Eco-phenotypic physiologies: a new kind of modeling for unifying evolution, ecology and cultural transmission

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We propose a mathematical framework of formal relations general enough to be applicable in:
- biology (ecology and evolutionary biology)
- cultural transmission (economics)

We are interested in modeling some biological concepts we will call “eco-phenotypic concepts”:

Development, plasticity, reaction norm, phenotypic heritability, epigenetics, and niche construction.
Consider a population composed at each time of $N_t$ agents and a set of resources $R_t$

A Physiology is an algorithm that defines the resource management behavior of the agent.

- the resources needed by the agent for the basic survival $\tilde{M}^i$
- the efficiency is the resource extraction $\alpha^i$
- the efficiency of their use $\beta^i$
- the agent’s resource intake target $G^i_t$

$$\bar{P}_t^i = (\tilde{M}^i_t, \alpha^i, \beta^i, G^i_t)$$ (1)
Environment

All the elements of the world and of the population that are not part of the agent.

- the resources $R_t$ that are available to the population.
- The number of agents $N_t$
- the vector of all the other agents’ physiologies $\bar{P}^{-i}_t$

$$\bar{E}^i_t = (R_t, N_t, \bar{P}^{-i}_t)$$ (2)
Resource extraction

\[ \sum_i R^i_t \leq R_t \]

- own resource intake target \( G^i_t \),
- others’ resource intake targets \( G^{-i}_t \),
- the vector of all extraction efficiencies \( \tilde{\alpha} \)

\[ \tilde{R}^i_t = (R_t, G^i_t, G^{-i}_t, \tilde{\alpha}) \]  \hspace{1cm} (3)

Notice that if \( R^i_t < \tilde{M}_t^i \) then the agent dies.
each male with physiology $i$, that extracted $R^i_t$ is matched with a female of physiology $j$ that extracted $R^j_t$.

$\gamma_{ij}^t$ the share of $R^i_t$ that an agent of physiology $i$ in a $ij$ matching devotes to own subsistence and $(1 - \gamma_{ij}^t)$ the share devoted for offspring production.

$$N_{t+1}^{ij}(R^i_t, R^j_t, \gamma^i_t, \gamma^j_t)$$  (4)
Niche construction and Resource Regeneration

\[ R_{t+1} = (R_t - \sum_i R_t^i)(1 + \lambda) \]

if individuals resource extraction and physiologies are *niche constructing* then \( \lambda_t(\bar{R}_t) \) so that

\[ R_{t+1} = (R_t - \sum_i R_t^i)(1 + \lambda_t(\bar{R}_t)) \]  

(5)
Reaction Norms and the New Generation’s Physiology (I)

Reaction norm: dictates how to use or not use information from the environment and from parental physiologies as cues to form a new physiology.

The reaction norm $X^i_{t+1}$ accepts as inputs
- the resources the new generation faces $R_{t+1}$
- the parental physiologies $P^i_t$ and $P^j_t$
- the physiologies agents in new generation meet during their formation process $\bar{P}_t$

$$P^i_{t+1} = X^i_{t+1}(R_t, P^i_t, P^j_t, \bar{P}_t) \quad (6)$$
Reaction Norms and the New Generation’s Physiology (II)

\[ P_{t+1}^i = X_{t+1}^i(R_t, P_t^i, P_t^j, \bar{P}_t) \]

- with probability \( p_{ij}^t \) the new individual born from matching \( ij \) takes \( i \)'s reaction norm \( X_{t+1}^i = X_t^i \)
- with probability \( 1 - p_{ij}^t \) the new individual born from matching \( ij \) takes \( j \)'s reaction norm \( X_{t+1}^i = X_t^j \).
Summing up the framework

- **Physiology:** \( \bar{P}_t^i = (\tilde{M}_t^i, \alpha^i, \beta^i, G_t^i) \)
- **Environment:** \( \bar{E}_t^i = (R_t, N_t, \bar{P}_t^{-i}) \)
- **Resource Extraction:** \( \bar{R}_t^i = (R_t, G_t^i, G_t^{-i}, \bar{\alpha}) \)
- **Matching and Reproduction:** \( N_{t+1}^{ij} (R_t^i, R_t^j, \gamma_t^{ij}, \gamma_t^{ji}) \)
- **Niche construction and resource generation:** \( R_{t+1} = (R_t - \sum_i R_t^i)(1 + \lambda_t(\bar{R}_t)) \)
- **Reaction Norms and new physiology:** \( \bar{P}_{t+1}^i = X_{t+1}^i (R_t, P_t^i, P_t^j, \bar{P}_t) \)
Next Steps

- Fixing one reaction norm, studying how the shape of the different elements impact the dynamics of the population
- Compare the patterns of different reaction norms (adaptive and forward looking reaction norms)
- Make reaction norms compete (plasticity in most successful population, necessary feature for a reaction norm to survive, ... )