Surprising Range of Signal Detection by Amoebae

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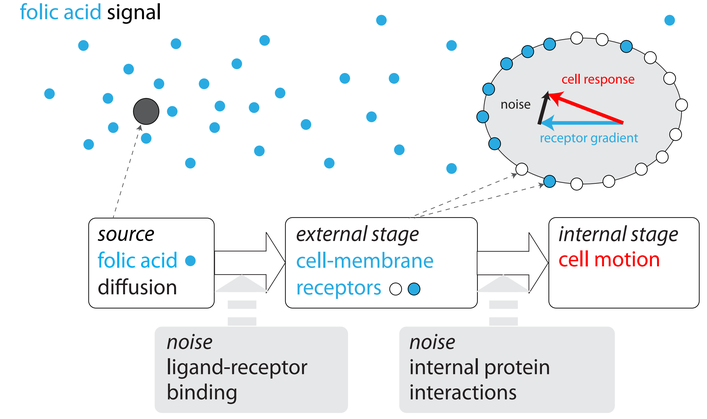
Summary

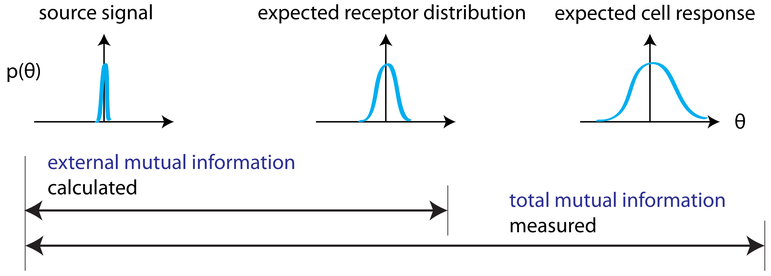
» We investigated the range of folic acid sensing by *Dictyostelium discoideum* (Dicty) amoebae.
» System was viewed as a Shannon's noisy communication channel, with two noise sources considered here:
  » external noise due to receptor-ligand binding kinetics, and
  » internal noise due to chemical reactions within the cell.
» The response was in the regime where, theoretically, the signal should be buried by external receptor-binding fluctuations alone.

Introduction

» We studied directed cell motion in chemical gradients (chemotaxis) in the case of Dicty amoebae inspired by the natural chemotaxis towards bacteria, following a folic acid signal

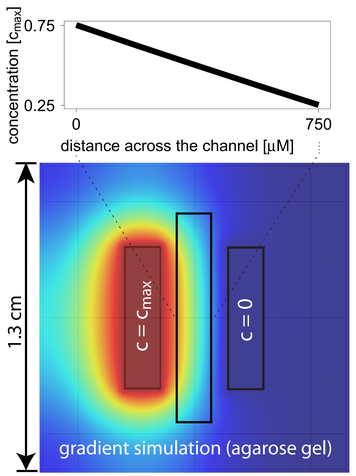


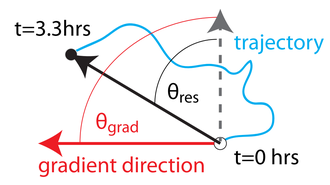
» Gradient detection was recast in the context of Shannon's information theory
- noise between the source and external stage was quantified using external mutual information calculated according to [Fuller; 2010]
- noise between the source and internal stage was quantified using total mutual information which was measured [see Methods]



Methods

» Static gradient was achieved using an agarose-based microfluidic device with two reservoirs held at constant concentrations [Cheng; 2007]
» Linear gradient was established in the middle, static channel by diffusion in steady state - this represents more realistic, natural environment - in contrast to flowing systems used for studies of cAMP signaling [Song; 2006, Fuller; 2010]
» For each cell, we measured the angle θ_{res} of total displacement vector during $\Delta t = 3.3$ hours
» The angle distribution $p(\theta_{res})$ was used to compute total mutual information according to [Fuller; 2010]





» Total mutual information I_{tot}: how much information one can acquire about θ_{grad} by looking at the cell response, θ_{res} :

$$I_{tot}(\theta_{res},\theta_{grad}) = \iint p(\theta_{res},\theta_{grad}) \log\left[\frac{p(\theta_{res},\theta_{grad})}{p_1(\theta_{res})p_2(\theta_{grad})}\right] d\theta_{res} d\theta_{grad}$$

» External mutual information I_{ext}: how much information one can acquire about θ_{grad} by knowing a distribution of receptor occupancy θ_{rec} .

Results and Discussion

FIGURE 1.

Comparison of:
» I_{tot}, (measured): information transferred from the source to the internal stage
» I_{ext} (calculated): information transferred from the source to the external stage. It depends on the local FA concentration which varies by a factor of 3 in the experiment: this is represented by the spread.
K_d = 150 nM, cell radius = 5 μm

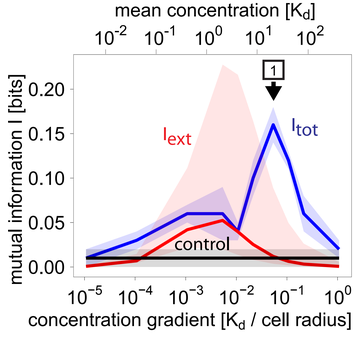
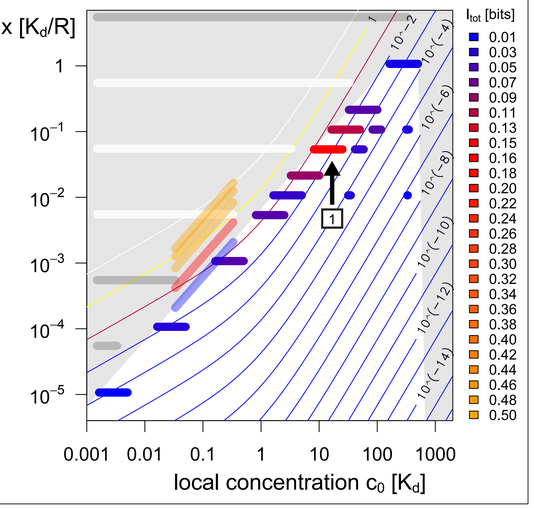


FIGURE 2.

Comparison of:
» I_{ext} : contours; theory
» I_{tot}: colored bars; three different experiments:
  a. blue-red: FA static experiments [this work]
  b. red-orange: cAMP flowing experiments [Fuller; 2010]
  c. gray-white: cAMP flowing experiments [Song; 2006]
Shaded area: inaccessible region in our experiment.



Conclusions

We found:
» Response across a range of 4 orders of magnitude.
» Surprising response at high local concentrations in saturating regime
» Apparent violation of Jensen's inequality $I_{tot} > I_{ext}$: the observed response is better than what it ought to be, by considering the receptor-ligand binding as the only source of noise in signal transmission. [1]
» Explanations: Very high membrane-bound or extracellular deaminase (degradator of FA) activity? This effect was calculated to contribute to degradation of less than 0.1% of FA even for the best response. [1]

References

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