Language, Culture & Computation:
the adaptive systems approach to the evolution of language

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Language Evolution

- I’m an evolutionary linguist

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- I'm an evolutionary linguist
- How is this even possible?

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- I'm an evolutionary linguist
- How is this even possible?
- A story about one attempt to find a way...
  - Starts with the use of computational models
  - Ends with a way of thinking about culture in the real world as a computational process

First things first...

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- What are evolutionary linguists interested in?

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- What are evolutionary linguists interested in?
  - An origins story for humans that involves language
  - Explaining the structure of language
- An evolutionary approach:
  - The universal properties of language arise from the fact that it is one of the most complex adaptive systems in nature

Why is language the way it is?

The orthodox Chomskyan view

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UNIVERSAL PROPERTIES
OF LINGUISTIC
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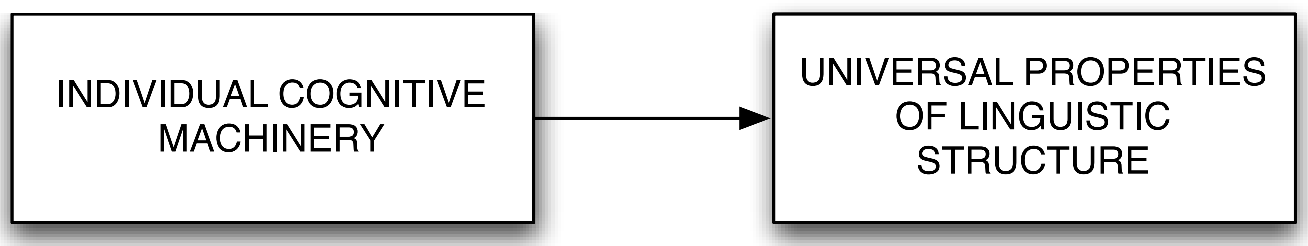

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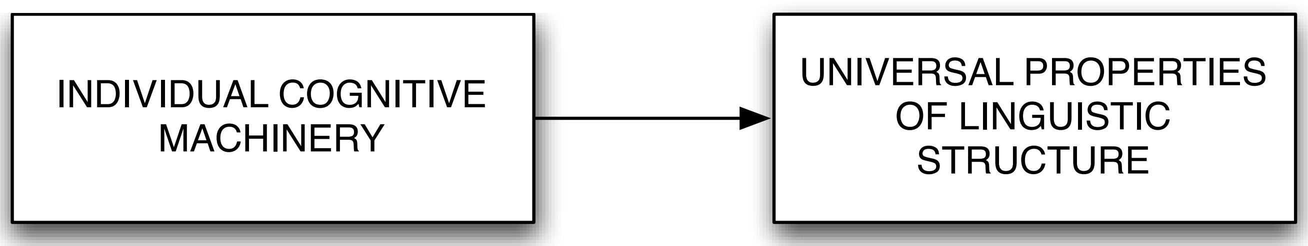

- Language structure is explained by innate constraints on a biological faculty for acquiring language

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- Very powerful and successful approach for linguistics
- Suggests:
  - We can infer human nature from human behaviour
  - We can move from description to explanation
- Led to interesting relationship between theoretical linguistics and machine learning

Is there something missing?

- Seemed to a lot of people that this approach is explanatorily unsatisfying
- Where do these innate constraints on the language faculty come from?

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- Seemed to a lot of people that this approach is explanatorily unsatisfying
- Where do these innate constraints on the language faculty come from?
- Could we look to biology to help us explain why the language faculty is the way it is?

Why is language the way it is?
Pinker & Bloom's (1990) view

- Assumptions:
  - We have domain-specific machinery to allow us to learn language
  - This is a useful skill (i.e. it's adaptive)
  - The machinery is complex

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  - We have domain-specific machinery to allow us to learn language
  - This is a useful skill (i.e. it's adaptive)
  - The machinery is complex
- Claim:
  - We have only one explanation for explaining adaptive complexity in nature... *natural selection*

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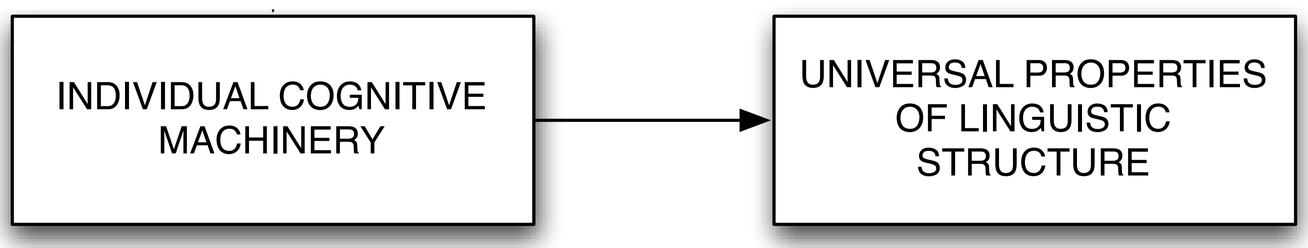

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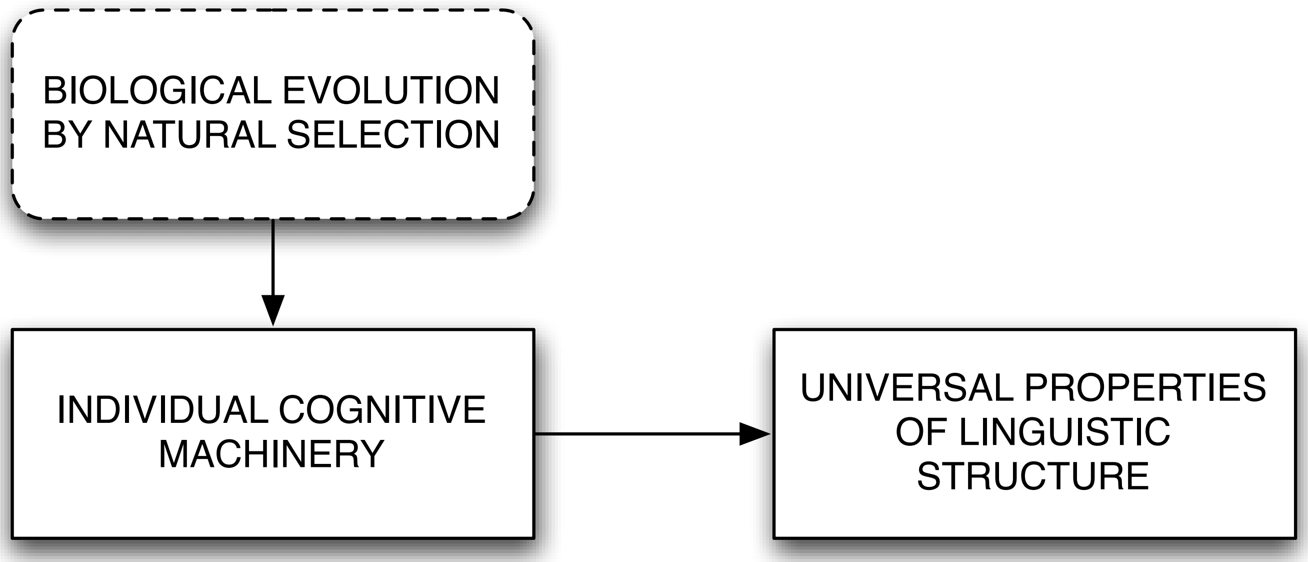

