How Quorum Sensing Interactions Affect Population Structure
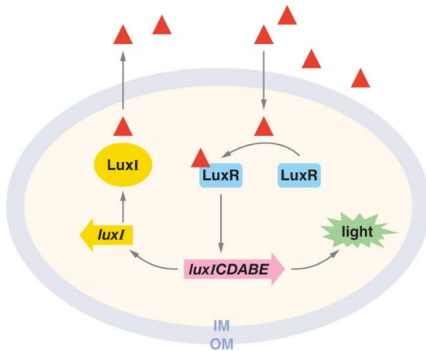
02-712 Final Project

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Computational Biology Department, Carnegie Mellon University

November 30, 2021

Background

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Quorum-Sensing Systems

Figure 1: Waters and Bassler (2005)

▶ Signal-Receptor molecule pairs that modulate gene expression

Quorum-Sensing Systems

Figure 1: Waters and Bassler (2005)

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- ▶ Once threshold density is reached, enough signal is received to upregulated target genes

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Quorum-Sensing Systems

Figure 1: Waters and Bassler (2005)
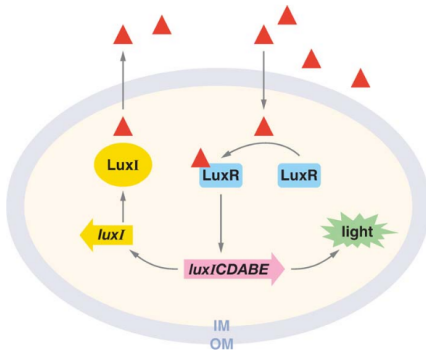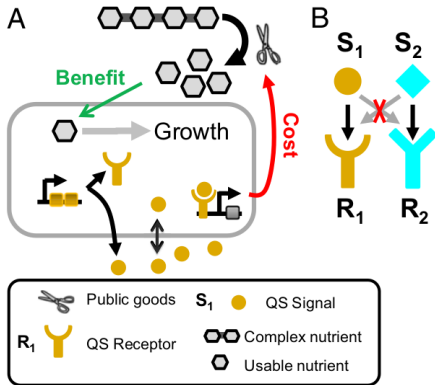
- ▶ Signal-Receptor molecule pairs that modulate gene expression
- ▶ Once threshold density is reached, enough signal is received to upregulated target genes
- ▶ Can lead to biofilms, antibiotic production etc.

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Public Goods and Cheating

Figure 2: Eldar (2011)

▶ When quorum is reached, bacteria produce a "public good"

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Public Goods and Cheating

Figure 2: Eldar (2011)

- When quorum is reached, bacteria produce a "public good"
- Everyone benefits from this even if they don't contribute

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Public Goods and Cheating
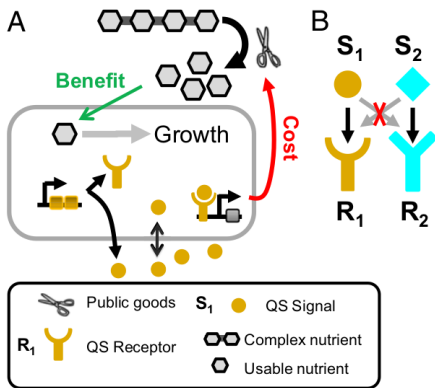

Figure 2: Eldar (2011)

- ▶ 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

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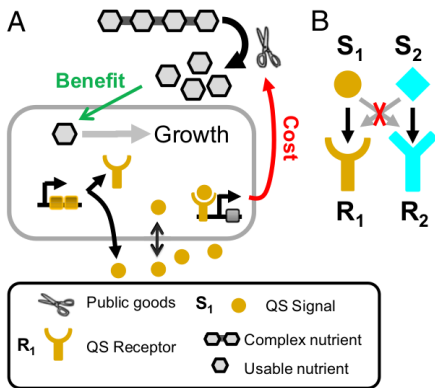○○○○

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Public Goods and Cheating

Figure 2: Eldar (2011)

- ▶ 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)
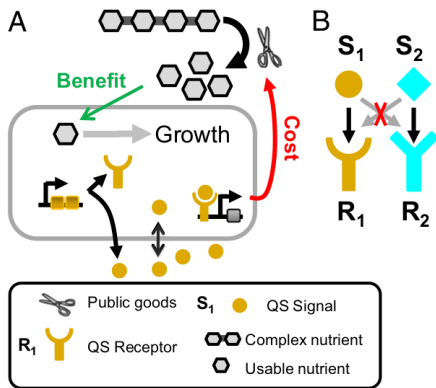
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Who Cares?

- check the discussion from Eldar (2011) for references

Maintaining Freeloaders as a Diversity Reservoir

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Who Cares?

