DYNAMIC ADAPTATION BEHAVIOR IN FLUCTUACTING ENVIRONMENTS IN BIOLOGICAL AND ECONOMICAL SYSTEMS

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The dynamic process of cellular differentiation and financial decisions depends on the architecture, quantitative parameters, and noise of underlying network structure. However, it remains unclear how these elements combine to control cellular and economical behavior . We analyzed how the network structure supports the dynamics of competence in *Bacillus subtilis* and one example of inversion decisions. In the biological case we analyzed the probabilistic differentiation of *Bacillus subtilis* cells into the state of competence. In the economical case we analyzed the dynamics of investment on public and private sectors. For the analysis we built a differential equation model for the genetic circuits of competence and for the investment network. Here we show that in the biological case, the entry into competence and return to vegetative growth can be understood in terms of excitability in the underlying genetic circuit on the other hand the economical system present two stable states being the noise in the interest parameter it regulates the transitions between the two states . Together, the data for the biological and economical systems reveal a noise-dependent network that is remarkably resilient and tunable in terms of its dynamic behavior.

INTRODUCTION

Upon encountering of fluctuacting environments in terms of markets or in the biological case nutrient limitation, exist several ways to choose. In the bacteria *B. subtilis* when it's changes occurs a minority cells become competent for DNA uptake while most commit irreversibly to sporulation (Fig. 1A) (1). The genetic basis for this behavior is a circuit involving comK and comS (Fig. 1B). The transcription factor ComK is necessary and sufficient for differentiation into competence (2, 4). ComK positively autoregulates its own expression but is degraded by the ClpPClpC-MecA protease complex (Fig. 1B) . ComS competitively inhibits this degradation and is repressed in competent cells, forming a negative feedback loop.

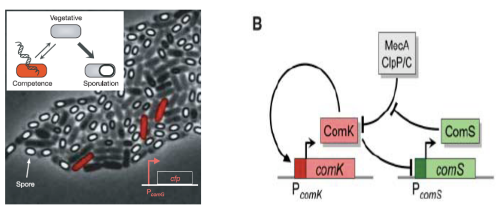


Fig 1. Competence is a probabilistic and transient differentiation process regulated by a genetic circuit.

OBJECTIVE

To understand how the network structure supports the dynamics of competence and inversion decisions.

BIOLOGICAL MODEL

Our model is a modification from the proposed by Suel *et al.*, 2006. This can be reduced to a system of two stochastic ordinary differential equations incorporating both the direct positive and the ComS-mediated negative feedback loops of ComK. In dimensionless form:

$$\frac{dK}{dt} = ak + \frac{bkK^n}{ko^n + K^n} - \frac{K}{1+K+S} - \gamma K \qquad \frac{dS}{dt} = \frac{bs}{1+\left(\frac{K}{k1}\right)^p} - \frac{S}{1+K+S} - \gamma S$$

Here, K and S represent the concentration levels of ComK and ComS protein, respectively. aK and bS represent minimal and fully activated rates of ComK production, respectively

RESULTS

Modeling of the core competence network reveals an excitable system.

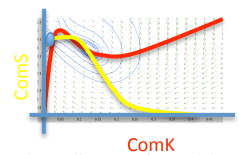


Fig 2. Phase plane diagram formed by the system of equations shown before. Nullclines for equations (1) and (2) are shown in red and yellow, respectively. Green arrows represent the vector field of the dynamical system. The stable steady-state corresponding to vegetative growth is indicated with a blue filled circle. The saddle and the unstable competent fixed points are indicated with open circles.

•To explore the effects of perturbing the parameters of the system

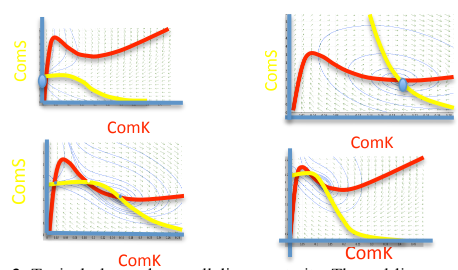


Fig. 3. Typical phase-plane nullclines portraits. The red line corresponds to the ComK nullclines, and the yellow line to the ComS nullclines. Furthermore, the filled black dots denote stable fixed points, and the empty ones correspond to unstable fixed points. Parameter values are the same in all cases, except: (A) bk = 0.08, bs = 0.68, (B) bk = 0.12, bs = 0.92, (C) bk = 0.14, bs = 0.68, and (D) bk = 0.08, bs = 0.8.

The vegetative state can be perturbed by noise

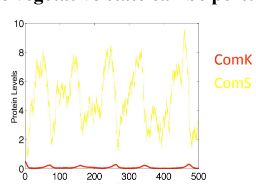
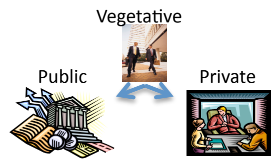


Fig. 4. Simulations of ComS (green) and ComK (blue) activities as a function of time. Note the negative correlation between the ComS and ComK levels during competence, consistent with experimental observations (1).

ECONOMICAL MODEL



$$\frac{dP}{dt} = \frac{B^2}{1+i*B} - aP \qquad \frac{dB}{dt} = \frac{i*P^2}{1+P} - bB$$

Fig 5. Dynamical investment decisions. P and B represent the amount of money in the private and public states respectively. I*i* is the interest rate defined by the central bank.

Modeling of the core investment decision network reveals an bistable system.

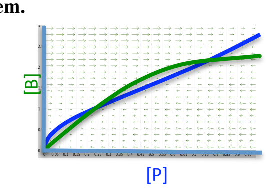


Fig 6. Phase plane diagram formed by the system of equations shown before. Nullclines for equations (3) and (4) are shown in blue and green, respectively. Green arrows represent the vector field of the dynamical system. The two stable steady-states corresponding to the two sectors, private and public. The saddle unstable sector fixed points are indicated with open circle.

CONCLUSIONS

We found that an excitable genetic core module containing positive and negative feedback loops can explain both entry into, and exit from, the competent state. (Fig. 2).

Excitable dynamics driven by noise naturally generate stochastic and transient responses, thereby providing an ideal mechanism for competence regulation.

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1. G. M. Suel et al., Nature 440, 545 (2006). / 2. R. M. Berka et al., Mol. Microbiol. 43, 1331 (2002). / 3. D. van Sinderen et al., Mol. Microbiol. 15, 455 (1995). 4. H. Maamar, D. Dubnau, Mol. Microbiol. 56, 615 (2005).