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
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- Language is (almost) unique in nature
- It involves three complex adaptive systems:
  - Biological evolution
  - Individual learning
  - Cultural transmission
- Language arises from the interaction of these three
Learning biases drive linguistic evolution

Individual Learning

Cultural Transmission

Biological Evolution

Evolution determines learning mechanisms

Linguistic structure changes fitness landscape

Language
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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- The Iterated Learning Model (mid 90s onwards)
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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
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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. broken telephone)
Previous modelling work
(a whistle-stop tour)
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- Key insight: *transmission bottlenecks*
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  • 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
• 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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• Two obvious mechanisms to explain this:
  • 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 (forthcoming) *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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  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 (forthcoming) 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  □ ○ △
    • Three colours  🟢 ➤ 🟡 🟠
    • Three motions  ——— ➤ \\ 
  □

• 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
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• Language divided randomly into two sets:
  • SEEN set: 14 string-picture pairs
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• 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
kihemiwi
kunige
Language becomes easier to learn

![Diagram showing error over generations]

- Generations
- Error

a)
After Generation 1:
After Generation 1:

24 words
After Generation 10:
After Generation 10:

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

- Looks like it might be just that there are fewer words.
How has language become easier?

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- 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:

miniku

poi

tupin

tupim

tuge
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*
- Cumulative cultural adaptation without intention
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
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• 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 error decreases over generations](image-url)
Language becomes systematic

![Graph showing the relationship between Structure and Generations, with markers for different conditions indicatingLanguage becomes systematic.](image)
Example final language
(10 “generations” later)
Adaptation again
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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
The emergence of culturally transmitted communication
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- The previous paradigm assumed that individuals:
  - want to communicate
  - know what to communicate about
  - have a dedicated “channel” for communication
  - want to share their communication system.
The emergence of culturally transmitted communication

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  • want to communicate
  • know what to communicate about
  • have a dedicated “channel” for communication
  • want to share their communication system.

• In other words, they are already symbolic learners
  • Can we explore the genuine emergence of symbols in the lab?
  • New experiment inspired by study in evolutionary robotics (Quinn 2001)
The Embodied Communication Game: A test-bed for the emergence of symbolic communication

- Participants play a two-player cooperative computer game where the other player is in another room
- Steer a character round a room with different coloured floor tiles and try to finish up on the same colour as the other player
- Similar to study by Galantucci (2005) but without a communication channel

Scott-Phillips, Kirby & Ritchie (forthcoming)
Player 1 sees:

Points in succession: 0  Highest: 3

Press space when you're finished

Player 2 sees:

Points in succession: 0  Highest: 3

Press space when you're finished
Player 1 sees:

Points in succession: 0   Highest: 3

Press space when you’re finished

Player 2 sees:

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Rules
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- Score if on same colour after both press finish
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- Score if on same colour after both press finish
- Always at least one colour that’s in both rooms (but equally there may be colours that are unique to room)
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• After turn, other player’s colours are revealed
Rules

• Score if on same colour after both press finish

• Always at least one colour that’s in both rooms (but equally there may be colours that are unique to room)

• Colour assignment is completely random after each turn

• After turn, other player’s colours are revealed

• It is possible to find a strategy for winning on every turn
Player 1 sees:

```
[Diagram]
Points in succession: 0   Highest: 3
Press space when you're finished
```

Player 2 sees:

```
[Diagram]
Points in succession: 0   Highest: 3
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Player 1 sees:

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Press space when you’re finished

Player 2 sees:

Points in succession: 0   Highest: 3

Press space when you’re finished
Player 1 sees:

Player 2 sees:

Points in succession: 0
Highest: 3

Press space when you're finished
Player 1 sees:

Points in succession: 0    Highest: 3

Press space when you're finished

Player 2 sees:

Points in succession: 0    Highest: 3

Press space when you're finished

yellow
Move & stop (default strategy)

Oscillations

Loop

C-shape
A typical pattern of emergence
A typical pattern of emergence

1. First a “default” strategy emerges
A typical pattern of emergence

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2. Then a signal to mean “something’s wrong!”
A typical pattern of emergence

1. First a “default” strategy emerges
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3. Ritualised to mean a particular colour
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1. First a “default” strategy emerges
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4. Extended to the other colours
A typical pattern of emergence

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- Demonstrates again the fundamental importance of the socio/cultural process
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• We can study it in the lab
  • The Embodied Communication Game shows how sequential behaviours can become meaningful
  • The iterated learning experiments show how this can lead to systematic structure
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- Cultural evolution a crucial part of an explanatory account of language structure
- We can study it in the lab
  - The Embodied Communication Game shows how sequential behaviours can become meaningful
  - The iterated learning experiments show how this can lead to systematic structure
- What’s left for biological evolution?
  - Preadaptations enabling learning of complex sequential signals (we’re the only primate that can do this)