

Mathematical Linguistics and Language Evolution

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Introduction

- We want to unify mathematical approaches (Nowak, Komarova and Niyogi 2002).
- We are interested in applying mathematical linguistics to language evolution

Overview

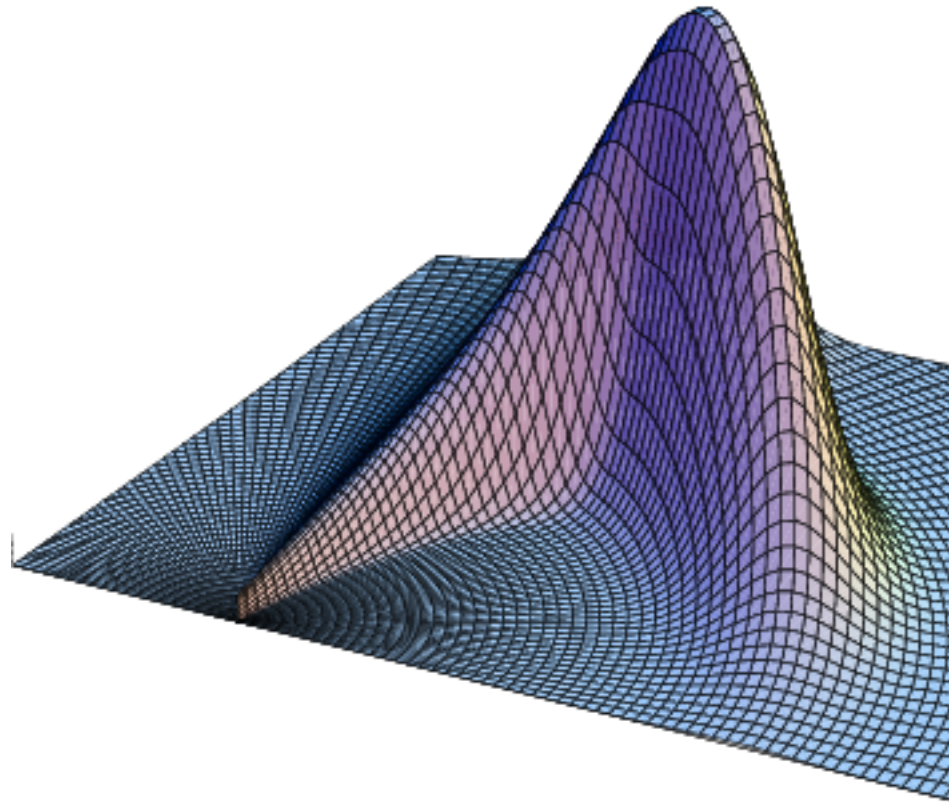
- What kinds of arguments are we interested in?
- What definitions of complexity might be useful?
- How do these notions of complexity hold up?
- Where do we go from there?

The Rhetoric of Complexity

- Linguistic structure is complex and must therefore be innate.
- Language is too complex to have not arisen by natural selection (gradualist/adaptationist)/is too complex to have been the result of selection (saltationist/exaptationist).
- Language is too complex and monolithic to be epistatic/is too complex to be the result of a few genes

Arguing about Evolution

- About change in frequencies of traits.
- Set of traits and measure on that set (ordering).



Underlying Assumptions

- Traits: phenotypic differences correspond systematically to differences in complexity (e.g. a small change in a trait equals a small change in complexity).
- Measures: complexity is a useful measure of fitness.

Complexity of What?