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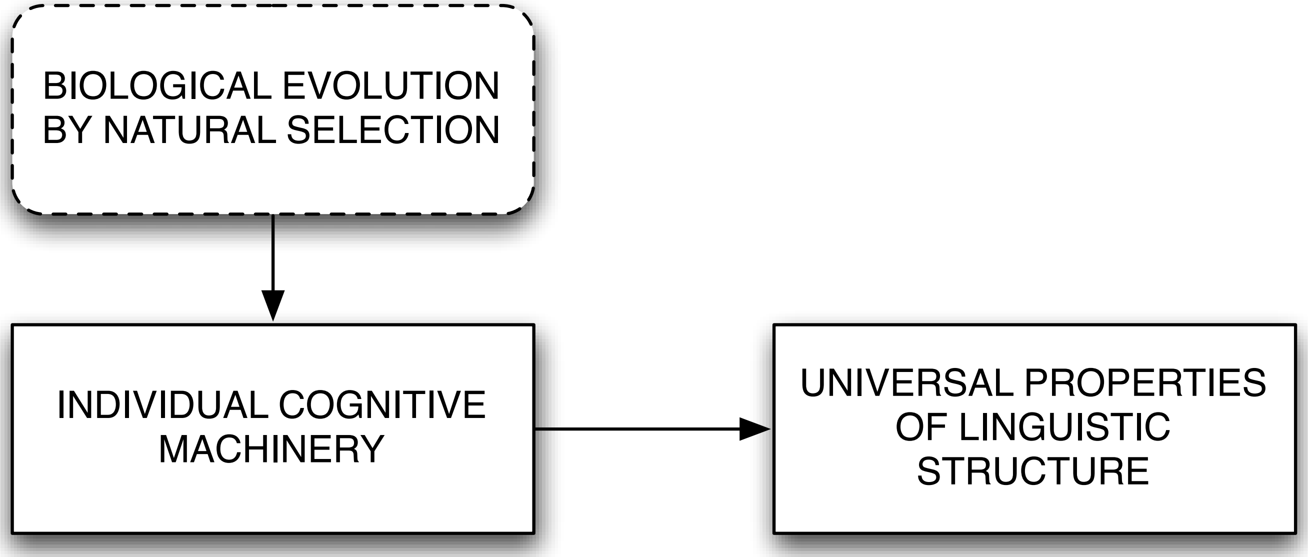

- Language structure is explained by innate constraints that have adapted through natural selection for communicative function

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- After Pinker & Bloom, enormous increase in speculation about language evolution
- Things seem simple, but actually very complicated!
- Two interacting *adaptive systems* at play:
  - Individual learning
  - Biological evolution of learning mechanisms
- Can we be confident in our intuitions?

The rise of computer simulation

- Don’t rely on verbal argument or intuition
  - Use computer simulation to model evolution of language learners
  - First paper, Hurford (1989), led to “Edinburgh approach”
- At the same time, *Artificial Life* in general started looking at evolution and learning
  - Use multi-agent modelling, machine learning, evolutionary computation

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  - Where do the constraints come from?

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- Chomskyan approach suggests a mix of learned features and innate constraints
  - Where do the constraints come from?
- Baldwin (1896) suggests that learned behaviours can become innate
- Various models test this for language acquisition (e.g. Turkel, Briscoe, Yamauchi, Batali...)
  - Depends on learning cost, rate of change etc.

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- Computational models of language learning
  - Build model of learning; test on language problem
- Computational models of language evolution
  - Build model of population of language learners; use language problem as selection pressure
- But where do these language problems come from?

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- The Problem of Linkage
  - Language does not straightforwardly emerge from the idealised individual speaker/hearer
- It is the result of a socio/cultural process
  - Language structure emerges from the interaction of individuals (albeit ones with particular biases)

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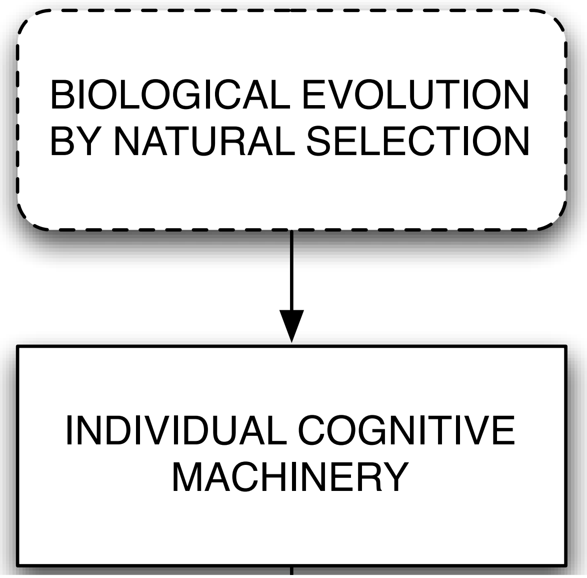

