Supplementary information

From disorganised equality to efficient hierarchy:

How group size drives the evolution of hierarchy

in human societies

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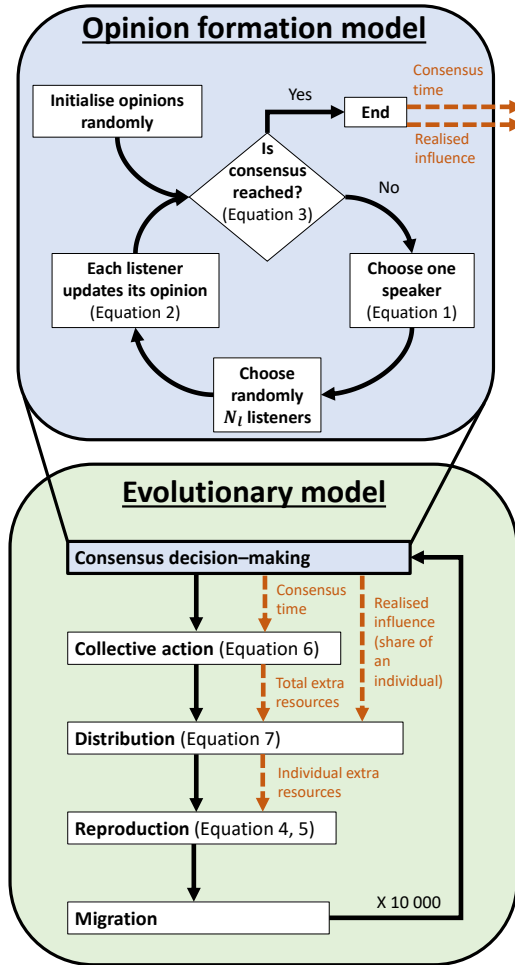
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Figure 1: Diagrams representing the opinion formation model (top) and the life cycle of the evolutionary model (bottom). A box represents a process. A diamond represents a condition. The black arrows show the next step. The dashed orange arrows represent the important variables that feed in a process or result from a process. For instance, the distribution of resources depends (i) of the realised influence of an individual and the total extra resources, and (ii) provides the amount of individual extra resources. The consensus decision-making in the life cycle of the evolutionary model is described by the opinion formation model represented on the top.
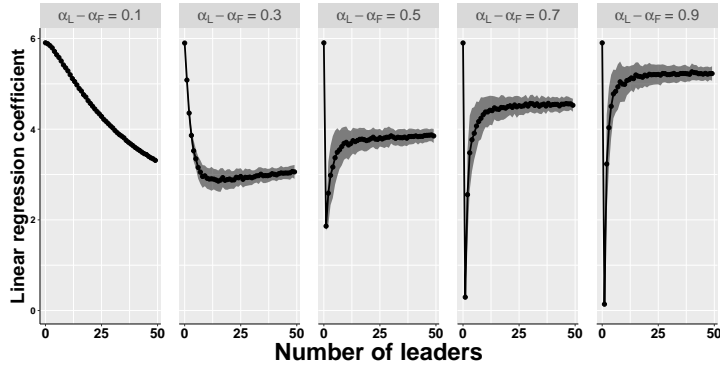
Figure 2: Scalar stress measured by the linear regression coefficient (slope) of consensus time on group size as a function of number of leaders and difference of influence between leaders and followers. The influence of leaders and followers are symmetric around 0.5, e.g. a difference of influence of 0.3 means $\alpha_{\mathrm{L}} = 0.65$ and $\alpha_{\mathrm{F}} = 0.35$. We note that the relation between consensus time and group size is not perfectly linear for a small number of leaders and thus, the coefficient estimated is slightly off. However, the relation is close to linear, and so the regression coefficient qualitatively aids understanding the results. 100 independent replicates have been realised for each group size and social organisation. The ribbons represent the standard deviation across replicates. The parameters used are $N_{\mathrm{l}} = 30$ and $x_{\theta} = 0.05$. The group sizes considered for the replicated simulations are from 50 to 1000 with an increment of 50.
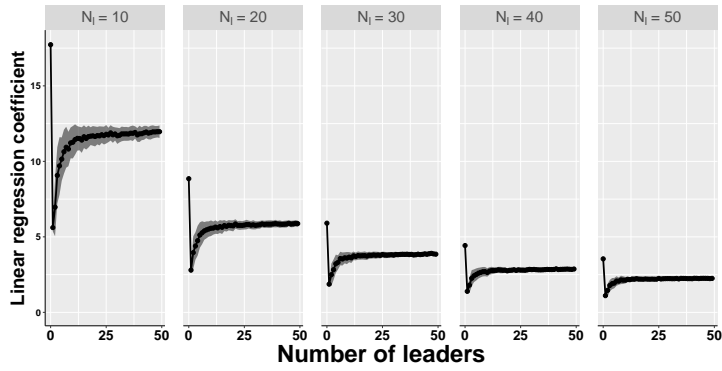
Figure 3: Scalar stress measured by the linear regression coefficient (slope) of consensus time on group size as a function of numbers of leaders and the number of listeners N_l. 100 independent replicates have been realised for each group size and social organisation. We note that the relation between consensus time and group size is not perfectly linear for a small number of leaders and thus, the coefficient estimated is slightly off. However, the relation is close to linear, and so the regression coefficient qualitatively aids understanding the results. The ribbons represent the standard deviation across replicates. The parameters used are $\alpha_L = 0.75$, $\alpha_F = 0.25$ and $x_\theta = 0.05$. The group sizes considered for the replicated simulations are from 50 to 1000 with an increment of 50.
