The Language Organism
Lecture 3: Evolving innate signalling systems

Simon Kirby

simon@ling.ed.ac.uk

Recap on signalling and communication

Recap on signalling and communication

- Computational models allow us to bridge between theory and prediction for understanding complex dynamic systems with many interacting components

Recap on signalling and communication

- Computational models allow us to bridge between theory and prediction for understanding complex dynamic systems with many interacting components
    - Or they allow us to play with those systems and figure out how they work

Recap on signalling and communication

- Computational models allow us to bridge between theory and prediction for understanding complex dynamic systems with many interacting components
    - Or they allow us to play with those systems and figure out how they work
- First example: communication in animals with innate signalling systems

Recap on signalling and communication

- Computational models allow us to bridge between theory and prediction for understanding complex dynamic systems with many interacting components
    - Or they allow us to play with those systems and figure out how they work
- First example: communication in animals with innate signalling systems

- Treat signalling system as a mapping between a fixed set of *meanings* and a fixed set of *signals*

Recap on signalling and communication

- Computational models allow us to bridge between theory and prediction for understanding complex dynamic systems with many interacting components
    - Or they allow us to play with those systems and figure out how they work
- First example: communication in animals with innate signalling systems

- Treat signalling system as a mapping between a fixed set of *meanings* and a fixed set of *signals*
- Modelled as (innately-determined) matrices of weighted associations

Recap on signalling and communication

- Computational models allow us to bridge between theory and prediction for understanding complex dynamic systems with many interacting components
    - Or they allow us to play with those systems and figure out how they work
- First example: communication in animals with innate signalling systems

- Treat signalling system as a mapping between a fixed set of *meanings* and a fixed set of *signals*
- Modelled as (innately-determined) matrices of weighted associations
- Different matrices give different production and reception behaviours

Recap on signalling and communication

- Computational models allow us to bridge between theory and prediction for understanding complex dynamic systems with many interacting components
    - Or they allow us to play with those systems and figure out how they work
- First example: communication in animals with innate signalling systems

- Treat signalling system as a mapping between a fixed set of *meanings* and a fixed set of *signals*
- Modelled as (innately-determined) matrices of weighted associations
- Different matrices give different production and reception behaviours
- Communicative accuracy for a speaker and hearer can be defined as the proportion of utterances where hearer converges on same meaning as speaker

Comments on the worksheets

Where do these signalling matrices come from?

Where do these signalling matrices come from?

- If they are innately specified, they are somehow the result of the organism's genes

Where do these signalling matrices come from?

- If they are innately specified, they are somehow the result of the organism's genes

- How would an organism end up with a set of genes that gives them a good communicative accuracy score?

Where do these signalling matrices come from?

- If they are innately specified, they are somehow the result of the organism's genes

- How would an organism end up with a set of genes that gives them a good communicative accuracy score?

- **Theory**: natural selection will give us organisms with genes that specify signalling systems which have high communicative accuracy

Where do these signalling matrices come from?

- If they are innately specified, they are somehow the result of the organism's genes

- How would an organism end up with a set of genes that gives them a good communicative accuracy score?

- **Theory**: natural selection will give us organisms with genes that specify signalling systems which have high communicative accuracy

- But can we be sure this is right?

- We need to model it...

Where do these signalling matrices come from?

- If they are innately specified, they are somehow the result of the organism's genes

- How would an organism end up with a set of genes that gives them a good communicative accuracy score?

- **Theory**: natural selection will give us organisms with genes that specify signalling systems which have high communicative accuracy

- But can we be sure this is right?

- We need to model it...

- ...but first, some basic theory

Evolution by natural selection: preconditions

- Favourable heritable traits become more common over time, due to differential reproduction

- Three conditions:

  - Variation

  - Heredity

  - Selection

Variation

Variation

Variation

Variation

- different bodies
- different properties
- different abilities
- different phenotypes

Heredity

- These traits are passed on from parent to offspring

Selection

- Not all traits are equal
- Some traits improve your chances of passing those traits on, some don’t
- Differential reproduction
- “The difference that makes a difference”

Evolution by natural selection, adaptation and the appearance of design

Evolution by natural selection, adaptation and the appearance of design

- Through this process, organisms tend to become well-suited to the pressures that operate on them
    - Relatively good at finding food, avoiding predators, attracting mate(s), rearing young, communicating, ...