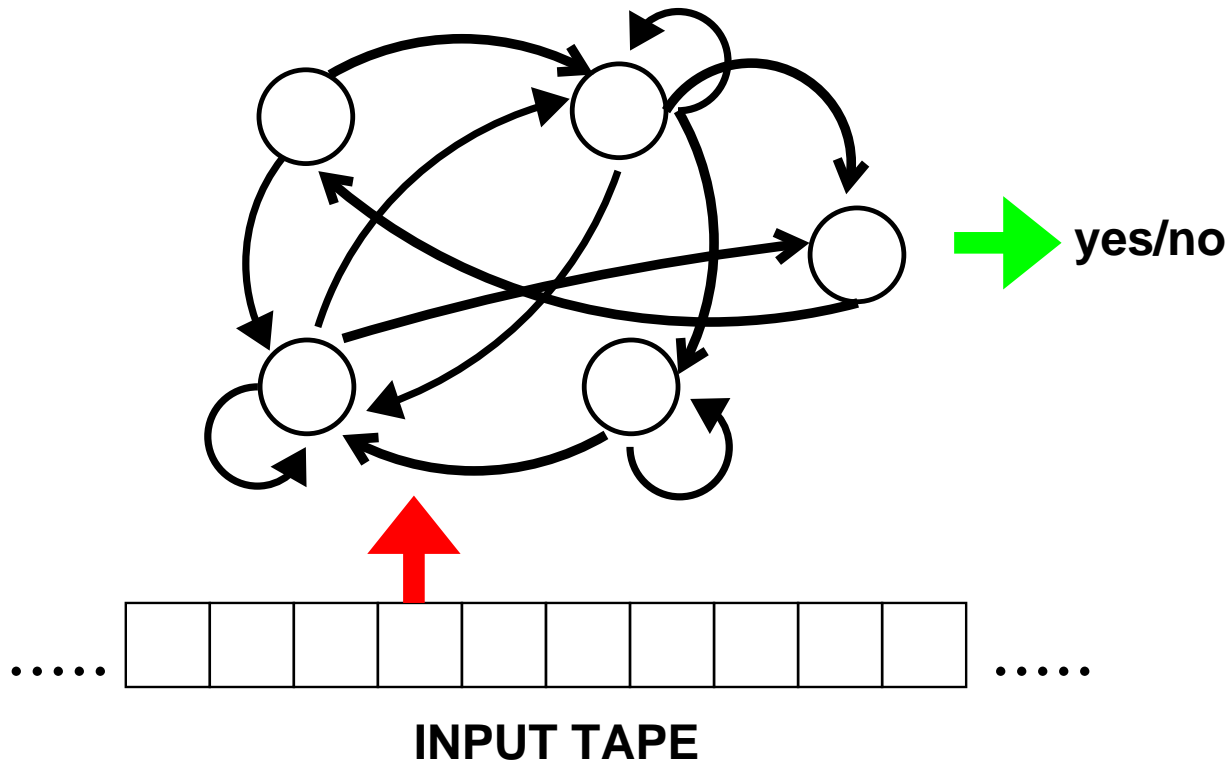
- Neural Hardware vs. Grammar (Knowledge of Language)
- Our Question: What can the complexity of formal mentalist (generative) theories tell us about language evolution? (change in linguistic trait frequencies)

Formal Measures of Linguistic Complexity

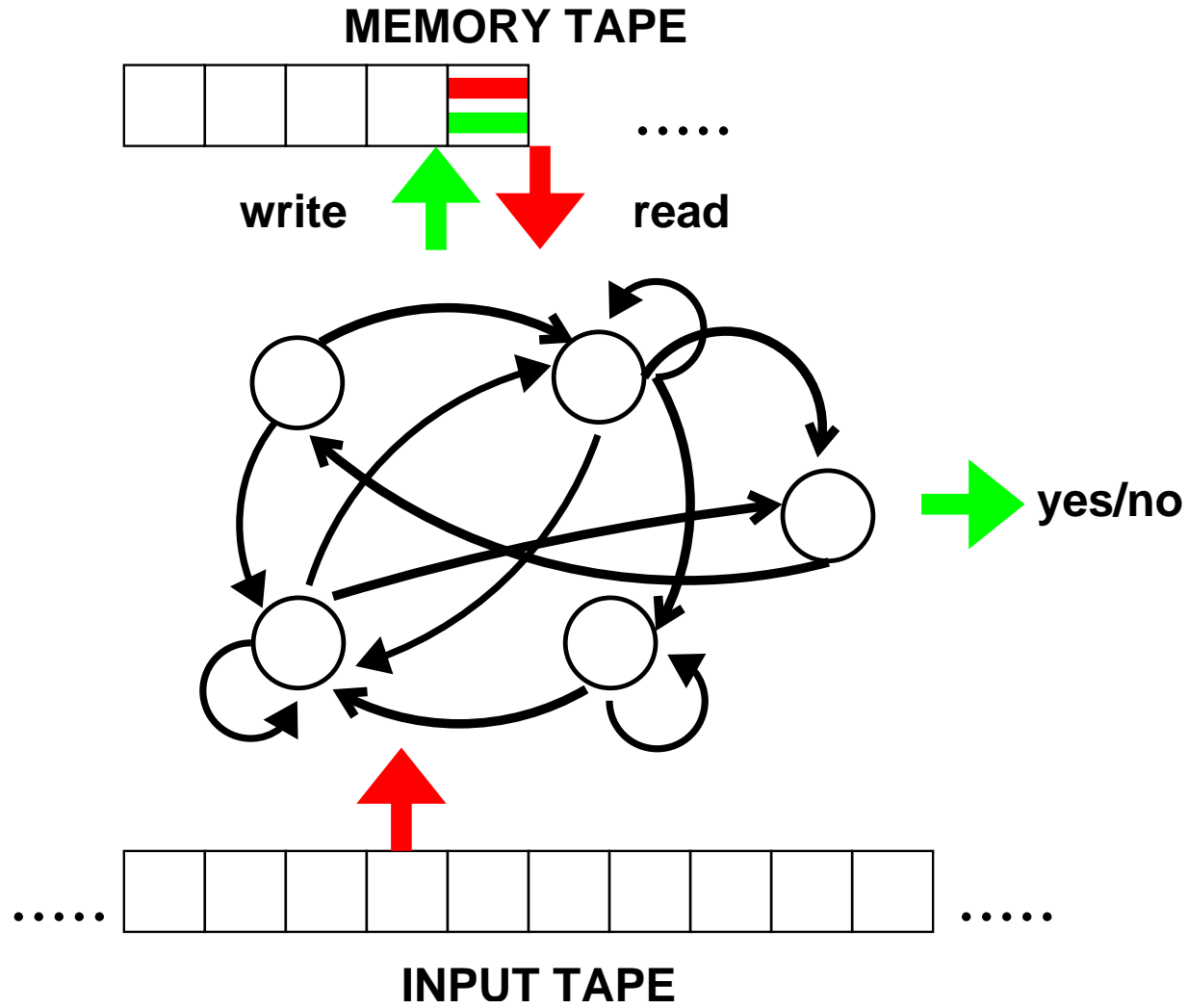
- Space and Time bounded Hierarchies (Barton, Berwick, Ristad 1987)
- Chomsky Hierarchy (language theoretic complexity)
 - Studied in terms of formal languages.
 - Originally defined in terms of phrase structure grammars.
 - Many other definitions possible.
 - Four levels (originally)

