The Role of Analysis and Recombination in the Evolution of Language Structure

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OVERVIEW

I. A question and an answer
   – What are analysis and recombination?

II. Origin of human culture
    – Theoretical argumentation (archaeology, evolutionary theory)
    – The role of analysis and recombination

III. The evolution of compositionality in language
    – Empirical data (artificial language learning studies)
    – Adaptation of forms to meanings through analysis and recombination

IV. Conclusion
- Why is human language structure so complex?

- *Because only humans can do analysis and recombination of symbols.*
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![Diagram of grammatical structure]

E.g.
Constituency,
Redundancy
- Why is human language **structure** so complex?
- *Because only humans can do analysis and recombination of symbols*

<table>
<thead>
<tr>
<th>IRREGULAR</th>
<th>REGULAR</th>
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<tbody>
<tr>
<td>am     was</td>
<td>look  looked</td>
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<tr>
<td>think  thought</td>
<td>walk  walked</td>
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<tr>
<td>tell   told</td>
<td>work  worked</td>
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<tr>
<td>see    saw</td>
<td>play  played</td>
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</table>

- `am` = ‘am’
- `was` = ‘was’
- `think` = ‘think’
- `thought` = ‘thought’
- `tell` = ‘tell’
- `told` = ‘told’
- `see` = ‘see’
- `saw` = ‘saw’

- `look-` = ‘look’
- `walk-` = ‘walk’
- `work-` = ‘work’
- `play-` = ‘play’
- `- ∅` = ‘present’
- `-ed` = ‘past’

Regularity allows:
- Generalisation
- Compression
- Why is human language structure so complex?
- *Because only humans can do analysis and recombination of symbols*
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*Dobzhansky (1973):* “Nothing in biology makes sense except in the light of evolution”

... also applicable to linguistic behaviour!
II. Language Origins

• A puzzle:
  If cumulative culture is so adaptive, why is it so rare? *(Boyd & Richerson 1996)*

• An answer:
  Because the cognitive biases favoured by non-cumulative culture are at odds with those required for cumulative culture *(Tamariz 2008)*
Origins of culture

(Tamariz 2008) Not one but two major transitions

1. Emergence of early culture
2. Emergence of cumulative culture
Nonhuman cultural traditions

- Holistic transmission tied to function
- Broken chains
  - Innovation through “local enhancement”
  - Maximum complexity: individual learning
  - No accumulation (Marshall-Pescini & Whiten, 2008)
1. Transition to early culture

• Holistic transmission tied to function
• Unbroken chains
  – Some innovation (analysis, recombination)
  – Some accumulation of structure

If some complexity, innovation deleterious to function
So norms/pressures against innovation

Oldowan & Acheulean stone tools: negligible innovation for 1 Million years!

Language: holistic protolanguage, very little analysis / recombination (*Wray 2000*)
2. Transition to cumulative culture

- Analytic transmission
- Accumulation of features
  - Extensive innovation (analysis, recombination)
  - Interaction of different traditions

Language: grammar, compositionality

Very advantageous!
(Boyd & Richerson 1996)
If it is so advantageous, why is cumulative culture so rare?

An adaptive gap

• Early culture poses pressure
  – For rigid imitation
  – Against analysis and recombination
• Cumulative culture
  – Requires analysis and recombination
If it is so advantageous, why is cumulative culture so rare?

Bridging the gap

• Large groups / group contact → many coexisting traditions
• Cultural environment favours “local enhancement”
• The cultural environment triggers its own evolution!
III. Adaptation of linguistic forms to meanings
Adaptation between form structure and meaning structure

Language is a system of signs (*Saussure*)
Adaptation between form structure and meaning structure

Adaptation of meanings to forms

Traces of form structure in the meanings
Adaptation between form structure and meaning structure

Adaptation of forms to meanings

Traces of meaning structure in the forms

→ Focus on this
Artificial Language Learning
Kirby, Cornish & Smith 2008

Generation 0: random signals
kimako ➔ koni
kanige ➔

Generation 1
komako ➔ kuni
winige ➔

3 features x
3 values
27 different meanings
A corpus of diachronic ‘linguistic’ data

8 lineages

Examine one lineage with pressure for expressivity

**Artificial Language Learning**

Kirby, Cornish & Smith 2008
Artificial Language Learning
Kirby, Cornish & Smith 2008

• One of the final languages

• Their results
  – Learning of forms
  – Structure of the language (systematicity)
  – Compositionality *is apparent*, but it is *not quantified*
Analysis and recombination

• Evidence for analysis
  – Independent transmission of *components* of the forms

• Evidence for recombination
  – Are they *recombined* in different ways?

→ Evolutionary dynamics
  – Form units and their frequency
  – Adaptation to the structure of meanings
## Evolutionary dynamics - Variant units

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**Legend:**
- `keko`: Keiko
- `keke`: Keke
- `kiki`: Kiki
- `kiko`: Kiko
- `kio`: Kio
- `ko`: Ko
- `koku`: Koku
- `ku`: Ku
- `ni`: Ni
- `niki`: Niki
- `niko`: Niko
- `nuko`: Nuko
- `kehu`: Kehu
- `nike`: Nike
- `nimu`: Nimu
- `niwa`: Niwa
- `po`: Po
- `wa`: Wa
- `wagu`: Wagu
- `wapo`: Wapo
- `keke 1`: Keke
- `keko 1`: Keko
- `ike 1`: Ike
- `kiki 1`: Kiki
- `kiko 1`: Kiko
- `mu 1`: Mu
- `neki 1`: Neki
- `neko 5`: Neko
- `niki 3`: Niki
- `nuki 1`: Nuki
- `nike 1`: Nike
- `nimu 1`: Nimu
- `niwa 1`: Niwa
- `po 1`: Po
- `wa 2`: Wa
- `wagu 1`: Wagu
- `wapo 1`: Wapo

