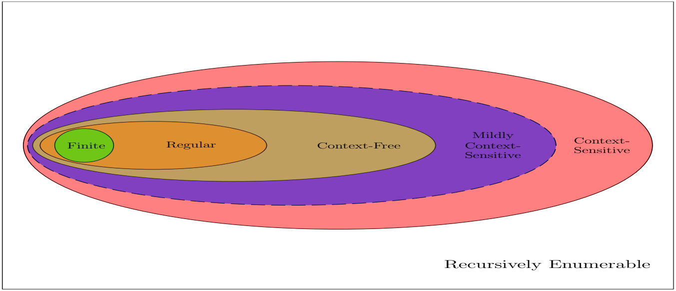
Results: Do feasible learners exist?

1. Identification in the limit from positive data (Gold 1967)
2. Identification in the limit from positive and negative data (Gold 1967)
3. Identification in the limit from positive data from r.e. texts (Gold 1967)
4. Learning context-free and r.e. distributions (Horning 1969, Angluin 1988, Chater and Vitanyí 2007)
5. Probably Approximately Correct learning (Valiant 1984, Anthony and Biggs 1991, Kearns and Vazirani 1994)



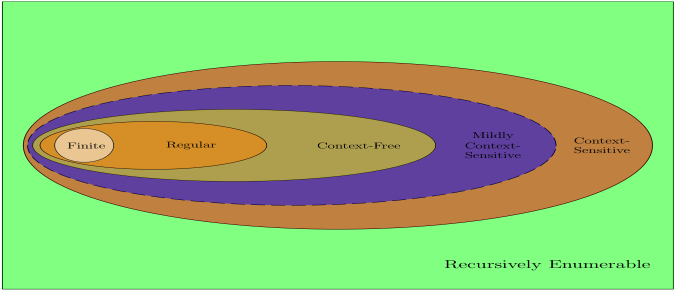
Results: Do feasible learners exist?

1. Identification in the limit from positive data (Gold 1967)
2. Identification in the limit from positive and negative data (Gold 1967)
3. Identification in the limit from positive data from r.e. texts (Gold 1967)
4. Learning context-free and r.e. distributions (Horning 1969, Angluin 1988, Chater and Vitanyí 2007)
5. Probably Approximately Correct learning (Valiant 1984, Anthony and Biggs 1991, Kearns and Vazirani 1994)



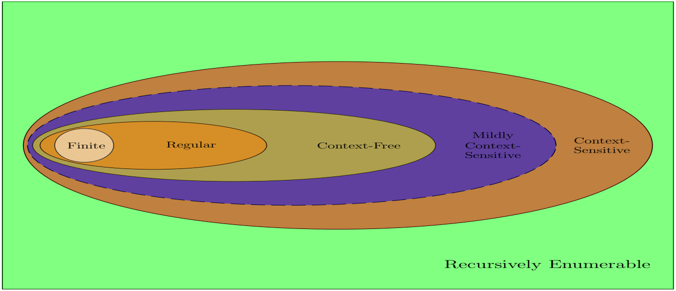
Results: Do feasible learners exist?

1. Identification in the limit from positive data (Gold 1967)
2. Identification in the limit from positive and negative data (Gold 1967)
3. Identification in the limit from positive data from r.e. texts (Gold 1967)
4. Learning context-free and r.e. distributions (Horning 1969, Angluin 1988, Chater and Vitanyí 2007)
5. Probably Approximately Correct learning (Valiant 1984, Anthony and Biggs 1991, Kearns and Vazirani 1994)



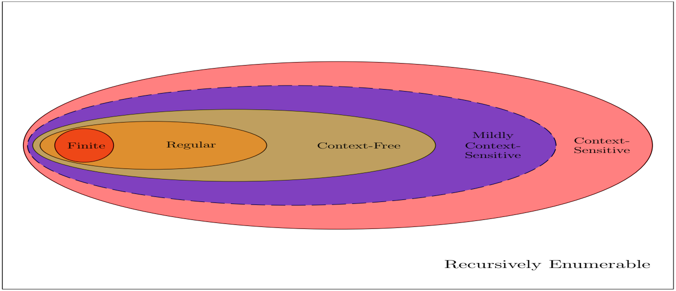
Results: Do feasible learners exist?