The Chomsky Hierarchy: Type 3 (FSA)

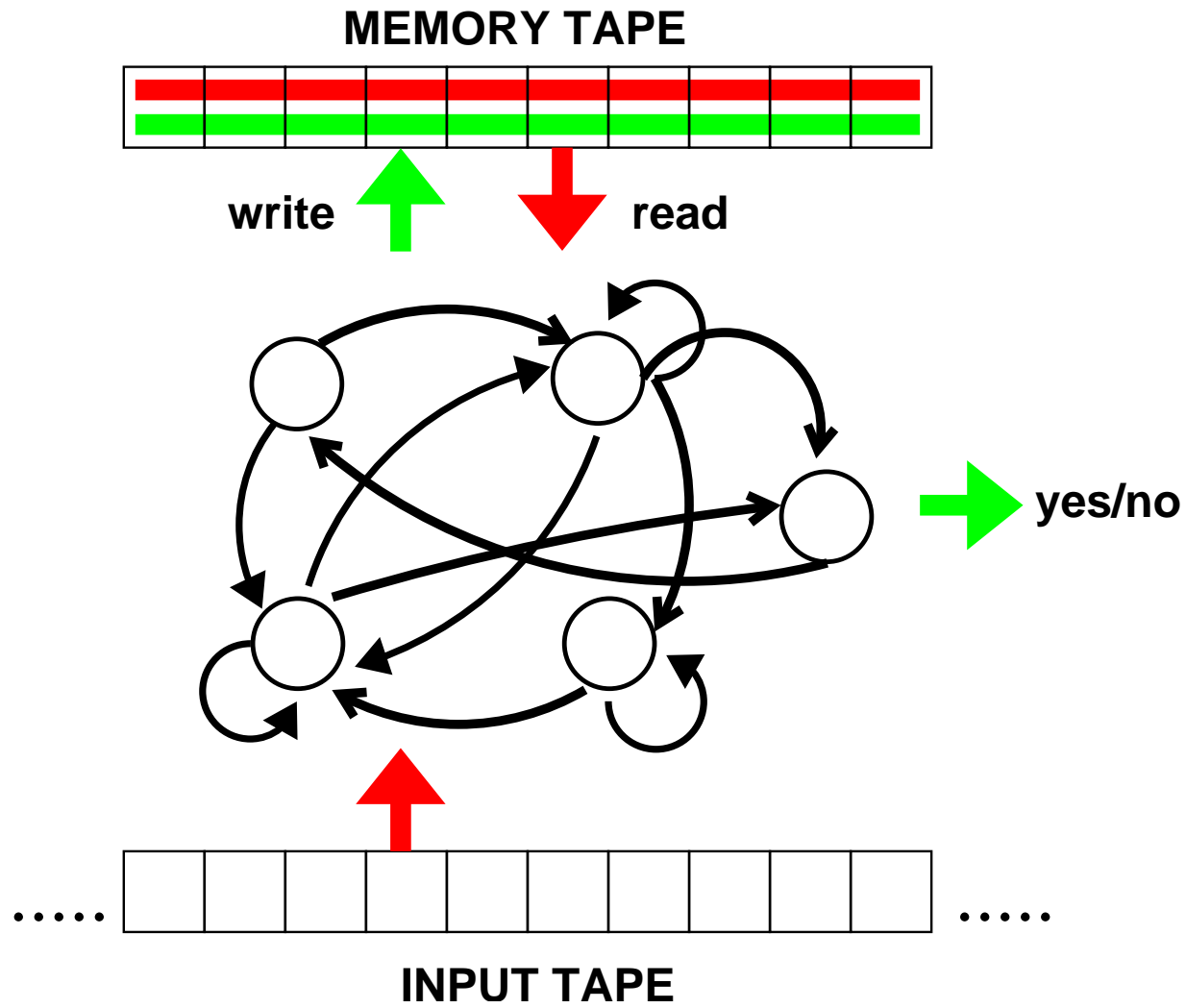
(NO MEMORY TAPE)



