Simulating score distribution of vervet monkey populations using linear continuous-time branching process

Ying Tan, with Le Zeng, supervised by Sophie Hautphenne

The University of Melbourne

Motivation

Dominance hierarchy is common in many animal populations, including vervet monkeys (*Chlorocebus pygerythrus*). Under such conditions, a higher ranked individual gets access to more resources and mating opportunities. Female ranks depend on kinship at birth and can be later elevated or downgraded as a result of conflicts [1]. A continuous-time branching process is used to simulate the evolution of score distribution of female monkeys.

Model

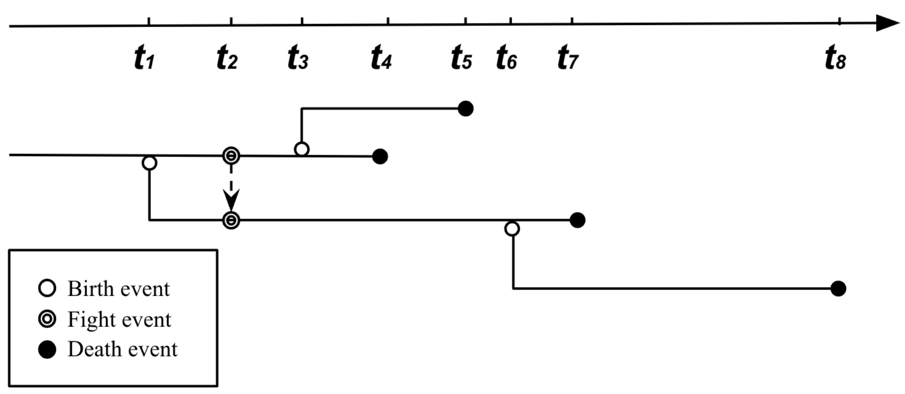

Figure 1. An illustration of the continuous-time model

Birth event:
- $\lambda_1, \lambda_2, \lambda_3$: birth rates for monkeys in rank 1 (low), 2 (mid) and 3 (high)

Death event:
- μ_1, μ_2, μ_3: death rates for monkeys in rank 1 (low), 2 (mid) and 3 (high)

Fight event:
- φ_1, φ_2 and φ_3 denote the fight rates for monkeys in rank 1, 2 and 3 respectively
- A monkey initiates a fight, selected based upon the fight rates of all individuals. The opponent is then selected based on **f** (*fighting probability*) of all pairs (with the initiator) in the population.
- The outcome is modelled by a Bernoulli trial with the parameter $\mathbf{p_{initiator}}$ (*winning probability of the initiator*).
- The elo-ratings* of both monkeys are updated accordingly.

$$RatingDifference = RenormalisedRating_{opponent} - RenormalisedRating_{initiator}$$

$$f = \frac{1}{1 + 10^{|RatingDifference|}} \qquad p_{initiator} = \frac{1}{1 + 10^{RatingDifference}}$$

Elo-rating [2]:

Assumption: daughters inherit the ratings of mothers at birth
- k = 100 (a constant that defines the score increments after a fight)
- p is the *winning probability of the higher-rated individual*

Higher-rated individual wins:

$$WinnerRating_{new} = WinnerRating_{old} + (1-p)\times k$$
$$LoserRating_{new} = LoserRating_{old} - (1-p)\times k$$

Lower-rated individual wins:

$$WinnerRating_{new} = WinnerRating_{old} + p\times k$$
$$LoserRating_{new} = LoserRating_{old} - p\times k$$

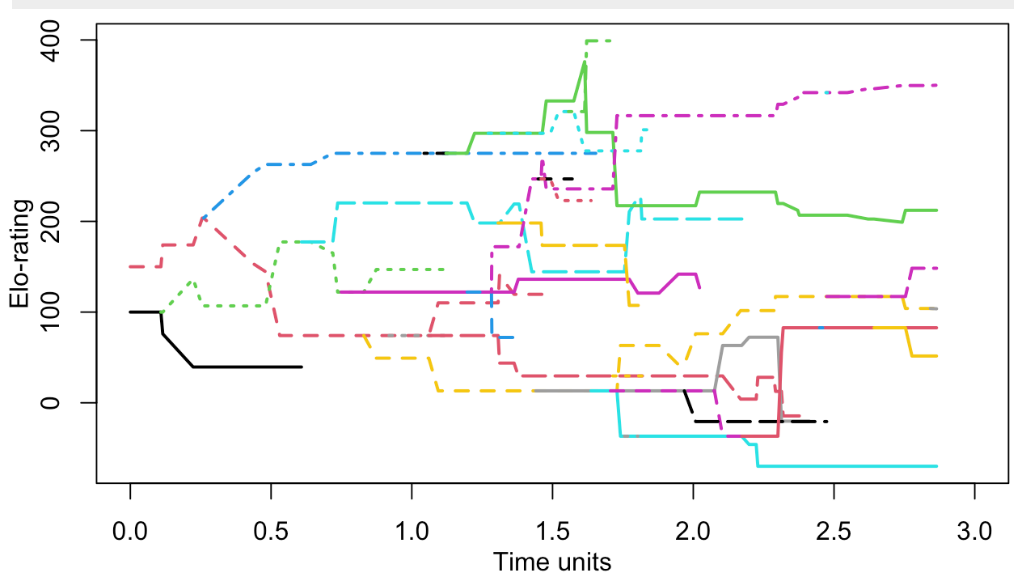

Figure 2. The evolution of elo-ratings of monkey population in a single simulation, starting population = 2, starting ratings = (100, 150), φ1 = 1, φ2 = 2, φ3 = 3

Results

Rank classification:
- Based on percentiles of elo-ratings: the top 1/3 classified as rank 3 (high), middle 1/3 as rank 2 (middle), bottom 1/3 as rank 1 (low).