1. Identification in the limit from positive data (Gold 1967)
2. Identification in the limit from positive and negative data (Gold 1967)
3. Identification in the limit from positive data from r.e. texts (Gold 1967)
4. Learning context-free and r.e. distributions (Horning 1969, Angluin 1988, Chater and Vitanyí 2007)
5. Probably Approximately Correct learning (Valiant 1984, Anthony and Biggs 1991, Kearns and Vazirani 1994)



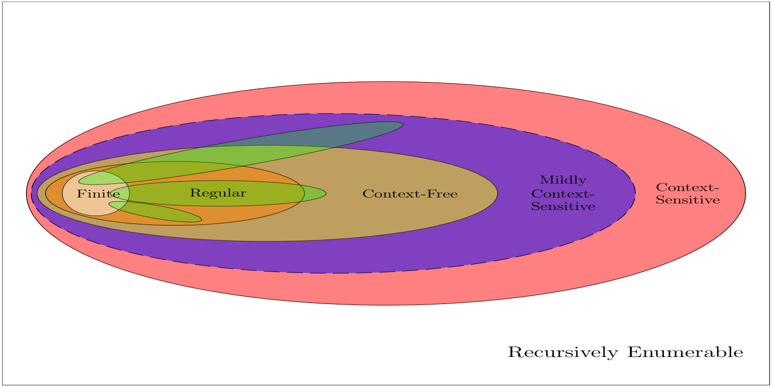
Results: Do feasible learners exist?

1. Identification in the limit from positive data (Gold 1967)
2. Identification in the limit from positive and negative data (Gold 1967)
3. Identification in the limit from positive data from r.e. texts (Gold 1967)
4. Learning context-free and r.e. distributions (Horning 1969, Angluin 1988, Chater and Vitanyí 2007)
5. Probably Approximately Correct learning (Valiant 1984, Anthony and Biggs 1991, Kearns and Vazirani 1994)



Positive Results

Many classes which cross-cut the Chomsky hierarchy and exclude some finite languages are feasibly learnable in the senses discussed (and others).



(Angluin 1980, 1982, Garcia et al. 1990, Muggleton 1990, Denis et al. 2002, Fernau 2003, Yokomori 2003, Clark and Thollard 2004, Oates et al. 2006, Niyogi 2006, Clark and Eryaud 2007, Heinz 2008, to appear, Yoshinaka 2008, Case et al. 2009, de la Higuera 2010)

Lessons from formal learning theories

Learning requires a structured hypothesis space, which excludes at least some finite-list hypotheses.

Gleitman 1990, p. 12:

> *'The trouble is that an observer who notices everything can learn nothing for there is no end of categories known and constructable to describe a situation [emphasis in original].'*

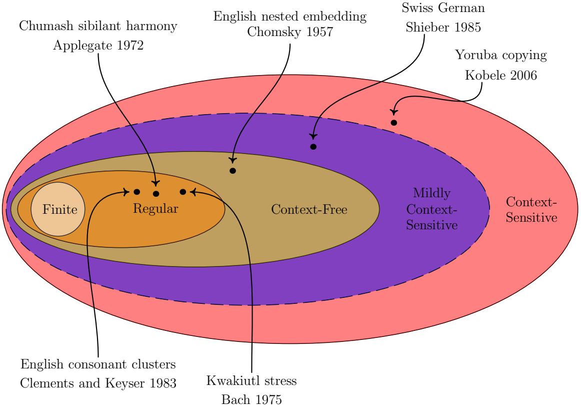
Lessons from formal learning theories

Learning requires a structured hypothesis space, which excludes at least some finite-list hypotheses.