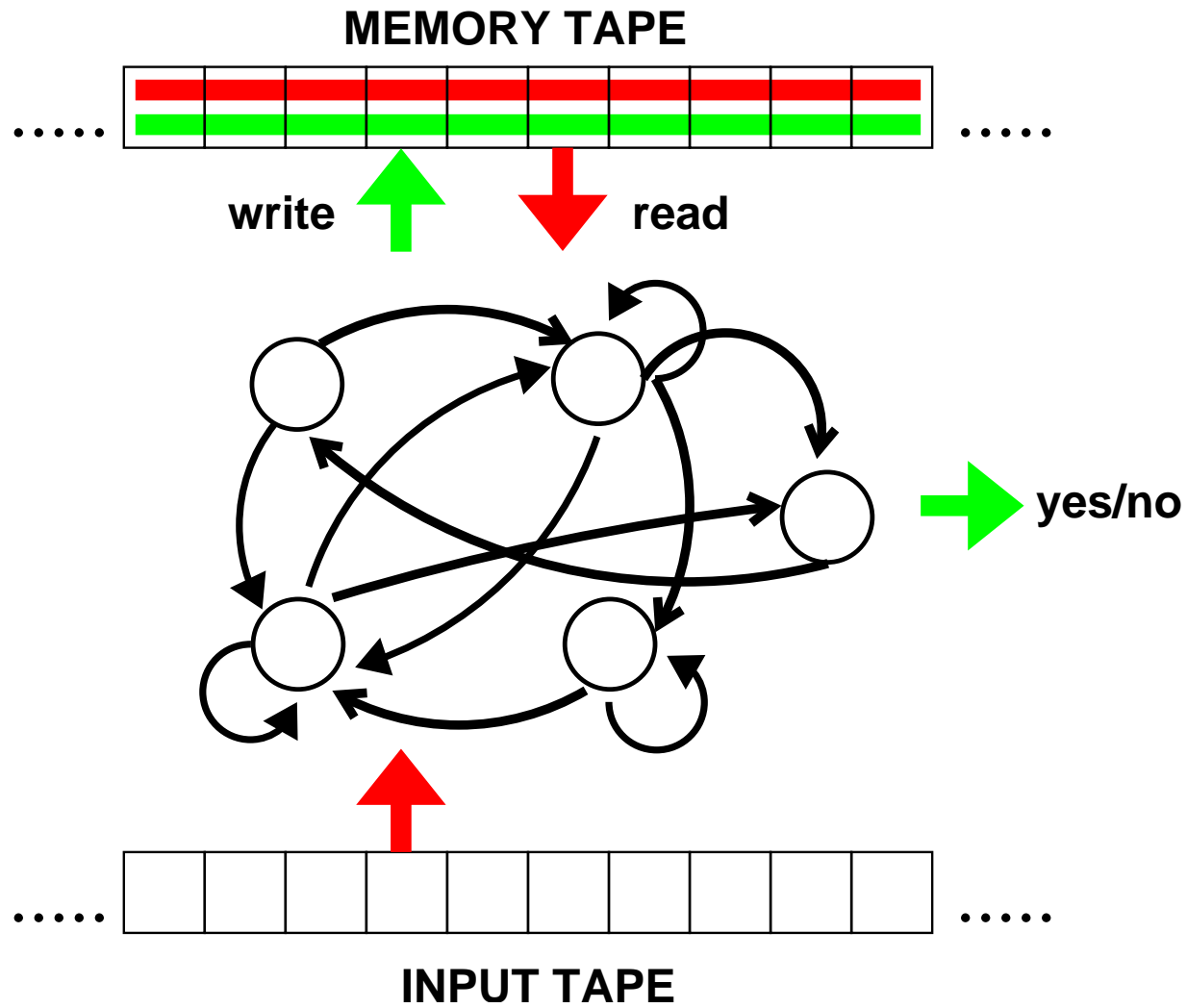
The Chomsky Hierarchy: Type 2 (PDA)



