

How Quorum Sensing Interactions Affect Population Structure

02-712 Final Project

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Background

Quorum-Sensing Systems

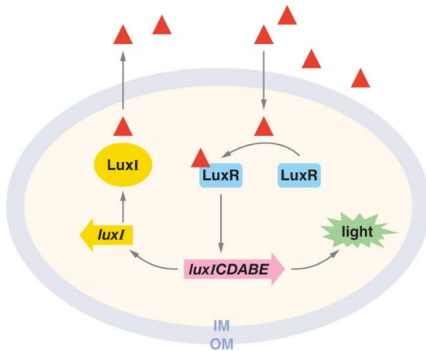
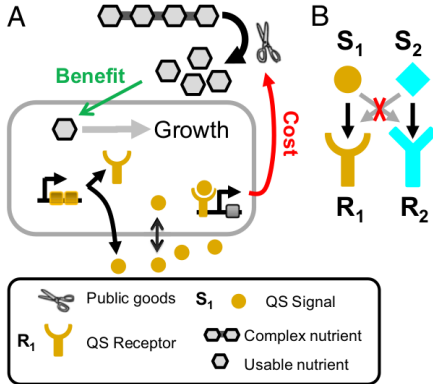


Figure 1: @qs_diagram

- ▶ Signal-Receptor molecule pairs that modulate gene expression
- ▶ Once threshold density is reached, enough signal is received to upregulate target genes

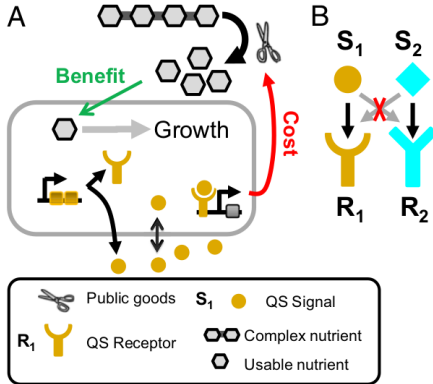
Public Goods and Cheating



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Figure 2: @eldar_2011

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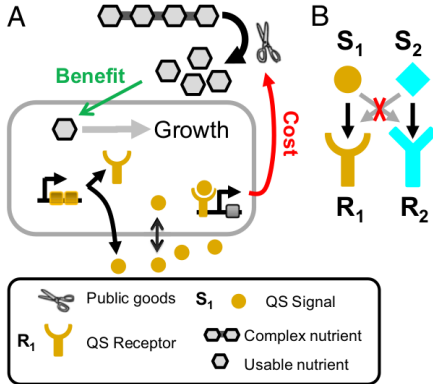


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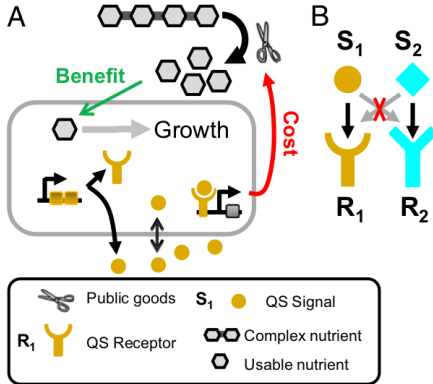


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- ▶ When quorum is reached, bacteria produce a “public good”
- ▶ Everyone benefits from this even if they don’t contribute
- ▶ Must produce the receptor, signal molecule and good to contribute
- ▶ Cheaters DO prosper (if you are a bacterium)

Who Cares?

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- ▶ Analysis of QS systems can help inform strategies for resisting pathogenesis
 - ◇ interfere with microbiome colonization
 - ◇ interfere with biofilm formation and competitions

Methods

Basic ODE Model

Social conflict drives the evolutionary divergence of quorum sensing

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Model Equations

$$\frac{dn_i}{dt} = n_i \left(\frac{P_d}{P_d + 1} (1 - rf(R_i^{\text{active}})) - n_{\text{tot}} - \gamma_n \right)$$

$$\frac{dS_i}{dt} = \beta_S (n_i - S_i)$$

$$\frac{dE}{dt} = -\beta_E E + \sum_i f(R_i^{\text{active}}) n_i$$

$$\frac{dP_d}{dt} = J_{P_d} + V_{\text{max}} E - \beta_{P_d} \left(\frac{P_d}{P_d + 1} \right) n_{\text{tot}}$$