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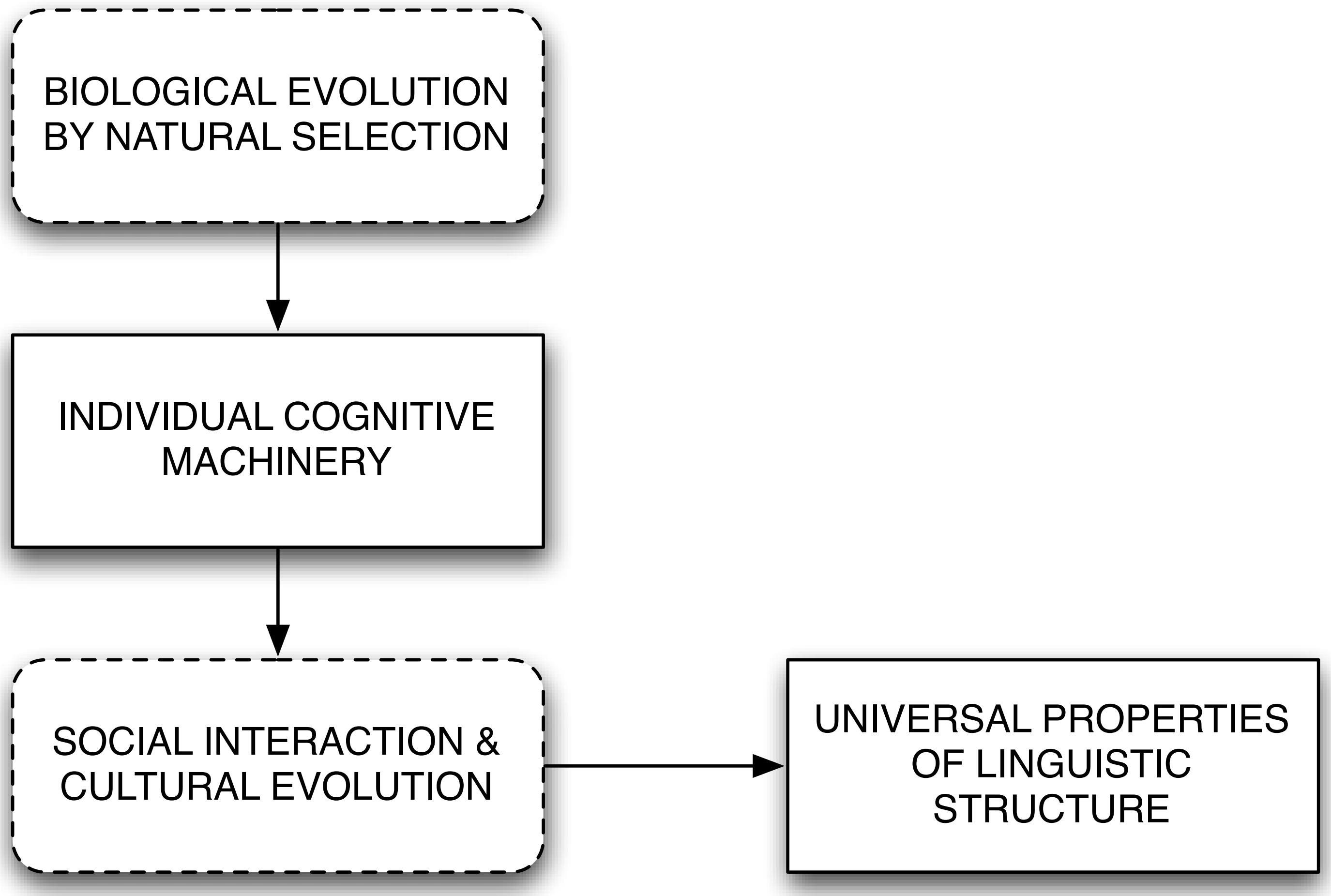

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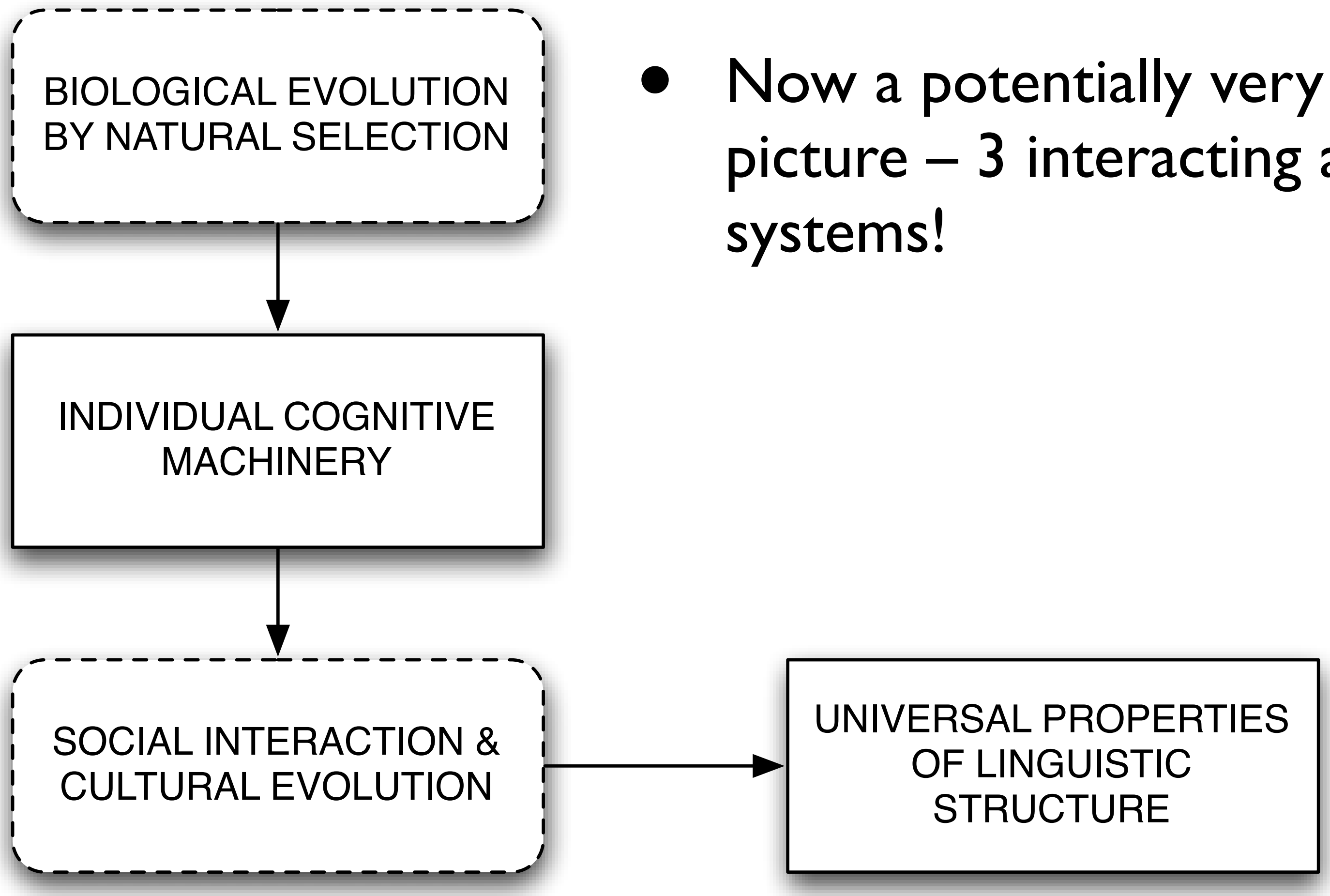