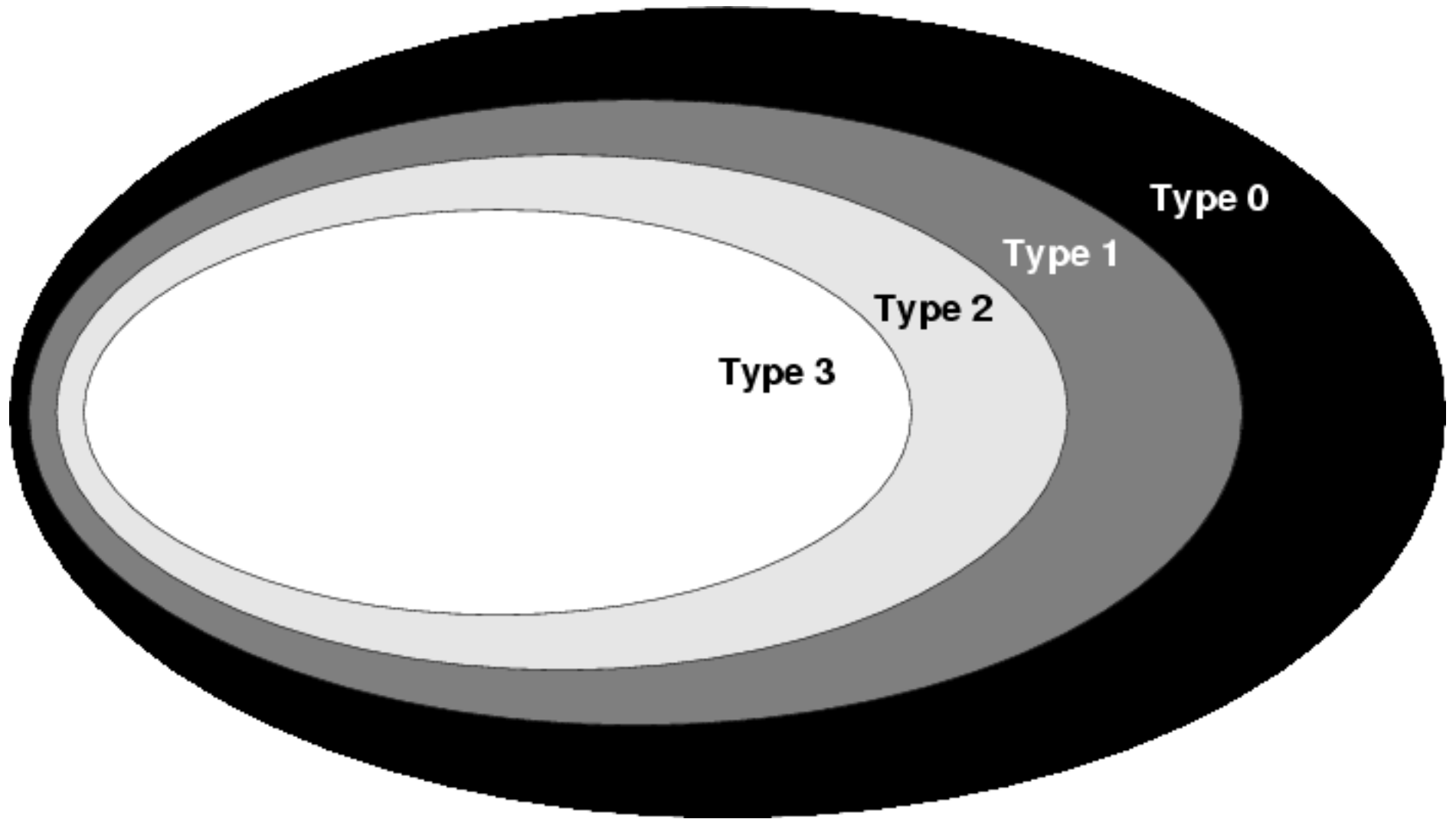
The Chomsky Hierarchy: Type 1 (LBA)



The Chomsky Hierarchy: Type 0 (TM)



The Chomsky Hierarchy



Use of the Chomsky Hierarchy in Language Evolution

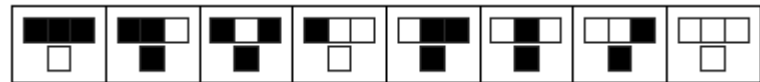
- Nowak, Komarova and Niyogi (2002) - Argue that Chomsky hierarchy must be brought together with mathematical models of evolution
- Hashimoto and Ikegami (1996) - Describe language as evolving up the Chomsky hierarchy
- Fitch and Hauser (2004) - Test monkeys/humans for type 3 versus type 2 grammar learning
- Briscoe (2002) - Argues that appropriate models of language evolution must use mildly context-sensitive grammar formalisms
- Steedman (PC) - Suggests that language should be as low as possible on the CH for evolutionary reasons

Assumption 1: Phenotypes Correspond to Complexity Classes

- How hard is it for evolution to find some class of computing devices?
- Many simple systems with simple components are universal.