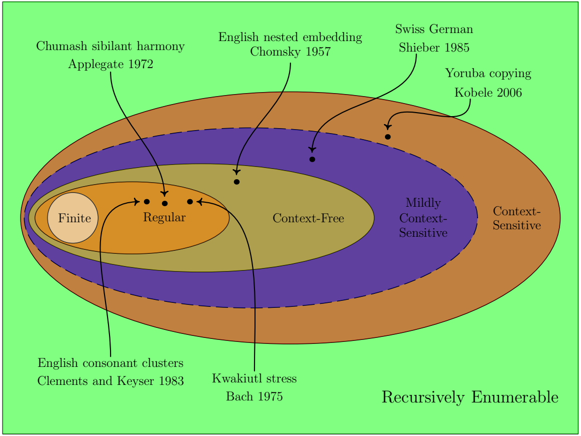
Gleitman 1990, p. 12:

> *'The trouble is that an observer who notices everything can learn nothing for there is no end of categories known and constructable to describe a situation [emphasis in original].'*

Hypothesis spaces for language learning



Strategy #1: learn everything (e.g. Chater and Vitanyí 2007)

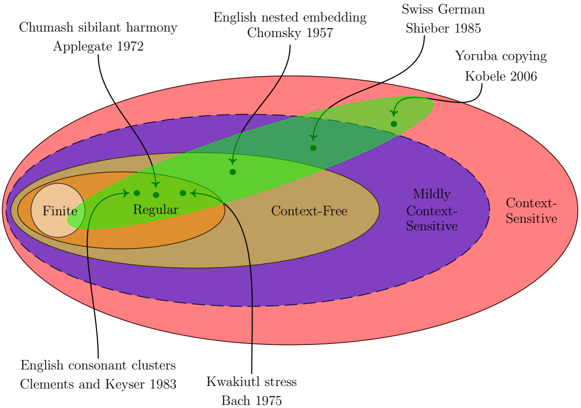


Problems

1. Possible in principle, not feasible in practice
2. Predicts any pattern is possible with sufficient data

Strategy #2: Single hypothesis space for language

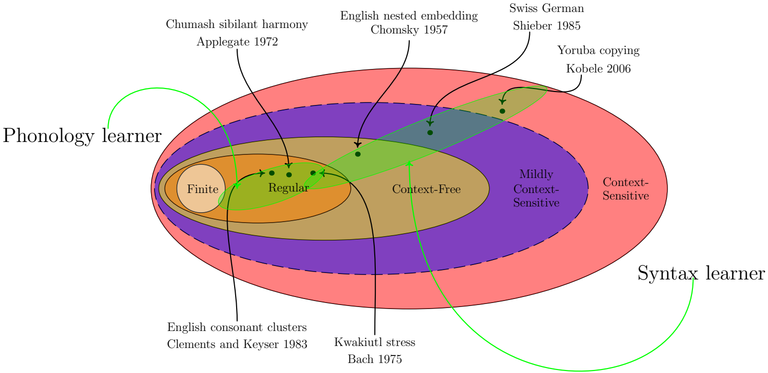
(e.g. Clark 2010)



Problems

1. Predicts syntactic patterns ought to be found within words.

Strategy #3: Distinct hypothesis spaces for phonology and syntax

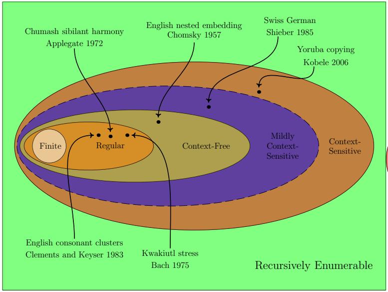


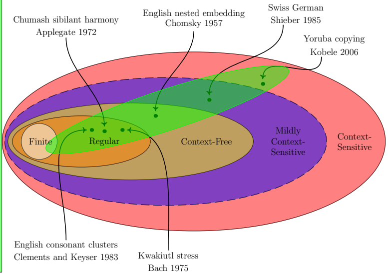
1. The complexity differential between phonology and syntax can be explained if language-learning itself is *modular.*
2. People make *different* kinds of generalizations over words than they do over sentences.