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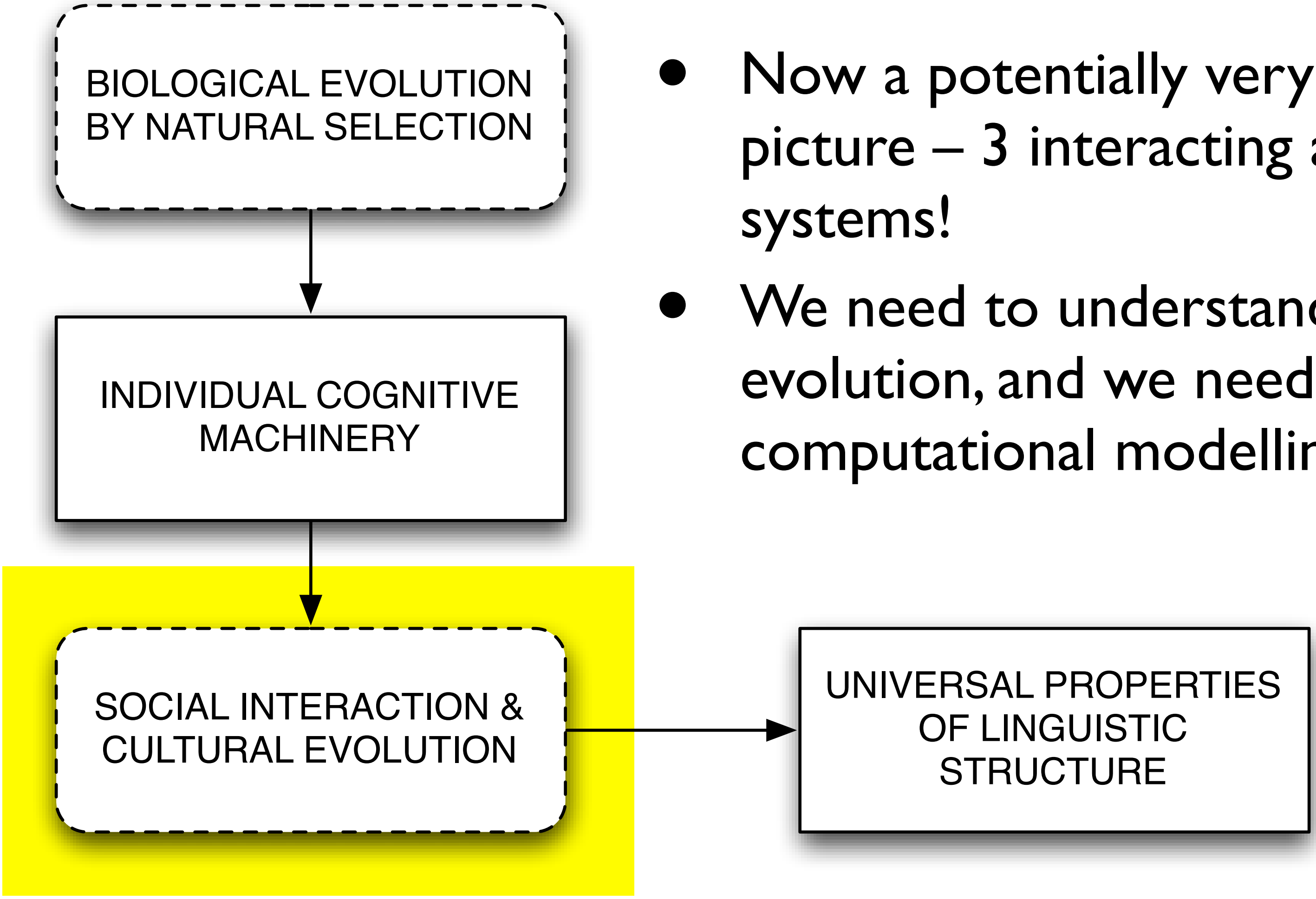

- Now a potentially very complex picture – 3 interacting adaptive systems!
- We need to understand cultural evolution, and we need computational modelling to help us