- check the discussion from Eldar (2011) for references

Maintaining Freeloaders as a Diversity Reservoir

Kin Recognition for Strains

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Who Cares?

- ▶ check the discussion from Eldar (2011) for references

Maintaining Freeloaders as a Diversity Reservoir

Kin Recognition for Strains

Designing Cheaters to Disrupt Pathogen Growth

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Basic ODE Model

Social conflict drives the evolutionary divergence of quorum sensing

Avigdor Eldar[1]

Department of Molecular Microbiology and Biotechnology, Faculty of Life Sciences, Tel Aviv University, Tel Aviv 69978, Israel

▶ Equations taken from Eldar (2011)

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Basic ODE Model

Social conflict drives the evolutionary divergence of quorum sensing

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Department of Molecular Microbiology and Biotechnology, Faculty of Life Sciences, Tel Aviv University, Tel Aviv 69978, Israel

- ▶ Equations taken from Eldar (2011)
- ▶ Deterministic ODE model of bacteria

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Basic ODE Model

Social conflict drives the evolutionary divergence of quorum sensing

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Department of Molecular Microbiology and Biotechnology, Faculty of Life Sciences, Tel Aviv University, Tel Aviv 69978, Israel

- ▶ Equations taken from Eldar (2011)
- ▶ Deterministic ODE model of bacteria
- ▶ We focused on QS interactions over Evolution

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Signal-Receptor Activation Matrix K_{ac}

- ▶ Represents all receptors-signal pairs $(R_i S_i)$ present in at least 1 OTU in the population

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Signal-Receptor Activation Matrix K_{ac}

- ▶ Represents all receptors-signal pairs $(R_i S_i)$ present in at least 1 OTU in the population
- ▶ Different sets of receptor-signal combinations can produce the same K_{ac}

Signal-Receptor Activation Matrix K_{ac}

- ▶ Represents all receptors-signal pairs $(R_i S_i)$ present in at least 1 OTU in the population
- ▶ Different sets of receptor-signal combinations can produce the same K_{ac}
- ▶ K_{ac} is of dimension $|R| \times |S| = |N| \times |N|$

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Facultative Cheaters

Matrix for 2 strains $R_1 S_1$ and $R_2 S_2$
$$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

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Facultative Cheaters

Matrix for 2 strains $R_1 S_1$ and $R_2 S_2$
$$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

Obligate Cheater

Matrix for 2 strains $R_1 S_1$ and $R_0 S_0$
$$\begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}$$

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Facultative Cheaters

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Obligate Cheater

Matrix for 2 strains $R_1 S_1$ and $R_0 S_0$
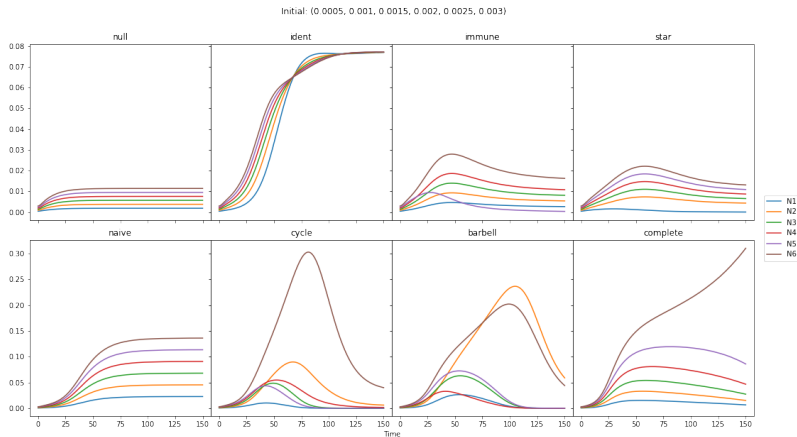
$$\begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}$$

Custom Matrix

Matrix for 2 strains $R_1 R_2 S_1$ and $R_2 S_2$

or 3 strains $R_1 S_1$, $R_2 S_1$ and $R_2 S_2$

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

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Comparing Different K_{ac} Matrices

Initial: (0.0005, 0.001, 0.0015, 0.002, 0.0025, 0.003)

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How K_{ac} Sparsity Affects Population Structure

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Simulating With Human Gut Microbiome Data

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Discussion

Chaining K_{ac} has strong effects on model dynamics

- changes can occur independent of sparsity

Discussion

Chaining K_{ac} has strong effects on model dynamics

- changes can occur independent of sparsity
- decreasing sparsity does . . .

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Moral of the Study

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Moral of the Study

Cheating may help but cooperating is best!

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Moral of the Study

Cheating may help but cooperating is best!

(for bacteria)

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