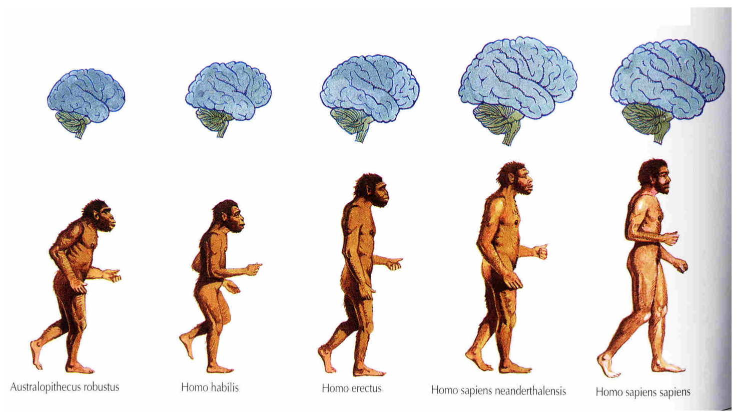

Brain-Culture Coevolution

Facilitating Factors in the Autocatalytic Evolution of Cultural Complexity and Brain Size

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a place of mind

Summary

Brains and culture can exert selection pressures on each other under a number of conditions. We explore the effects of fecundity, learning biases, mitigated metabolic costs, migration rate, genetic mutation rate, and individual learning.

Introduction

During the Pleistocene, the human brain more than doubled in size. Researchers from many different disciplines have proposed various hypotheses to explain this expansion. In light of recent work showing the selection pressures that culture can exert on genes, we present a gene-culture coevolution model that demonstrates some of the conditions under which increased adaptive complexity can exert a selection pressure for larger brains, which in turn could support and exert a selection pressure for increased adaptive complexity. We demonstrate that individual learning is not essential and show how differential fecundity, evolved learning biases, mitigated metabolic costs, and migration can support this autocatalytic process, even with low mutation rates (10^{-6}).

Functions

Let:

N_0 = current subpopulation size

m = minimum subpopulation size

c = mean subpopulation culture

r = generational growth rate

b_i = individual brain size

c_i = individual adaptive complexity sum

Carrying Capacity

$k = m * ln\,(c + 1) + m$

Number of children

$N = N_0 + rN_0\left(1 - \frac{N_0}{k}\right)$

Death rate

$$d(\lambda, b_i, c_i) = \begin{cases} b_i = 0 & 0 \\ b_i > 0 & \frac{b_i}{100} * e^{\left(-\lambda * \frac{c_i}{b_i}\right)} \end{cases}$$

Method

Set up population with initial conditions.

Simulation

BIRTH: **foreach** *Subpopulation* **do**
- Calculate number of children
- **foreach** *Child* **do**
  - Randomly assign to parent with probability $\text{culture}_{\text{parent}}^{\text{fecundity power}}$
  - **if** *Random* < *Brain Mutation Probability* **then**
    - $brain_{\text{child}} \leftarrow brain_{\text{parent}} \pm brainMutation$
  - **else**
    - $brain_{\text{child}} \leftarrow brain_{\text{parent}}$

LEARNING: **foreach** *Subpopulation* **do**
- **foreach** *Child* **do**
  - Child randomly selects person to learn from with probability $\text{culture}_{\text{adult}}^{\text{learning bias power}}$
  - **foreach** *min(Child brain slot, Adult brain slot)* **do**
    - $brain_{\text{child}} \leftarrow$ random from $normal[\mu =$ parent value$, \sigma = 0.01]$
  - Child learns remaining brain slots from self for individual learning
  - Child population replaces adult;

MIGRATION: **foreach** *Subpopulation* **do**
- **foreach** *Individual* **do**
  - Move to a different subpopulation Migration probability

SELECTION: **foreach** *Subpopulation* **do**
- **foreach** *Individual* **do**
  - **if** *Random* < *d(λ,brain,culture)* **then**
    - Kill individual

References

Laland, K., Odling-Smee, J., and Myles, S. (2010). How culture shaped the human genome: bringing genetics and the human sciences together. *Nature Reviews Genetics*, 11(2):137–148.