The Iterated Learning Model

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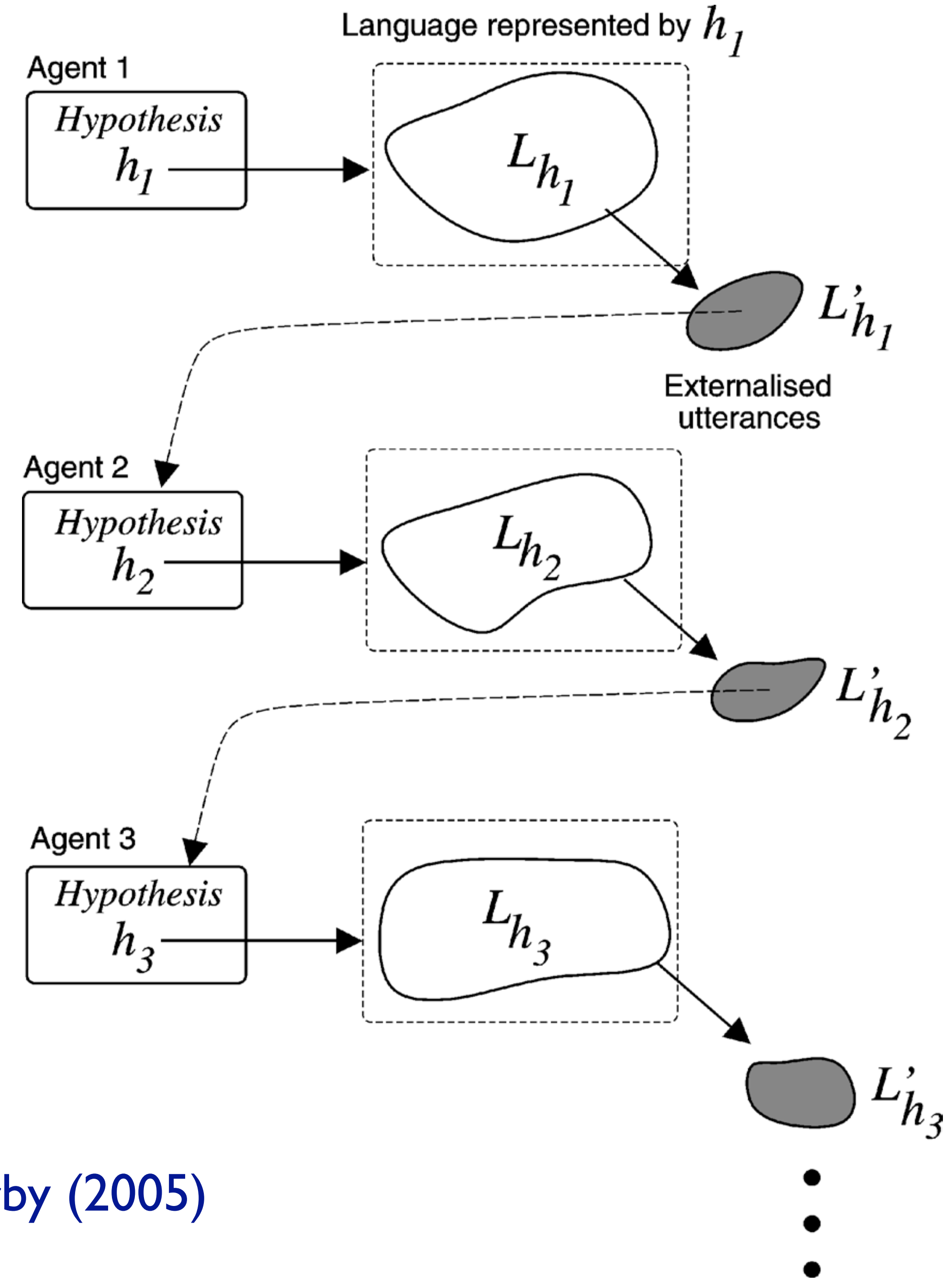
  - e.g. Batali at UCSD, Steels in Paris/Brussels using robotic models
- In Edinburgh, the *Iterated Learning Model*
  - e.g. Brighton, Smith, Zuidema, Dowman, Hurford
  - an explicit model of cultural transmission of language



Brighton, Smith, Kirby (2005)

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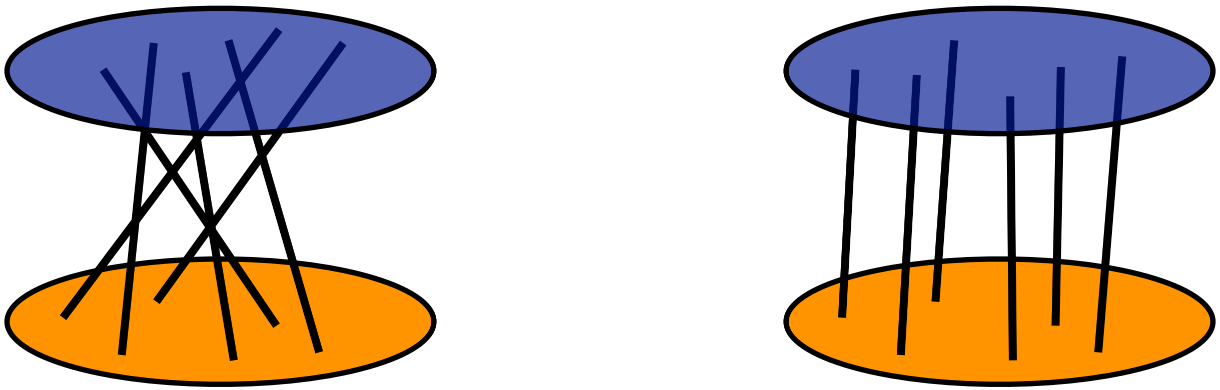
- What we find:
  - Languages do not simply mirror learning constraints
  - Cultural evolution has explanatory role
- The more difficult the learning task is, the more structured the languages become
  - Cultural evolution is another *adaptive system*