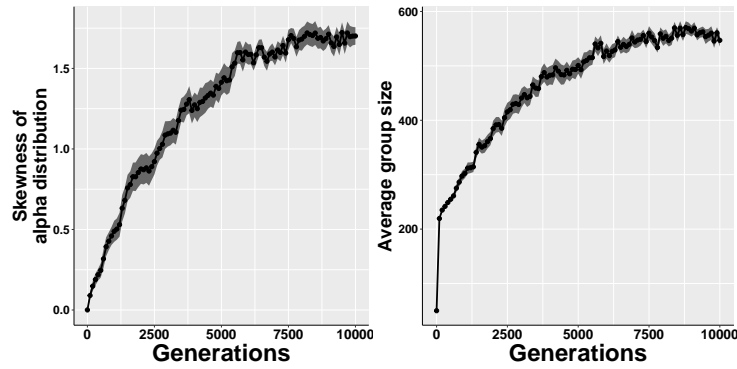
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Figure 4: Evolution of the average skewness of distribution of influence α and the average group size as a function of generations in the absence of intergenerational transmission of resources ($S = 0$). Reducing the transmission of resources also decreases the total amount of resources available. To distinguish the effect of the transmission of resources from a decrease of resources produced, we maintain the amount of resources produced to be the same value than simulations with $S = 0.9$, by multiplying the total amount of resources produced $B_j(t)$ by 1.9. The values presented are the average across 32 replicates. The error bars represent the standard error from the mean between replicates.
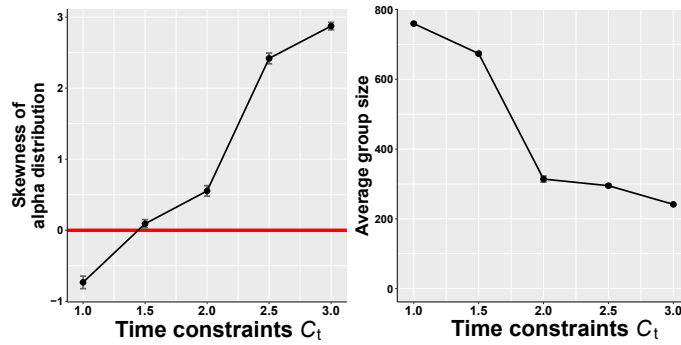
Figure 5: Average value of Pearson's moment coefficient of skewness of the distribution of influence α and average group size across 5000 generations and across 32 replicates as a function of the time constraints on group organisation C_t. The simulations are run for 10000 generations and the first 5000 generations are ignored to limit the effects of initial conditions. The error bars represent the standard error from the mean between replicates.
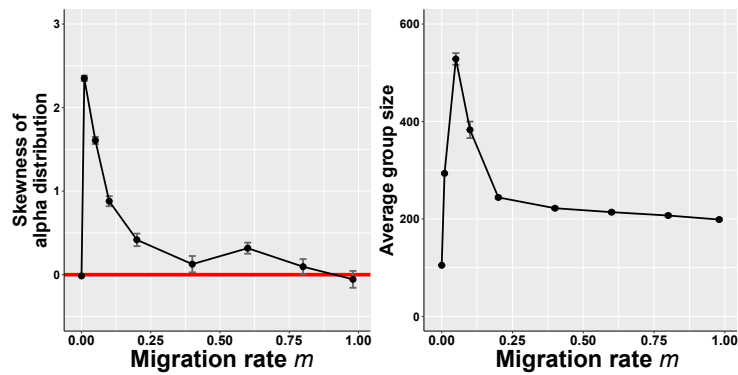
Figure 6: Average value of Pearson's moment coefficient of skewness of the distribution of influence α and average group size across 5000 generations and across 32 replicates as a function of migration rate m.The time constraints on group organisation is moderate $C_t = 2$. The parameter ranges from $m = 0$ i.e. each group is independent to $m = 1 - \frac{1}{N_p}$ i.e. a well-mixed population. The simulations are run for 10000 generations and the first 5000 generations are ignored to limit the effects of initial conditions. The error bars represent the standard error from the mean between replicates.
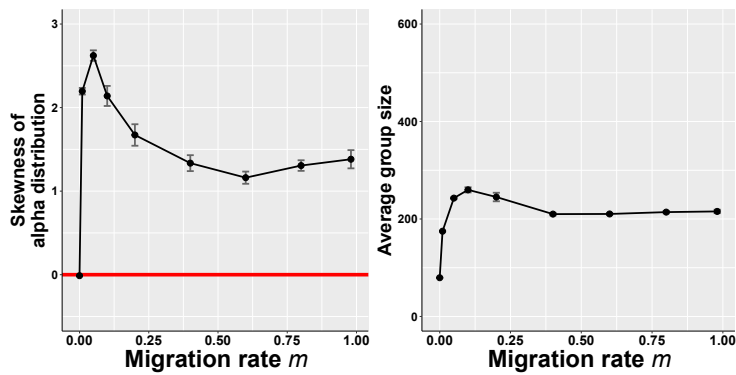
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Figure 7: Average value of Pearson's moment coefficient of skewness of the distribution of influence α and average group size across 5000 generations and across 32 replicates as a function of migration rate m. The time constraints on group organisation is high $C_{\text{t}} = 3$. The parameter ranges from $m = 0$ i.e. each group is independent to $m = 1 - \frac{1}{N_p}$ i.e. well-mixed population. The simulations are run for 10000 generations and the first 5000 generations are ignored to limit the effects of initial conditions. The error bars represent the standard error from the mean between replicates.