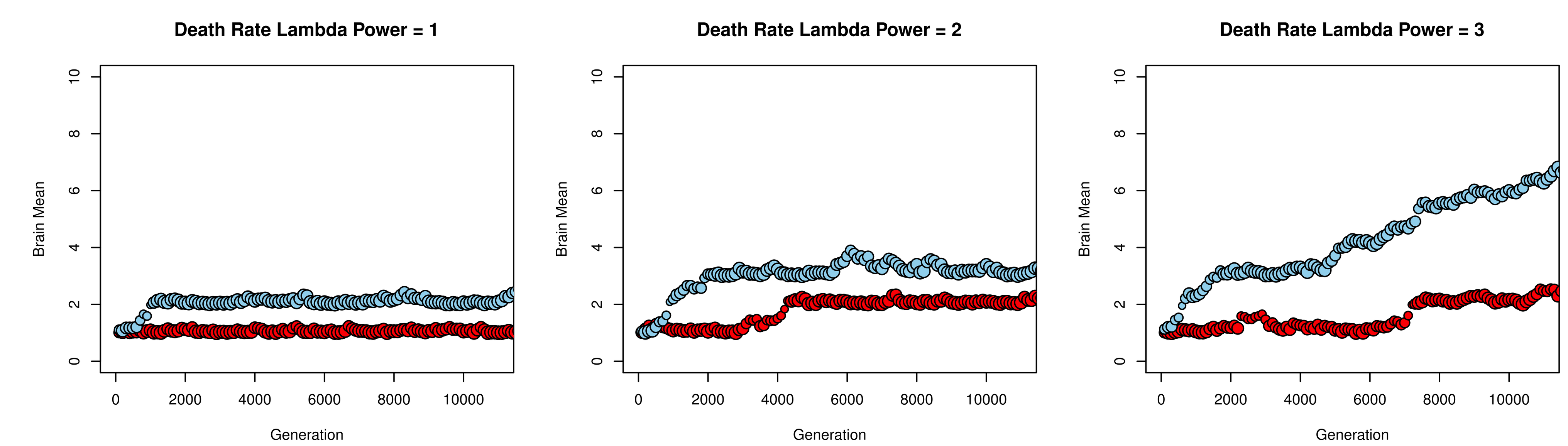
Mesoudi, A. (2011). Variable cultural acquisition costs constrain cumulative cultural evolution. *PLoS ONE*, 6(3):e18239.

Premo, L. S. and Kuhn, S. L. (2010). Modeling effects of local extinctions on culture change and diversity in the paleolithic. *PLoS ONE*, 5(12):e15582.

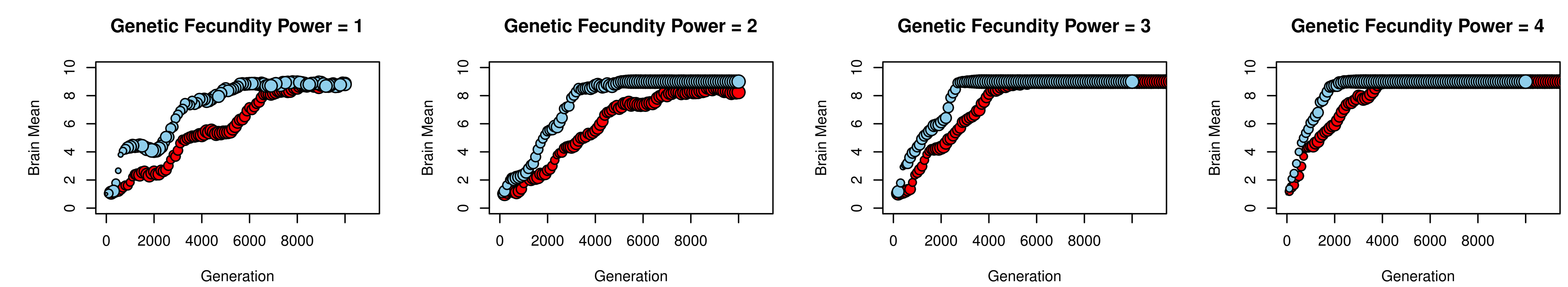
Results

Note. The radius of each circle in the graph indicates the ratio of mean adaptive complexity to mean brain size in the population. A larger circle indicates a larger ratio. Red circles do not have individual learning. Blue circles have individual learning.