An example: the evolution of compositionality

- Languages involve non-random mappings between meanings and signals



- When signals are strings, this is manifested as *compositionality*

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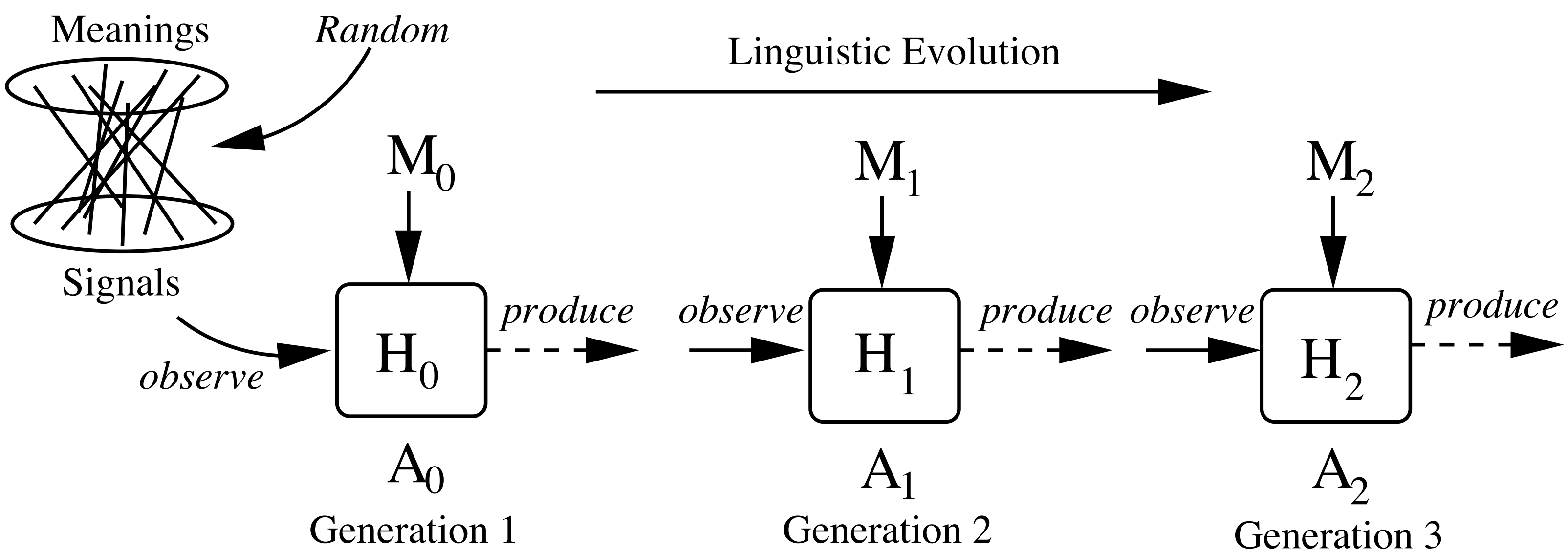
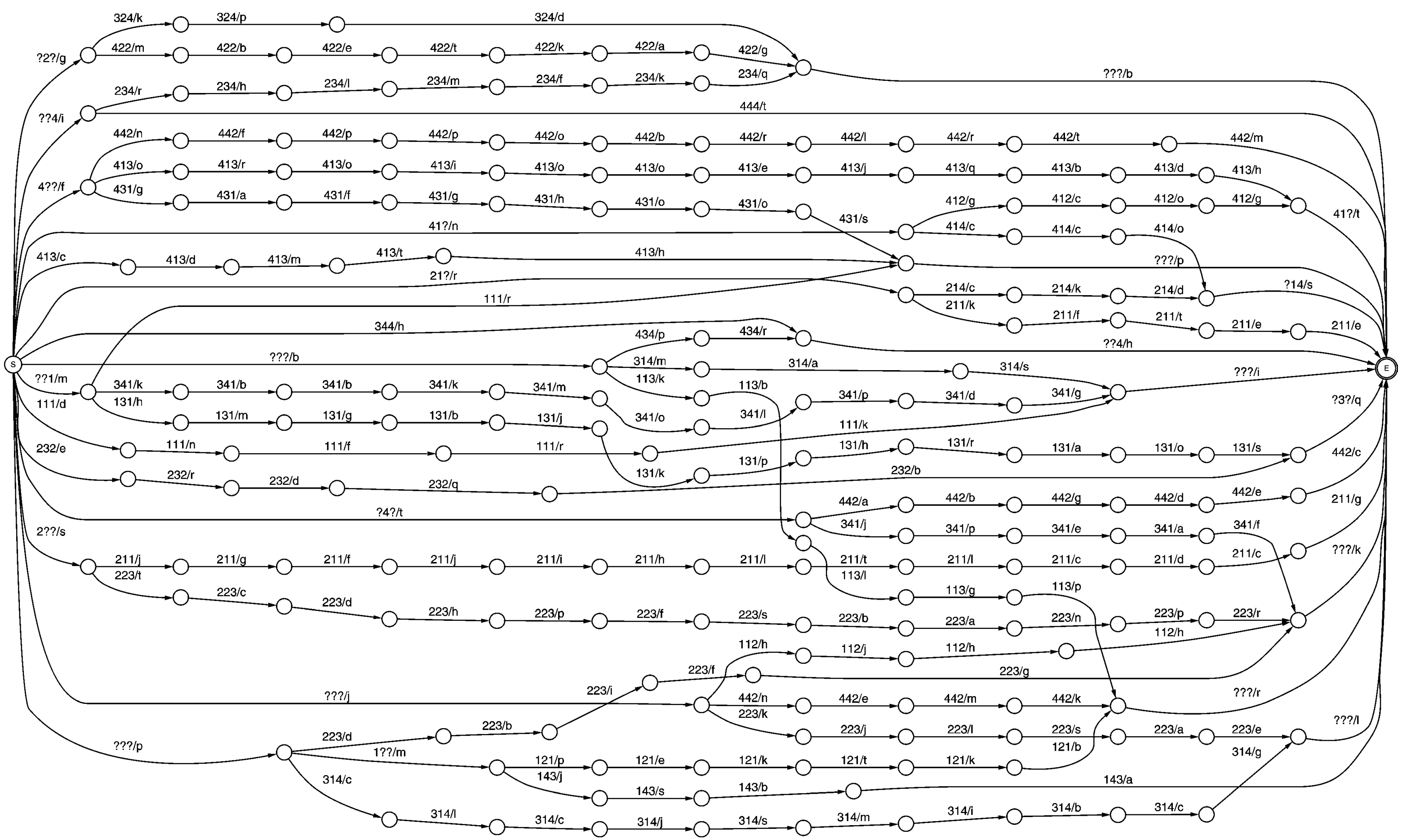


- Many variants of this approach depending on model of meanings and model of learning
- Examples from Brighton (2003) using simple feature vectors and FST induction

Typical evolution



- Initial state: unstructured, random, inexpressive

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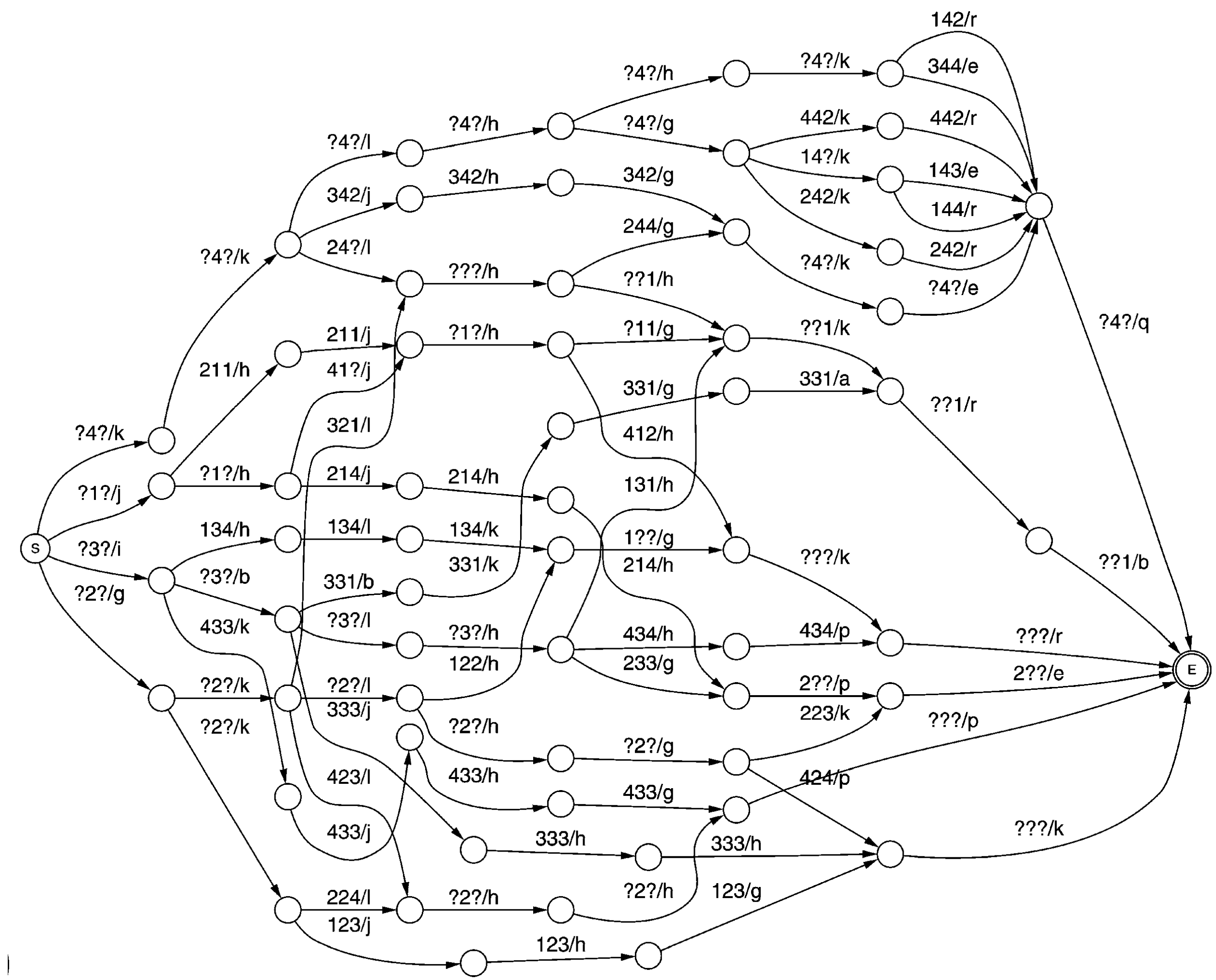

