Language Evolution in the Lab: from models to experiments in evolutionary linguistics

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The evolutionary approach to language
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• Language is (almost) unique in nature
The evolutionary approach to language

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• It involves three complex adaptive systems:
  • Biological evolution
  • Individual learning
  • Cultural transmission

• Language arises from the interaction of these three
The challenge...
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• Evolutionary linguistics rests on the premise:
  • to understand why language is the way it is, we need to understand these adaptive processes and their interaction
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  • to understand why language is the way it is, we need to understand these adaptive processes and their interaction

• But how do we do this?

• One approach: build models
  • explore the adaptive processes in miniature, and then apply what we learn to the real thing
This talk

• I’m going to focus on cultural transmission
  • mainly because its importance has been underemphasised in traditional evolutionary approaches

• I want to show that you can study this in the lab
  • New experimental methodologies inspired by earlier computational models

• Ultimately this gives us a new perspective on the biological prerequisites for human language
Previous computational models
(a whistle-stop tour)
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- Multi-agent modelling techniques applied to cultural evolution
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  - Multi-agent modelling techniques applied to cultural evolution
  - Embed simple models of learners in a dynamic population and an “environment” about which they try to communicate
Previous computational models
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• The Iterated Learning Model (mid 90s onwards)
  • Multi-agent modelling techniques applied to cultural evolution
  • Embed simple models of learners in a dynamic population and an “environment” about which they try to communicate
  • Agents learn to communicate by observing others, who themselves learned the same way (cf. the game “telephone”)
Previous modelling work
(a whistle-stop tour)
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• Key insight: *transmission bottlenecks*
Previous modelling work (a whistle-stop tour)

- Key insight: transmission bottlenecks
  - If a learner is given imperfect information about the language, e.g. noise, processing constraints, or simply not hearing all the data (cf. stimulus poverty)
  - ... cultural transmission becomes an adaptive system.
  - Language will adapt so that it appears to be designed to “fit” the bottleneck
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- **Key insight:** *transmission bottlenecks*
  - If a learner is given imperfect information about the language, e.g. noise, processing constraints, or simply not hearing all the data (cf. *stimulus poverty*)
  - ...cultural transmission becomes an adaptive system.
  - Language will adapt so that it appears to be designed to “fit” the bottleneck
  - Features like compositional syntax emerge spontaneously in these models
Design without a designer
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- Languages (arguably) have the “appearance of design”
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  - Biological evolution (cf. Pinker & Bloom 1990)
  - Intentional design by individuals
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• Computational models show a third alternative
  • Cultural evolution
  • Consistent with idea of the “invisible hand” (Keller 1990)
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• But can we demonstrate this in real human agents?
An experimental approach

• Combine diffusion chain and artificial language learning studies

Kirby, Cornish & Smith (2008) PNAS
An experimental approach

- Combine *diffusion chain* and *artificial language learning* studies
- Cultural transmission of an “alien language”

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  2. Ask an experimental subject to try and learn this language and test them

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An experimental approach

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• Cultural transmission of an “alien language”
  1. Start off with a random artificial language
  2. Ask an experimental subject to try and learn this language and test them
  3. Use their output on test as the language to teach the next subject in the experiment (and repeat)

Kirby, Cornish & Smith (2008) PNAS
Hypothesis

- There will be cumulative cultural adaptation of the language without intentional design by participants
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• Two ways of verifying this:
  • The language should become easier to learn
  • The language should become structured
The Language
The Language

• A set of 27 possible “meanings”
• Pictures with coloured objects in motion:
  • Three shapes  □ ○ △
  • Three colours  ⬛ ⬝ ⬞
  • Three motions  ---→ ∧∧⊙
The Language

- A set of 27 possible “meanings”
  - Pictures with coloured objects in motion:
    - Three shapes \( \square \; \bigcirc \; \triangle \)
    - Three colours \( \text{grey} \; \text{blue} \; \text{red} \)
    - Three motions \( \text{------} \; \text{\_\_\_} \; \text{\_\_} \; \text{\_\_} \)
- A large set of possible “signals”
  - Random sequences of between two and four syllables chosen from a set of nine
  - No spaces
Procedure
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- Language divided randomly into two sets:
  - SEEN set: 14 string-picture pairs
  - UNSEEN set: remaining 13 string-picture pairs
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• String displayed for 1 second, then string and picture for a further 5 seconds
Procedure

- Language divided randomly into two sets:
  - SEEN set: 14 string-picture pairs
  - UNSEEN set: remaining 13 string-picture pairs
- Subjects trained on SEEN set
- String displayed for 1 second, then string and picture for a further 5 seconds
- Tested on complete set,
  - randomly redivided into new SEEN and UNSEEN sets for next generation
kihemiwi
kihemwiwi
kunige
kunige
Language becomes easier to learn

![Graph showing language learning progress over generations with different markers and error reduction trends.](image-url)
After Generation 1:
After Generation 1:

24 words
After Generation 10:
After Generation 10:

5 words
How has language become easier?
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How has language become easier?