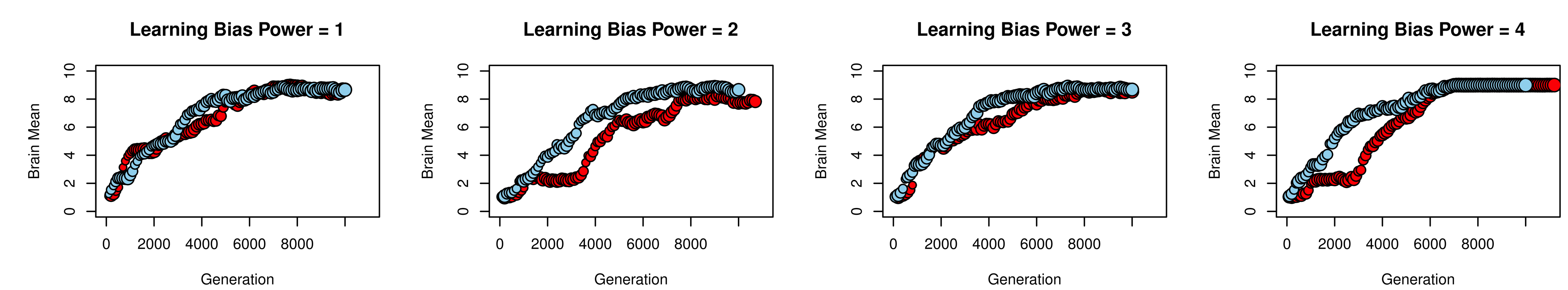
Effect of mitigated metabolic cost. To simulate an increasing metabolic cost, the death rate rises by 1% with each brain slot increase. Increasing the death rate λ increases the extent to which adaptive complexity can mitigate the metabolic cost. We could not demonstrate coevolution with a very large incremental brain cost or not enough of a brain cost difference for adaptive complexity to matter.



Effect of fecundity. As the relationship between adaptive complexity and number of children increases, the rate of coevolution increases. The effect of fecundity is larger than the effect of learning bias. The figures below control for selection to test the effects of fecundity.



Effect of learning bias. As the relationship between adaptive complexity and number of children who are learning from you increases, the rate of coevolution increases. This effect is not as large as fecundity. The figures below control for selection to test the effects of learning bias.



Effect of migration rate. Some migration necessary. Additional migration has little or no effect.

Effect of individual learning. Individual learning increases the rate of brain-culture coevolution. However, learning bias and fecundity parameter results indicate that it may not affect the final equilibrium. The effect of individual learning on the mitigated metabolic cost parameter is less clear since the model did not reach equilibrium in less than 15000 generations. Further investigation is required.

Conclusions and Future Plans

Our results indicate that brain-culture coevolution can be autocatalytic if increased adaptive complexity mitigates brain metabolic costs and/or increases an individual's chances of reproduction. Preliminary results suggest that learning biases play a role in increasing the rate of brain-culture coevolution. Crucially, our results indicate coevolution can occur without individual learning. Individual learning affects the rate of co-evolution, but its effect on equilibria is unclear. Our immediate plan is to map out interactions and boundary conditions in the parameter space. We will then explore the evolution of learning biases and further explore individual learning. Finally, we will explore how population dynamics (e.g. Premo and Kuhn, 2010) and constraints on cultural evolution (e.g. Mesoudi, 2011) affect brain-culture coevolution.