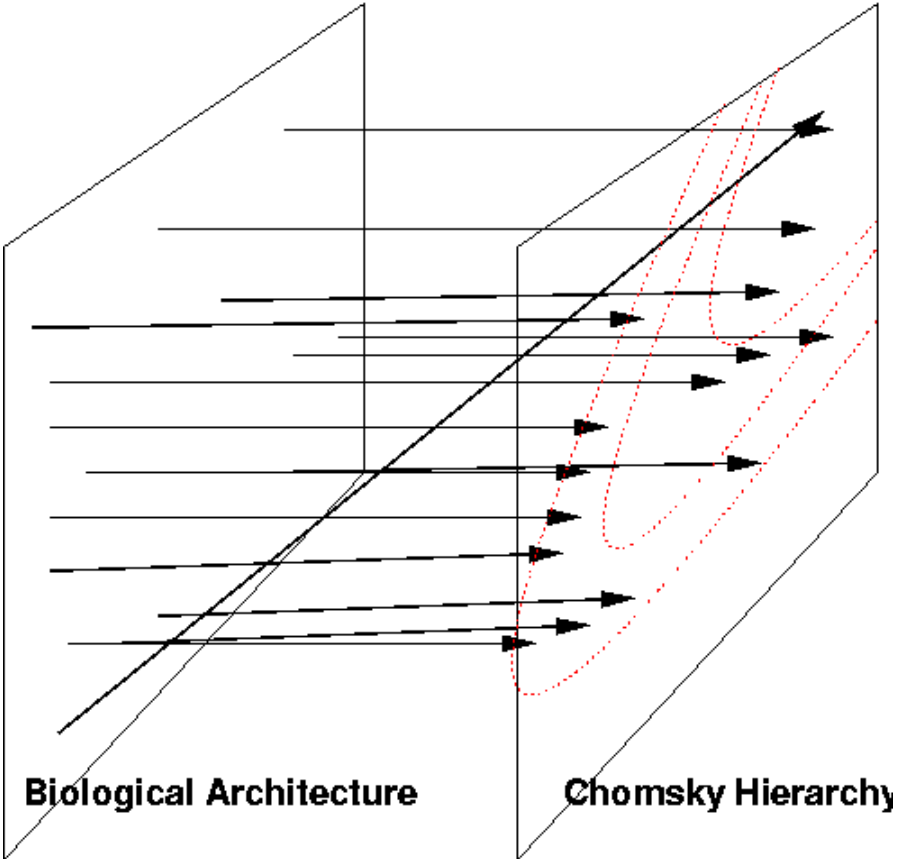
– Neural Networks: Siegelmann and Sontag (1991)

– Cellular automata: Wolfram (2002)

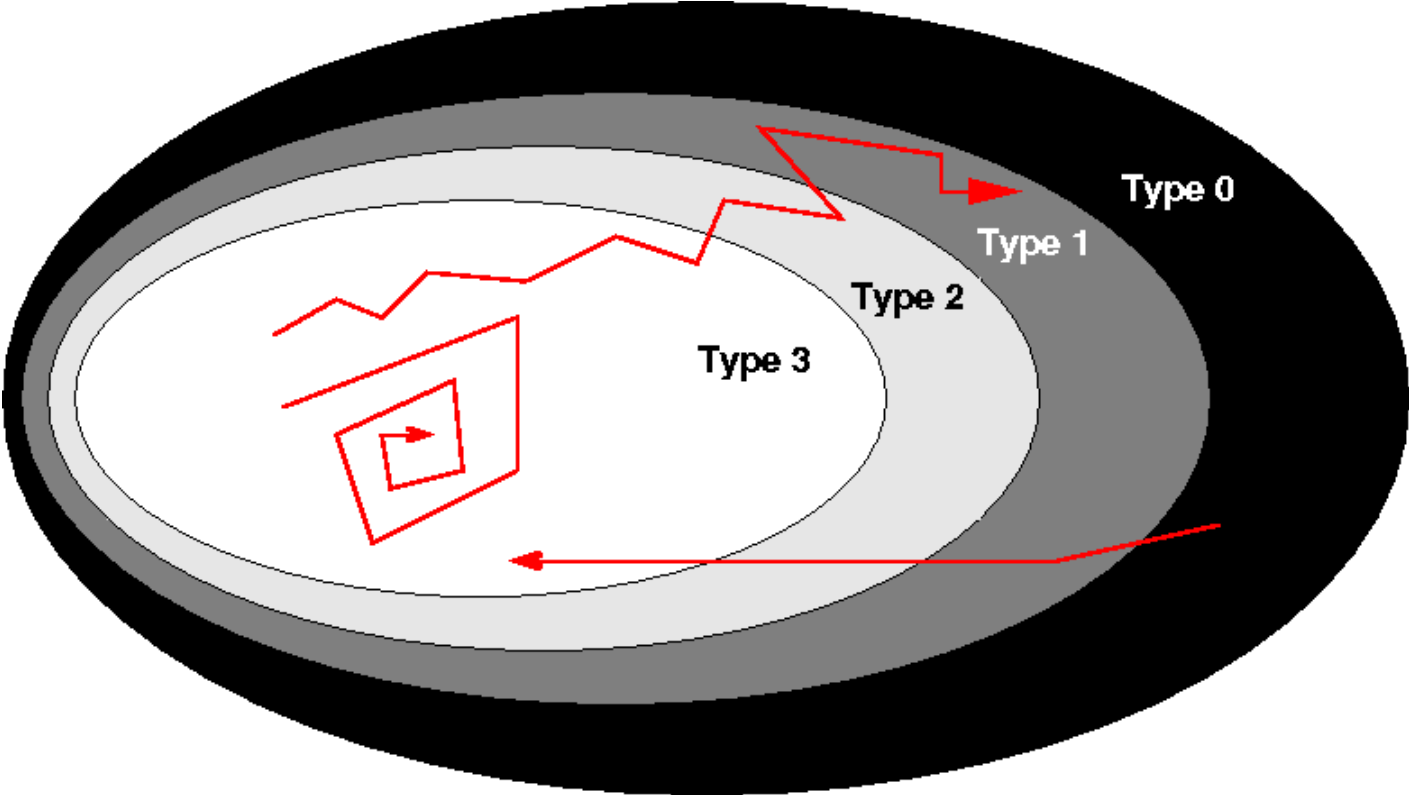


– Intersections of context free languages: $(a^n b^n c^m) \cap (a^w b^n c^n) = (a^n b^n c^n)$