Signal-Receptor Activation Matrix K_{ac}

- ▶ The interaction term is defined as $R^{active} = \frac{K_{ac}\vec{S}}{K_{RS} + K_{ac}\vec{S}}$

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- ▶ K_{ac} represents all receptors-signal pairs ($R_i S_i$) produced in each strain
- ▶ K_{ac} is of dimension $|R| \times |S| = |n| \times |n|$

Facultative Cheaters

Matrix for 2 strains R_1S_1 and R_2S_2

$$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

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Obligate Cheater

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Custom Matrix

Matrix for 2 strains $R_1R_2S_1$ and R_2S_2

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Our Work

- ▶ Implemented in python using `scipy.integrate.solve_ivp`

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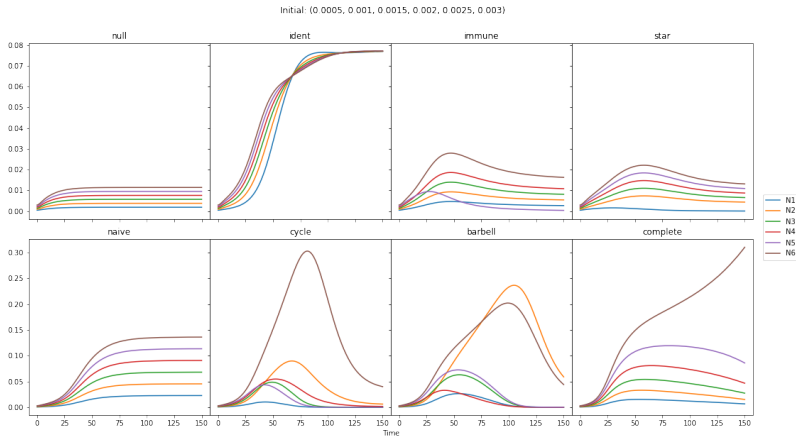
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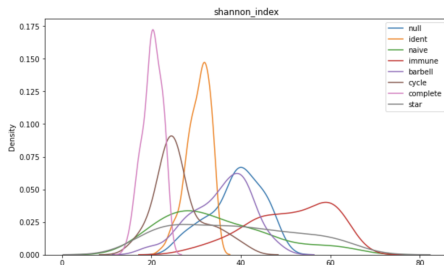
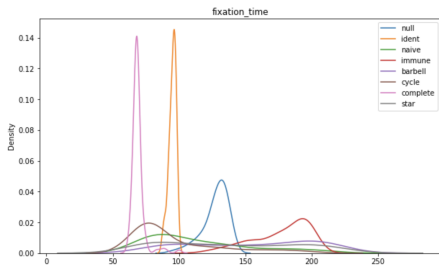
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- ▶ Generated different K_{ac} matrices and run simulations
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- ▶ Examine population structure and model dynamics
- ▶ Simulate using gut microbiome data as initial state
- ▶ All code/results easily available to use on Github

Results

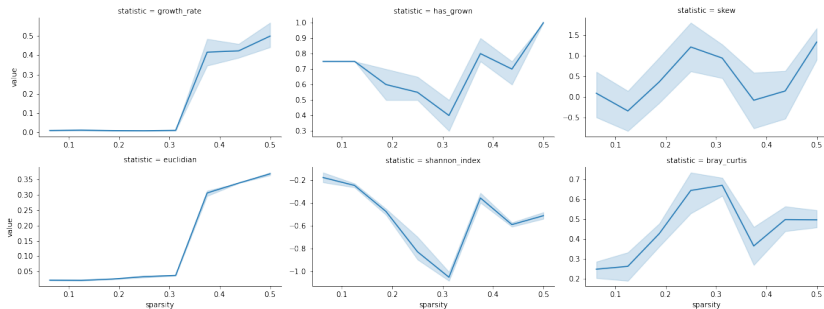
Comparing Different K_{ac} Matrices



How Different K_{ac} affect model dynamics



How K_{ac} Sparsity Affects Population Structure



Discussion

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- ▶ Patterns and sparsity can have large effects on population trajectories
- ▶ Not a linear relationship between sparsity and total growth rate
 - ◇ cheating doesn't always benefit everyone
- ▶ Different K_{ac} have strong effects on population diversity

Moral of the Study

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Cheating works...

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(for bacteria)

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Cheating works...

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but cooperating is better!

Bibliography I