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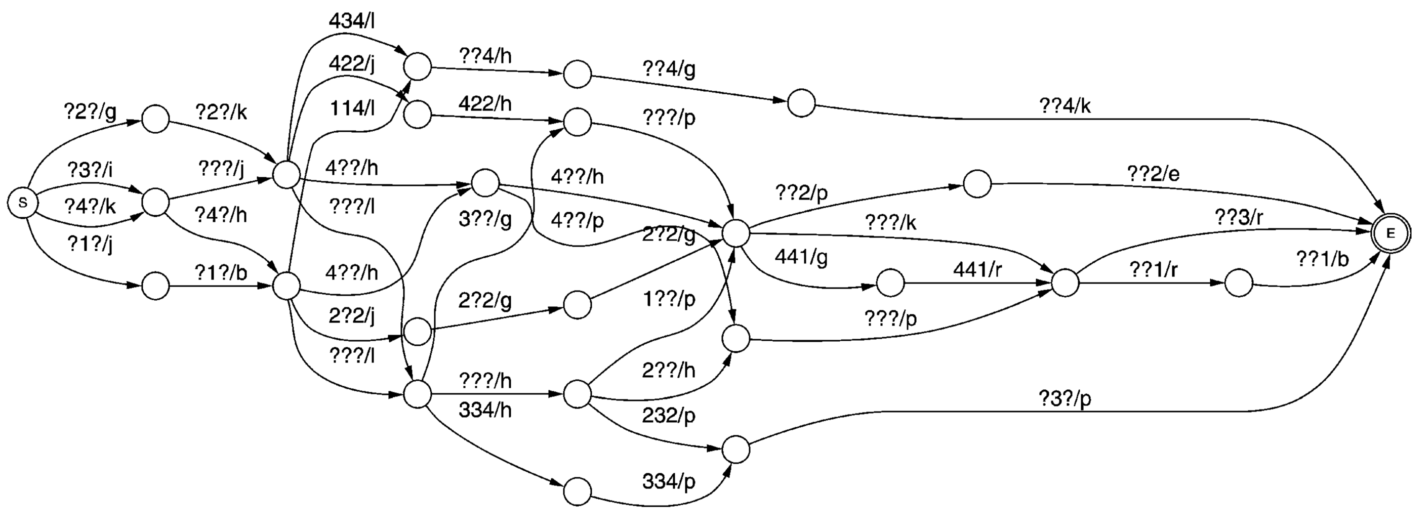

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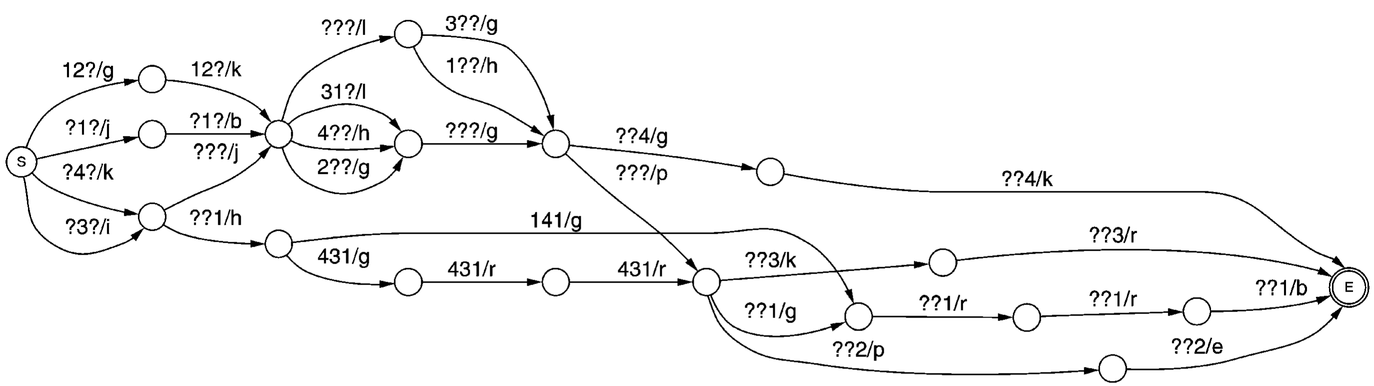