**Evolutionary Dynamics Diagram:**
- **Keiko:**
  - Keke → Keke
  - Kiki → Kiki
  - Kiko → Kiko
  - Kio → Kio
  - Ko → Ko
  - Koku → Koku
  - Ku → Ku
  - Ni → Ni
  - Niki → Niki
  - Niko → Niko
  - Nuko → Nuko
- **Kike:**
  - Kiki → Kiki
  - Kiko → Kiko
  - Kuki → Kuki
  - Kuko → Kuko
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- **Koku:**
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  - Kiko → Kiko
  - Kuki → Kuki
  - Kuko → Kuko
- **Ku:**
  - Kico → Kico
  - Kiko → Kiko
  - Kuki → Kuki
  - Kuko → Kuko
- **Ni:**
  - Niki → Niki
  - Niko → Niko
  - Nimo → Nimo
  - Niwa → Niwa
- **Niki:**
  - Niko → Niko
  - Nimo → Nimo
  - Niwa → Niwa
  - Niwa → Niwa
- **Niko:**
  - Niki → Niki
  - Nimo → Nimo
  - Niwa → Niwa
  - Niwa → Niwa
- **Nimo:**
  - Niki → Niki
  - Niko → Niko
  - Nmo → Nmo
  - Niwa → Niwa
- **Niwa:**
  - Niki → Niki
  - Niko → Niko
  - Nimo → Nimo
  - Niwa → Niwa
- **Po:**
  - Po → Po
  - Po → Po
  - Po → Po
  - Po → Po
- **Wa:**
  - Wa → Wa
  - Wa → Wa
  - Wa → Wa
  - Wa → Wa
- **Wagu:**
  - Wa → Wa
  - Wa → Wa
  - Wa → Wa
  - Wa → Wa
- **Wapo:**
  - Wa → Wa
  - Wa → Wa
  - Wa → Wa
  - Wa → Wa
Evolutionary dynamics - Frequency

• Like genetic drift: in the absence of variation, one variant goes to fixation

• Stability suggests adaptation

• Innovation (generation 5)
Evolutionary dynamics – Adaptation of forms to meanings

• Signal segments become associated with different aspects of the meaning
  – Initial segment: colour
  – Middle segment: motion?
  – Final segment: motion

• Quantitative analysis
Evolutionary dynamics – Adaptation of forms to meanings

Segment 1

- Colour
- Shape
- Motion

Generation

RegMap

0.0
0.2
0.4
0.6
0.8
1.0

0 1 2 3 4 5 6 7 8 9 10

Segment 1
Evolutionary dynamics –
Adaptation of forms to meanings
Evolutionary dynamics – Adaptation of forms to meanings

Segment 3

Colours: Green (Colour), Red (Shape), Blue (Motion)
Evolutionary dynamics – Adaptation of forms to meanings

• Adaptation of forms components to meaning components results in **Compositionality**

“The meaning of a whole word depends on the meaning of the parts, and the rules to combine them”

• Through analysis and recombination

“ponekuki”

po- = red
-kuki = bouncy
Artificial Language Learning
Population approach

• Kirby, Cornish & Smith (2008) 1 participant per generation. Enormous impact of individual variation

• Tamariz & Smith (2008) 10 participants for a single generation manipulate level of structure in the input
Artificial Language Learning
Population approach

• *Kirby, Cornish & Smith (2008)* 1 participant per generation
  Enormous impact of individual variation

• *Tamariz & Smith (2008)* 10 participants for a single generation
  manipulate level of structure in the input

- Sensitive to input structure
  \(p<0.001\)

- A lot of innovation

(Kirby, Cornish & Smith data show that innovation towards compositionality is selected for)
Artificial Language Learning
Musical language

• Participants expect/may intentionally create patterns in written language – Effect of extensive enculturation?
• Brown & Tamariz (submitted) a musical language, compare trained musicians vs. non-musicians
Artificial Language Learning
Musical language

- Participants expect/may intentionally create patterns in written language – Effect of extensive enculturation?
- Brown & Tamariz (submitted) a musical language, compare trained musicians vs. non-musicians

**RESULTS FOR MUSICIANS**

- Comparable to those of Tamariz & Smith (2008)
- Sensitive to input structure (p<0.001)
- Little innovation
Artificial Language Learning
Musical language

- Participants expect/may intentionally create patterns in written language – Effect of extensive enculturation?
- Brown & Tamariz (submitted) a musical language, compare trained musicians vs. non-musicians

**RESULTS FOR NON-MUSICIANS**

- Very different from Tamariz & Smith 2008
- NOT sensitive to input structure
- No innovation
Artificial language learning - Conclusions

• Compositionality
  – Analysis of *signals* and *meanings* into categories/components
  – Independent transmission of signal components
  – Recombination of signal components

• Evolutionary dynamics
  – Replication, variation, selection
  – Descent with modification

• Effects of enculturation (practice and literacy)
IV. Summary and conclusions

• Other animals can categorize their environment

• Only humans can categorize, analyze; imitate and recombine **components** of their own behavioural productions

• Components undergo evolutionary dynamics
  – Replication, variation, selection

  ➔ Cumulative culture

  ➔ Increasing levels of complexity

  “Standing on the shoulders of giants”
Summary and conclusions (and 2)

- Role of *analysis and recombination* in language origin, change and diversification
- Uniquely human capacities, low probability of evolving
- Once it evolved genetically, allowed a whole new system, **culture**, to evolve independently of genes