Evolution by natural selection, adaptation and the appearance of design

- Through this process, organisms tend to become well-suited to the pressures that operate on them
    - Relatively good at finding food, avoiding predators, attracting mate(s), rearing young, communicating, ...

- This is adaptation
    - "'design' in life - those properties of living things that enable them to survive and reproduce in nature." (Ridley, 1996, p. 5)

Modelling evolution

Modelling evolution

- Many ways of modelling evolution. One approach: *genetic algorithms* (see reading - Mitchell, 1998)

Modelling evolution

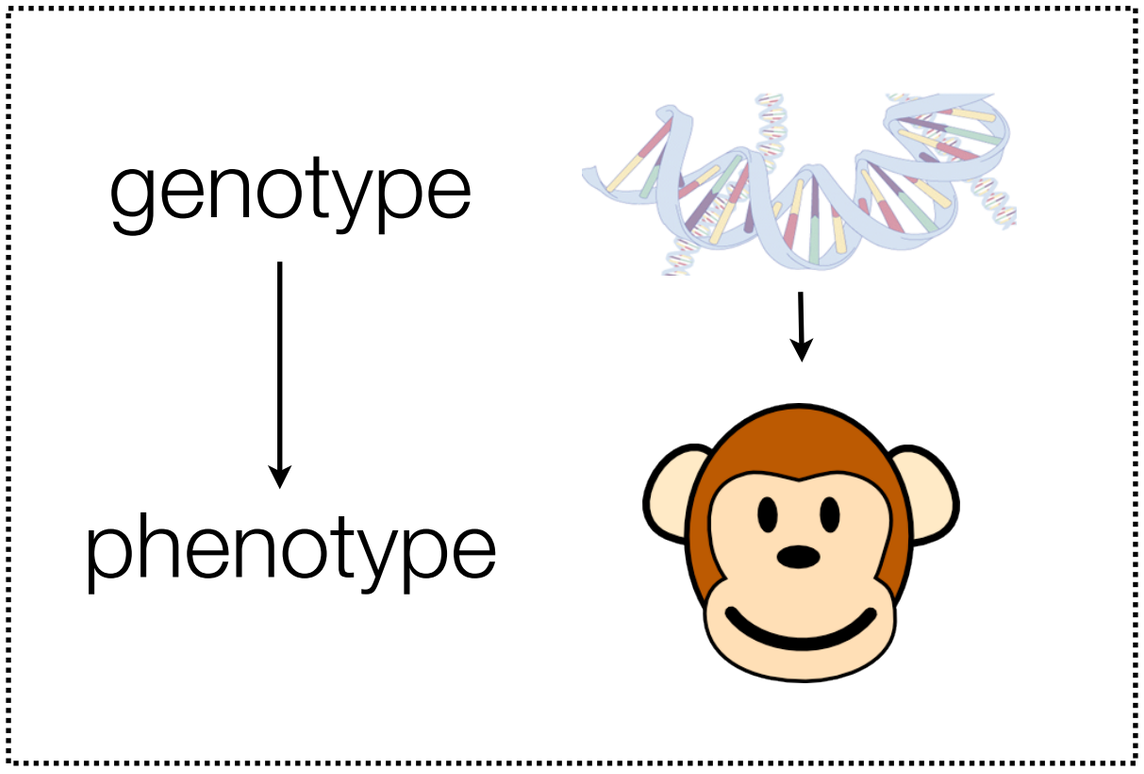
- Many ways of modelling evolution. One approach: *genetic algorithms* (see reading - Mitchell, 1998)

- Key ingredients:

Modelling evolution

- Many ways of modelling evolution. One approach: *genetic algorithms* (see reading - Mitchell, 1998)

- Key ingredients:



Modelling evolution

- Many ways of modelling evolution. One approach: *genetic algorithms* (see reading - Mitchell, 1998)

- Key ingredients:

1. A population of organisms
2. A task they are trying to succeed at
3. A measure of how *fit* they are at this task
4. A way of selecting the fittest
5. A way of allowing the genes of the fittest to survive
6. A mechanism for introducing variation into the gene pool

Our model

Our model

- Simplify things a bit: Treat genes and phenotype as equivalent and get rid of sex

Our model

- Simplify things a bit: Treat genes and phenotype as equivalent and get rid of sex

- The simulation:

Our model

- Simplify things a bit: Treat genes and phenotype as equivalent and get rid of sex

- The simulation:

    1. Create a population of random signal matrices

Our model

- Simplify things a bit: Treat genes and phenotype as equivalent and get rid of sex

- The simulation:

    1. Create a population of random signal matrices
    2. Assess each member of population for fitness

Our model

- Simplify things a bit: Treat genes and phenotype as equivalent and get rid of sex

- The simulation:

    1. Create a population of random signal matrices
    2. Assess each member of population for fitness
    3. Pick a parent based on fitness

Our model

- Simplify things a bit: Treat genes and phenotype as equivalent and get rid of sex

- The simulation:

    1. Create a population of random signal matrices
    2. Assess each member of population for fitness
    3. Pick a parent based on fitness
    4. Copy parent (with chance of mutation) to create new offspring

Our model

- Simplify things a bit: Treat genes and phenotype as equivalent and get rid of sex

- The simulation:

    1. Create a population of random signal matrices
    2. Assess each member of population for fitness
    3. Pick a parent based on fitness
    4. Copy parent (with chance of mutation) to create new offspring
    5. Do 3 & 4 enough times to come up with a new population that's the same size as the old one

Our model

- Simplify things a bit: Treat genes and phenotype as equivalent and get rid of sex

- The simulation:

  1. Create a population of random signal matrices
  2. Assess each member of population for fitness
  3. Pick a parent based on fitness
  4. Copy parent (with chance of mutation) to create new offspring
  5. Do 3 & 4 enough times to come up with a new population that's the same size as the old one
  6. Replace old population with new one

Our model

- Simplify things a bit: Treat genes and phenotype as equivalent and get rid of sex

- The simulation:

1. Create a population of random signal matrices
2. Assess each member of population for fitness
3. Pick a parent based on fitness
4. Copy parent (with chance of mutation) to create new offspring
5. Do 3 & 4 enough times to come up with a new population that's the same size as the old one
6. Replace old population with new one
7. Repeat steps 2 to 6 many times

Main research question

Main research question

- Under what conditions will we see the emergence of “optimal” communication systems? (i.e. when will we see a stable population of agents in which any pair of agents would have a communicative accuracy of 1.0)

Main research question

- Under what conditions will we see the emergence of “optimal” communication systems? (i.e. when will we see a stable population of agents in which any pair of agents would have a communicative accuracy of 1.0)

- Main parameter: *how do we assess fitness?*

- **What is the *fitness function*?**

Main research question

- Under what conditions will we see the emergence of “optimal” communication systems? (i.e. when will we see a stable population of agents in which any pair of agents would have a communicative accuracy of 1.0)

- Main parameter: *how do we assess fitness?*

- **What is the *fitness function*?**

- Key considerations:

  How do you pick communicative partners?
  Who gets rewarded for successful communication?

Main research question

- Under what conditions will we see the emergence of “optimal” communication systems? (i.e. when will we see a stable population of agents in which any pair of agents would have a communicative accuracy of 1.0)

- Main parameter: *how do we assess fitness?*

- **What is the *fitness function*?**

- Key considerations:

  How do you pick communicative partners?
  Who gets rewarded for successful communication?

- Find out answers by running simulations (and in the reading - Oliphant, 1996)

Readings

- Oliphant, M. (1996) The dilemma of Saussurean communication. *Biosystems*, 37:31-38

- Mitchell, M. (1998) An introduction to genetic algorithms. pp. 1-16.