Fixed parameters:
- $\lambda_1 = 1.5$, $\lambda_2 = 1.3$, $\lambda_3 = 1.8$ (extracted from dataset of vervet monkeys in South Africa since 2010)
- $\mu_1 = 1.2$, $\mu_2 = 1.1$, $\mu_3 = 1.1$ (set to achieve an almost critical model)

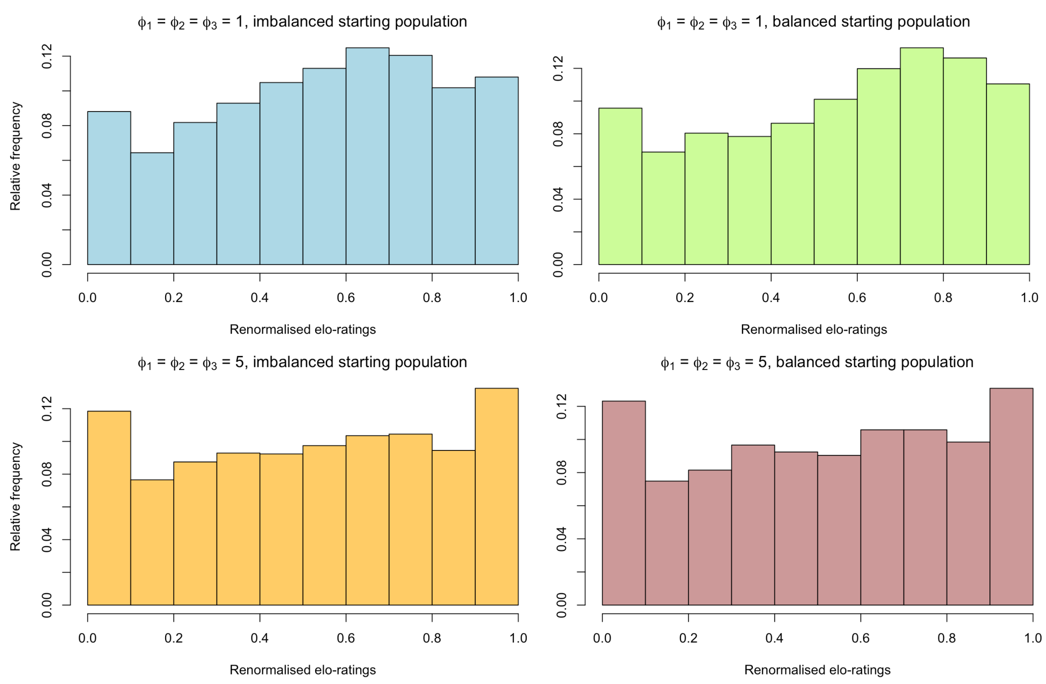

Figure 3. The distribution of elo-ratings of monkey populations with different initial configurations at the end of time unit 5, starting population = 6, of 500 simulation trials. Balanced renormalised ratings = (0, 0.2, 0.4, 0.6, 0.8, 1). Imbalanced renormalised ratings = (0, 0, 0, 0, 0, 0).

Observations:
- Generally, the scores tend towards the higher values.
- Populations with a higher fight rate tend to produce more uniformly distributed scores.
- However, the simulations end in 5 time units, meaning that long-term behaviours cannot be observed from the graphs.

Interpretation:
- Peak frequency towards the higher end: high-ranked monkeys give births to more children (born with high ratings), low fight rates enhance this pattern, given infrequent changes in scores.
- Small peaks at the extremes ($\varphi_1 = \varphi_2 = \varphi_3 = 5$): smaller population sizes by the end of time unit 5, hence relatively more frequent ratings of 0 and 1 (since these ratings exist in every trial).

Extensions

Photograph: by Bernard Dupont, distributed under a CC BY-SA 2.0 license

- To fit the model using real-life dataset to study the dynamics of population sizes.
- Introduce settings that closely mimic realistic behaviours in monkey population. E.g. fight events followed by the potential death of the loser.
- Track and compare the ratings and population sizes between different monkey families.

References

[1] L. A. Fairbanks and M. McGuire. Age, reproductive value, and dominance-related behaviour in vervet monkey females: cross-generational influences on social relationships and reproduction. Anim. Behav., 34(6):1710–1721, 1986.

[2] C. Neumann et al. Assessing dominance hierarchies: validation and advantages of progressive evaluation with Elo-rating.Anim. Behav., 82(4):911–921, 2011.