Strategy #3 accords with recent research within linguistics

- Recent computational models for learning phonology are successful in part because the generalization strategies employed do not consider every finite pattern nor do they extend beyond the regular boundary (Hayes and Wilson 2008, Albright 2009, Heinz 2010, Goldsmith and Riggle to appear…).
- Likewise, the learners for syntax are successful in part because the learners' generalizations are constrained to the right, non-superfinite classes of *non*regular patterns (Yang 2000, et seq., Clark and Eryaud 2007, Yoshinaka and Clark 2010, Becerra-Bonache et al. 2010, …)

Advocates of general purpose learners





Challenges

1. They must present a single learner capable of learning phonological and syntactic patterns from reasonably-sized sets of words and sentences, respectively (to our knowledge no such demonstration exists).
2. They must also either offer an explanation for the complexity differential or deny it.

One possibility: articulatory/perceptual grounding

Hypothesis

Sound sequences within words are constrained by psychophysical properties of the human nervous, motor, and auditory systems in ways that word sequences within sentences are not.

Long-distance patterns in phonology

Long-distance agreement (Ringen 1988, van der Hulst 1994, Hansson 2001, Rose and Walker 2004)

Samala Chumash (Applegate 1972)

ʃtoyonowonowaʃ ‘3s stood upright’
*stoyonowonowaʃ
*ʃtoyonowonowas

Long distance disagreement (Suzuki 1998)

Grassman’s Law

t^{h}rík-s	‘hair’
trík^{h}-es	‘hairs’
*t^{h}rík^{h}-es	

Latin Liquid dissimilation (Jensen 1974, Odden 1994)

nav-alis	‘naval’
lun-aris	‘lunar’
flor-alis	‘floral’
*flor-aris	

Is "long-distance" the right generalization?

Perhaps all long distance cases can be reduced to chained instances of strictly local generalizations.

1. Research exists which examines to what extent intermediary sounds in long-distance assimilation patterns are truly transparent and finds in many instances that the posture of the relevant articulator is maintained throughout pronunciation (Gafos 1996, Ní Chiosáin & Padgett 1997, Gordon 1999, Gafos and Benus 2003, Walker et al. 2009)
2. On the other hand, in Guaraní nasal harmony, research also exists which confirms the oral obstruent realization for voiceless stops that act transparent (Walker 1998).
3. What about the dissimilation cases?

If they deny the complexity differential. . .

We expect to find synactic patterns in phonology.

1. Nested embedding patterns in phonological words

2. Multiple crossing dependencies in phonological words

Testable Hypothesis

Artificial Language Learning Experiments

Cleeremans & McClelland 1991, Stadler & Frensch 1998, Dell et al. 2000, Goméz 2002, Onishi, Chambers, & Fisher 2002, Chambers, Onishi, & Fisher 2003, Pycha, Nowak, Shin & Shosted 2003, Wilson 2003, 2006, Fitch and Hauser 2004, Goldrick 2004, Newport & Aslin 2004, Petersson et al. 2004, Onnis, Monaghan, Richmond, & Chater 2005, Perruchet & Rey 2005, Bahlmann & Friederici 2006, De Vries et al. 2006 Peperkamp, Skoruppa & Dupoux 2006, Friederici, Bahlmann, Heim, Schubotz, & Anwander 2006, Finley 2008, submitted, in revision, Finley & Badecker 2008, 2009, Folia et al. 2008, Forkstam, Elwer, Ingvar, & Petersson 2008, Moreton 2008, Seidl, Cristià, Bernard, & Onishi 2009, Uddén, Araujo, Forkstam, Ingvar, Hagoort, & Petersson 2009, Koo & Callahan submitted, Moreton and Pater, MS, . . .

Conclusion

There are substantial similarities between phonology and syntax.

1. Both are generative.
2. Both are richly structured domains which subsequently limit the cross-linguistic variation.

But there is a significant difference.

1. Phonological patterns can be described with regular grammars, but syntactic patterns cannot.
2. The hypothesis that language-learning itself is modularized currently offers the best explanation for this fact.

Conclusion

There are substantial similarities between phonology and syntax.

1. Both are generative.
2. Both are richly structured domains which subsequently limit the cross-linguistic variation.

But there is a significant difference.

1. Phonological patterns can be described with regular grammars, but syntactic patterns cannot.
2. The hypothesis that language-learning itself is modularized currently offers the best explanation for this fact.

Thank You.