Optimal Mechanism to Adapt to Random Enviroments

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Abstract

Here we explore a model of the evolution of the phenotypes of a clonal population that develops in a fluctuating enviroment. It is a linear dynamical system where the matrix changes according to a random process. The relationship between this model and sequential learning is studied. More specifically, we draw attention to the long-term behavior of the number of cells with some phenotype and how it can be optimized sequentially using the Multiplicative Weight Updates algorithm - also called Boosting. This perspective describes Boosting as a model for the adaptation mechanims of the phenotypes.

Author summary

Introduction

There are several theories of how organisms survive in fluctuating enviromnts. Some rely in anticipatory behavior that depends on sensing changes [1]. A second type, describes phenotypic heterogeneity as an alternative when sensing is not possible [2]. In the second case heterogenity can be thought in three ways: as bet hedging, as a mixed strategy or as altruism. ***faltan cosas***

Here we study the model proposed in [2]:

$$x'(t) = A_{\epsilon(t)}x(t) \tag{1}$$

where x is an n-dimensional vector containing the number of cells with a certain phenotype; $\epsilon(t)$ is a random process that changes the matrix A over time and A_k is a matrix that represent the dynamics in enviroment k.

$$A_k = \begin{bmatrix} f_1^{(k)} + H_{11}^{(k)} & H_{12}^{(k)} & \cdots & H_{1n}^{(k)} \\ H_{21}^{(k)} & f_2^{(k)} + H_{22}^{(k)} & \cdots & H_{2n}^{(k)} \\ \vdots & \vdots & \ddots & \vdots \\ H_{n1}^{(k)} & H_{n2}^{(k)} & \cdots & f_n^{(k)} + H_{nn}^{(k)} \end{bmatrix} \tag{2}$$

The diagonal terms are such that pehontype k is favoured in enviroment k. The off-diagonal $H_{ij}^{(k)}$ terms quantify the infleunce phenotype j has in i during enviroment k.

Fluctuating Enviroments

The fluctuating enviroments are modelled by a Markov chain with m sates and with transition probabilites b_{ij}. We note p_j the probability of being in enviroment j.

The main result in [2] is a description of the long-time behaivior of the dynamics of model (1) in two regimes: sensing and phenotypic diversity. For the second regime the Lyapunov exponent takes the following form:

$$\tau\Lambda_s \approx \sum_i p_i \tau_i f_i^{(i)} + \sum_i p_i \tau_i H_{ii} - \sum_{i,j} p_j b_{ij} \log\left(1 + \frac{\Delta_{i,j}}{H_{i,j}}\right) \tag{3}$$

The first term of equation (3) is related to the fastest growing phenotypes. The second is some sort of diversity cost. The last term is a delay time cost that depends on $\Delta_{i,j} := 1/\delta_{i,j} + 1/\delta_{j,i}$ where $\delta_{i,j} := f_j^{(j)} - f_i^{(j)}$. This equation can be read from an optimization point of view in which each population with a particular phenotype tries to maximize:

$$J(H) := \sum_i p_i \tau_i f_i^{(i)} + \sum_i p_i \tau_i H_{ii} - \sum_{i,j} p_j b_{ij} \log\left(1 + \frac{\Delta_{i,j}}{H_{i,j}}\right) \tag{4}$$

by choosing the H_{ij}'s at each step. An algorithm that does this is a mechanism in which each phenotype adapts to the others, one step at a time, by maximizing the diversity of the total population while reducing the time it takes to adapt to a new enviroment.

The objective of this article is to describe such algorithm.

A Cooperation Game

Consider the following game. A player j has a set of possible actions A_j. At each turn, he chooses one. The are other that do as j does and adopt an action from their possible set of actions. For each of j's actions and the actions of the other players there is an utility function u_j that models j's well being in that situation. The question is how should

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Discussion

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Conclusion

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Supporting information

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