• Looks like it might be just that there are fewer words.

• If this were all that was going on, then subjects’ performance on unseen items should be random.

• This doesn’t appear to be the case...
Language becomes systematic

Measure shows the degree to which meaning and form are systematically related.

95% confidence
After Generation 1:
After Generation 6:
After Generation 7:
After Generation 8:
After Generation 9:
After Generation 10:
Language adapts to be structured

• Language adapts

• **Subjects are not aware of this**
  (they aren’t even aware they are being shown unseen items!)

• Systematic underspecification is an *adaptation by language to aid its own survival*, since it makes language learnable despite stimulus poverty

• Cumulative cultural adaptation without
More interesting structure?

• In reality language exhibits structure (e.g. morphology, syntax) that makes it learnable and expressive

• There's no pressure for expressivity in the experiment
More interesting structure?

• In reality language exhibits structure (e.g. morphology, syntax) that makes it learnable and expressive

• There’s no pressure for expressivity in the experiment

• Simple modification: filter out all ambiguous items from SEEN set before subjects see them
Language becomes easier to learn

![Graph showing the change in error with generations. The x-axis represents generations, and the y-axis represents error. The graph demonstrates a decrease in error over generations, indicating that language becomes easier to learn.](image)

Key:
- Circles: Language 1
- Squares: Language 2
- Diamonds: Language 3
- Triangles: Language 4

Note: The exact data points are not visible due to the image resolution.
Language becomes systematic

```
b)  
```

Generations

Structure

Language becomes systematic
<table>
<thead>
<tr>
<th>Example initial language</th>
</tr>
</thead>
<tbody>
<tr>
<td>lumonamo</td>
</tr>
<tr>
<td>nelu</td>
</tr>
<tr>
<td>kapihu</td>
</tr>
<tr>
<td>kinahune</td>
</tr>
<tr>
<td>kanehu</td>
</tr>
<tr>
<td>humo</td>
</tr>
<tr>
<td>lahupine</td>
</tr>
<tr>
<td>namopihu</td>
</tr>
<tr>
<td>lahupiki</td>
</tr>
<tr>
<td>moki</td>
</tr>
<tr>
<td>kalu</td>
</tr>
<tr>
<td>nane</td>
</tr>
<tr>
<td>luneki</td>
</tr>
<tr>
<td>mola</td>
</tr>
<tr>
<td>kalakihu</td>
</tr>
<tr>
<td>lanepi</td>
</tr>
<tr>
<td>pihukimo</td>
</tr>
<tr>
<td>mokihuna</td>
</tr>
<tr>
<td>kilamo</td>
</tr>
<tr>
<td>pilu</td>
</tr>
<tr>
<td>luki</td>
</tr>
<tr>
<td>kahuki</td>
</tr>
<tr>
<td>neki</td>
</tr>
<tr>
<td>namola</td>
</tr>
<tr>
<td>neluka</td>
</tr>
<tr>
<td>pinemohu</td>
</tr>
<tr>
<td>lumoka</td>
</tr>
</tbody>
</table>
Example final language
(10 “generations” later)

<table>
<thead>
<tr>
<th></th>
<th>n-ere-ki</th>
<th>n-ehe-ki</th>
<th>n-eke-ki</th>
<th>l-ere-ki</th>
<th>l-aho-ki</th>
<th>l-ake-ki</th>
<th>renana</th>
</tr>
</thead>
<tbody>
<tr>
<td>n-ere-plo</td>
<td>n-eho-plo</td>
<td>n-eki-plo</td>
<td>l-ane-plo</td>
<td>l-aho-plo</td>
<td>l-aki-plo</td>
<td>r-e-plo</td>
<td>r-aho-plo</td>
</tr>
<tr>
<td>n-e-pilu</td>
<td>n-eho-pilu</td>
<td>n-eki-pilu</td>
<td>l-ane-pilu</td>
<td>l-aho-pilu</td>
<td>l-aki-pilu</td>
<td>r-e-pilu</td>
<td>r-aho-pilu</td>
</tr>
</tbody>
</table>
Adaptation again
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  - only a sub-sample is seen by learners
  - ambiguous signals are filtered out
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Adaptation again

- Language adapts to the transmission “bottleneck”
- It must be learned even though:
  - only a sub-sample is seen by learners
  - ambiguous signals are filtered out
- Morphological/syntactic structure is a solution to this problem
- Note: subjects cannot be aware of the filtering, but language structure is very different
  - Demonstrates that adaptation is non-intentional
  - Culture gives us design without a designer
Conclusions
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- Cultural evolution must be a crucial part of an explanatory biolinguistic account of language structure
- We can study it in the lab
- Language evolution is not:
  - Natural selection of innate constraints that determine language structure
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• Cultural evolution must be a crucial part of an explanatory biolinguistic account of language structure
• We can study it in the lab

• Language evolution is not:
  • Natural selection of innate constraints that determine language structure

• So what’s left for biological evolution?
  • Preadaptations enabling learning of complex sequential signals paired with complex meanings (we’re the only primate that can do this)