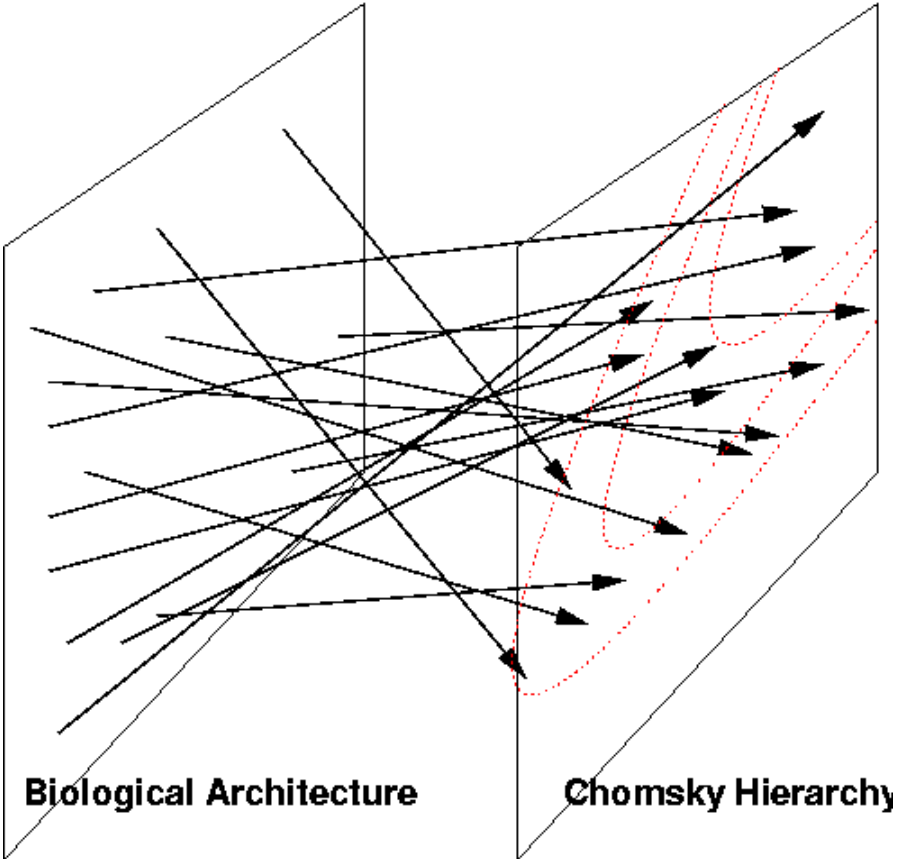
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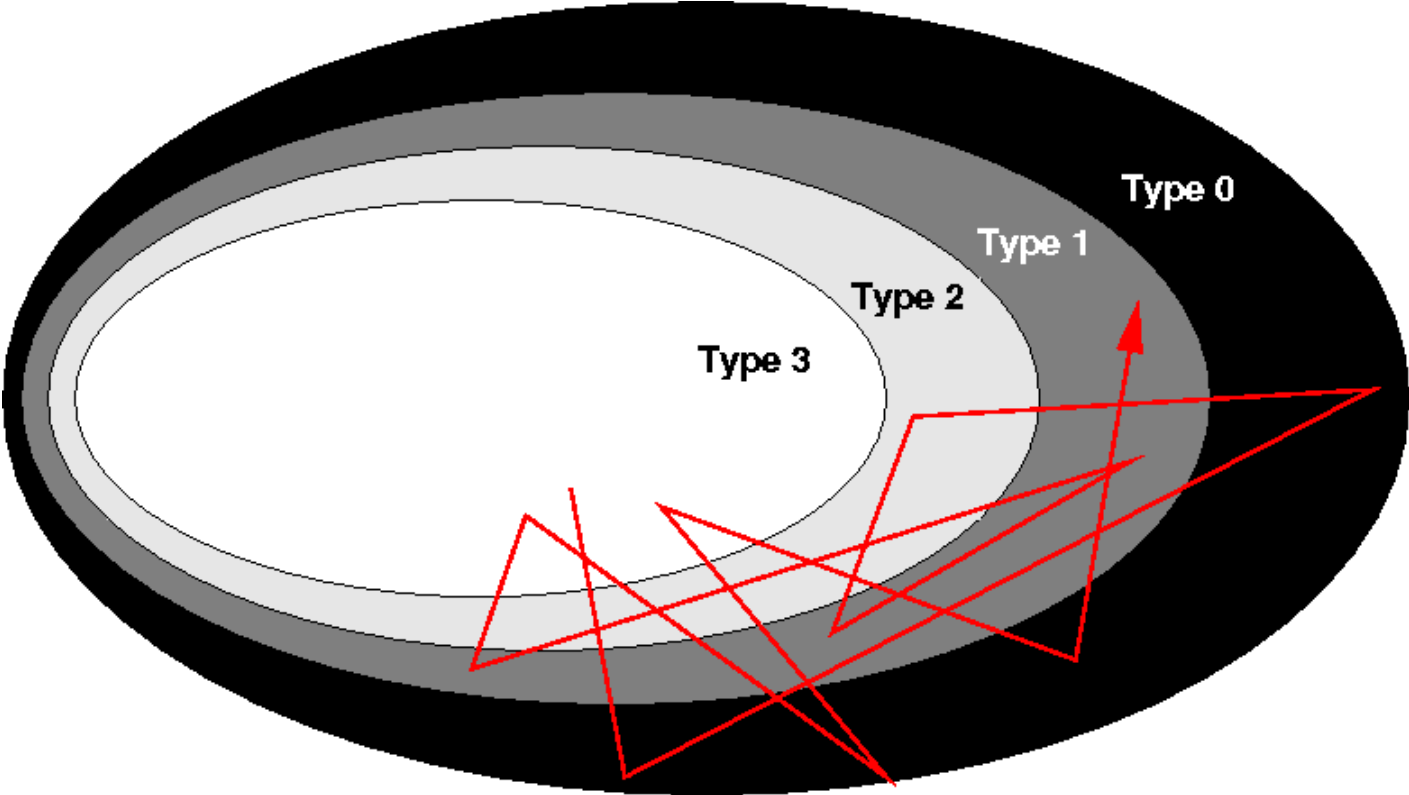
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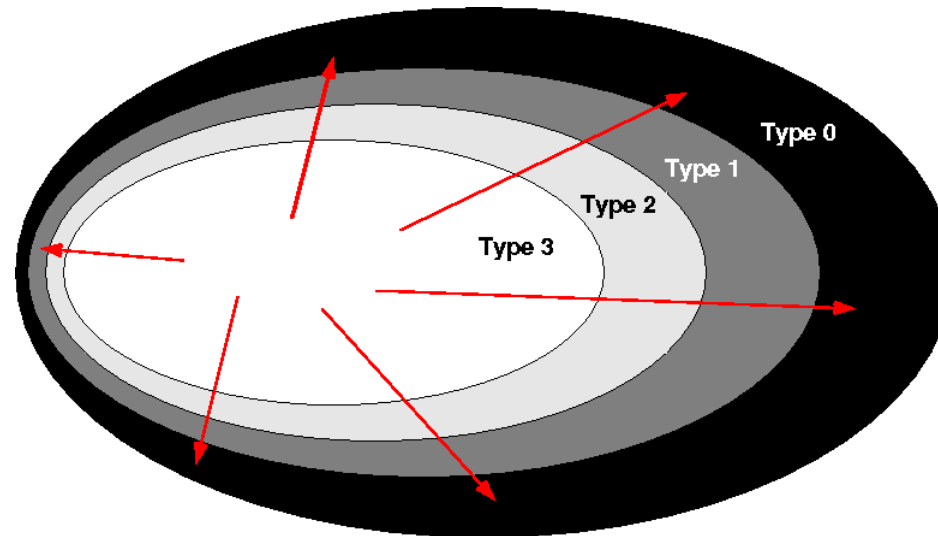


Assumption 1: Phenotypes Correspond to Complexity Classes



Assumption 2: Complexity is a Measure of Fitness

- To use the Chomsky Hierarchy as a tool we want the classes to be ordered by fitness
- $(\mathcal{C}_1 \subseteq \mathcal{C}_2) \longrightarrow (F(\mathcal{C}_1) \leq F(\mathcal{C}_2))$



Assumption 2: Complexity is a Measure of Fitness

- What properties of (formal) languages may be useful measures of fitness?
 - Expressivity
 - Produceability/Interpretability
 - Learnability
- What formal properties do these correspond to?
 - Growth rates: Number of strings of length $\leq n$
 - Recognition or parsing time
 - Learnability

Is Mathematical Linguistics Useful in Studying language Evolution?

- The Chomsky hierarchy was developed to organize the space of models of language.
- It identifies interesting properties of natural language (e.g types of dependencies).
- It is not naturally suited for defining a space of phenotypes or measures on that space.

Can we Fix it?

- Classes Characterized by other means (e.g. induction).
- Kolmogorov Complexity approaches?
- More fine grained classes - categorisation, generalization over categories (e.g. repetition, symmetry), concatenations.
- Any other suggestions?