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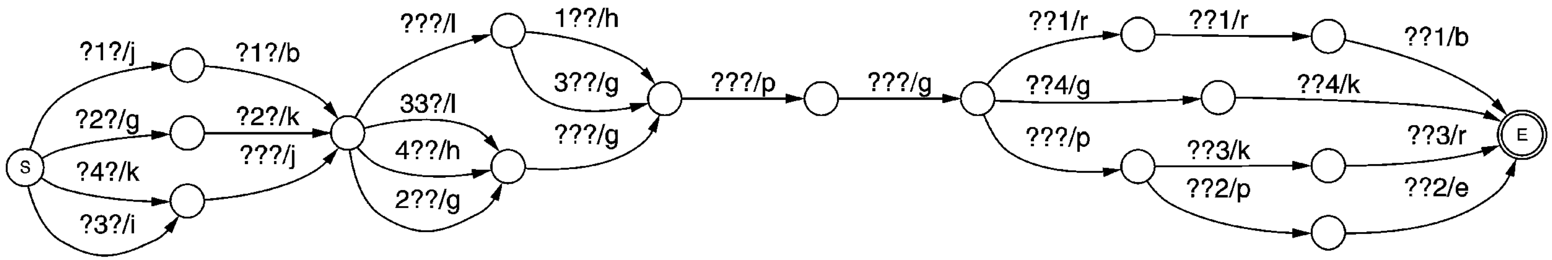

- Stable end state: compositional, expressive
- BUT: this only happens when there is a *bottleneck* on transmission

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- Cultural evolution leads to *compressible representational systems*

Cultural evolution and language

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- Cultural evolution has a profound effect
  - Properties of bottleneck shape language structure
  - We don't need natural selection
- Recent Bayesian generalisation of ILM shows:
  - We do not need strongly constraining innateness (Kirby, Dowman & Griffiths 2007)
  - Co-evolutionary results suggest *reverse* Baldwin effect (Smith & Kirby in prep)

Beyond models...

- Computational models show adaptation to bottleneck and emergence of generalisations
- Seems to reflect real language structure
- But hard to observe evolution through iterated learning "in the wild"
- Can we be sure this works in humans?

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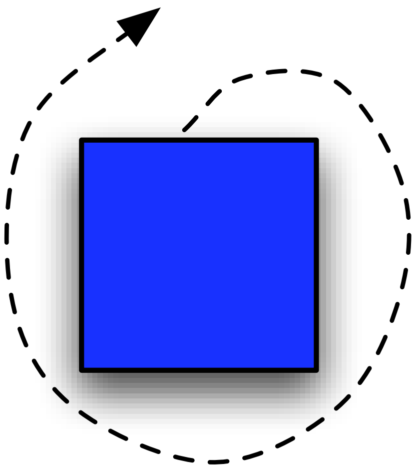

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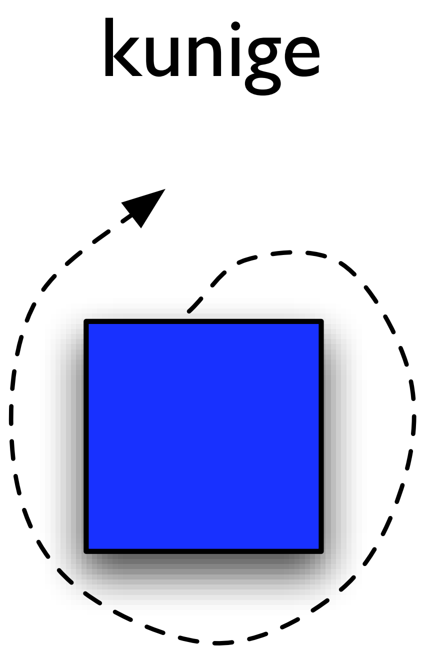

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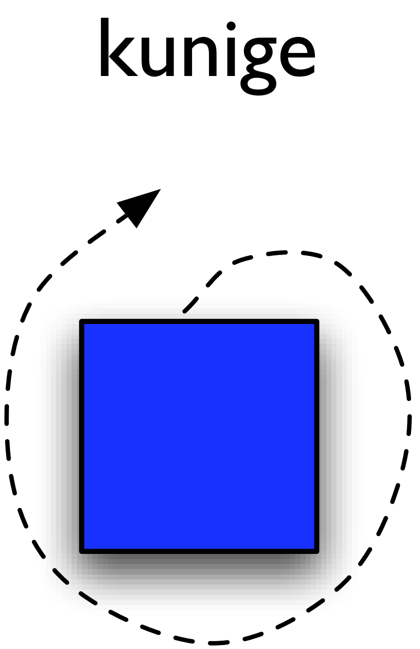

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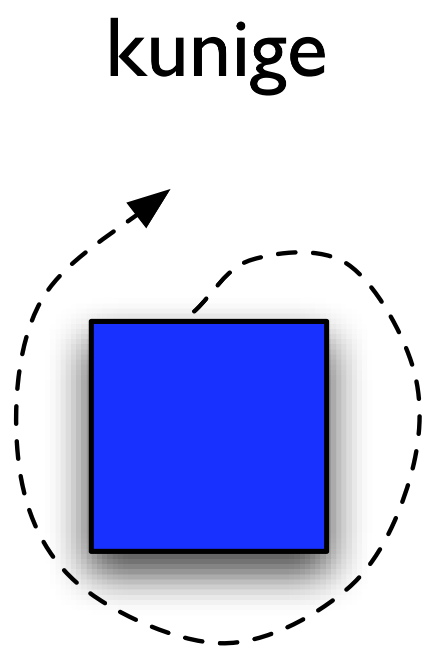
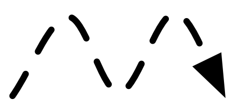
- Sample of output on test used as input language for next participant



Example initial language

lumonamo	kinahune	lahupine	□
nelu	kanehu	namopihu	○
kapihu	humo	lahupiki	△
moki	luneki	lanepi	□
kalu	mola	pihukimo	○
nane	kalakihu	mokihuna	△
kilamo	kahuki	neluka	□
pilu	neki	pinemohu	○
luki	namola	lumoka	△

Example final language
(10 “generations” later)

	n-ere-ki	l-ere-ki	renana	□
	n-ehe-ki	l-aho-ki	r-ene-ki	○
	n-eke-ki	l-ake-ki	r-ahe-ki	△
	n-ere-plo	l-ane-plo	r-e-plo	□
	n-eho-plo	l-aho-plo	r-eho-plo	○
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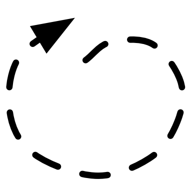
	n-e-pilu	l-ane-pilu	r-e-pilu	□
	n-eho-pilu	l-aho-pilu	r-eho-pilu	○
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- Compressible, compositional languages emerge
  - Dependent on bottleneck
- Adaptation driven by cultural evolution *not* intentional design by participants
  - Likely to be true for real language too

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- Revealed problems with previous fundamentals of linguistic explanation
- Suggests a way of thinking of culture itself as a computational system
- Future research question:
how general/powerful is cultural computation?