How Quorum Sensing Interactions Affect Population Structure

02-712 Final Project

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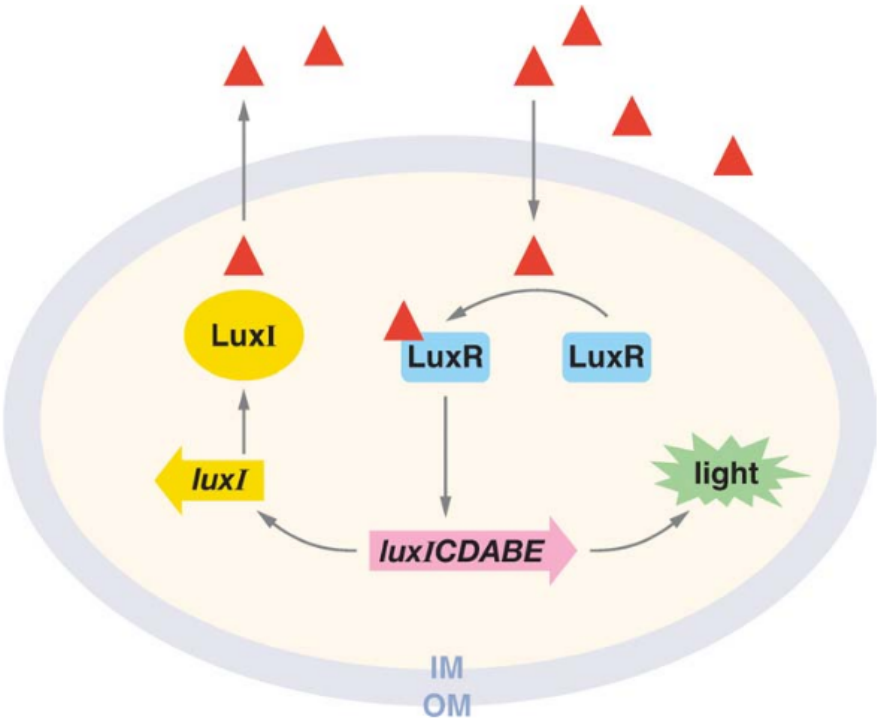
Background

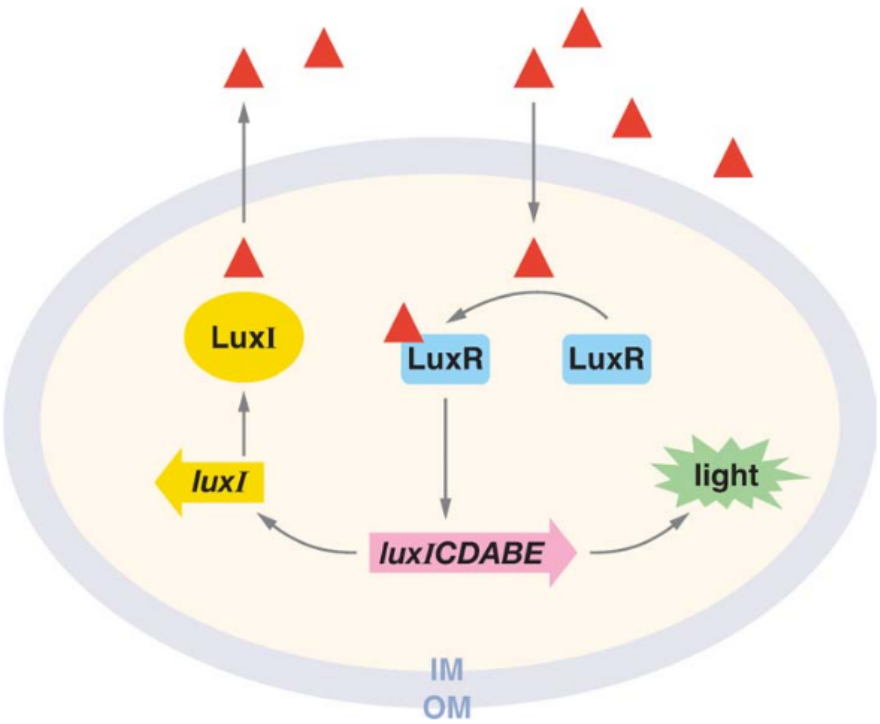
Quorum-Sensing Systems



- Signal-Receptor molecule pairs that modulate gene expression

Figure 1: Waters and Bassler (2005)

Quorum-Sensing Systems



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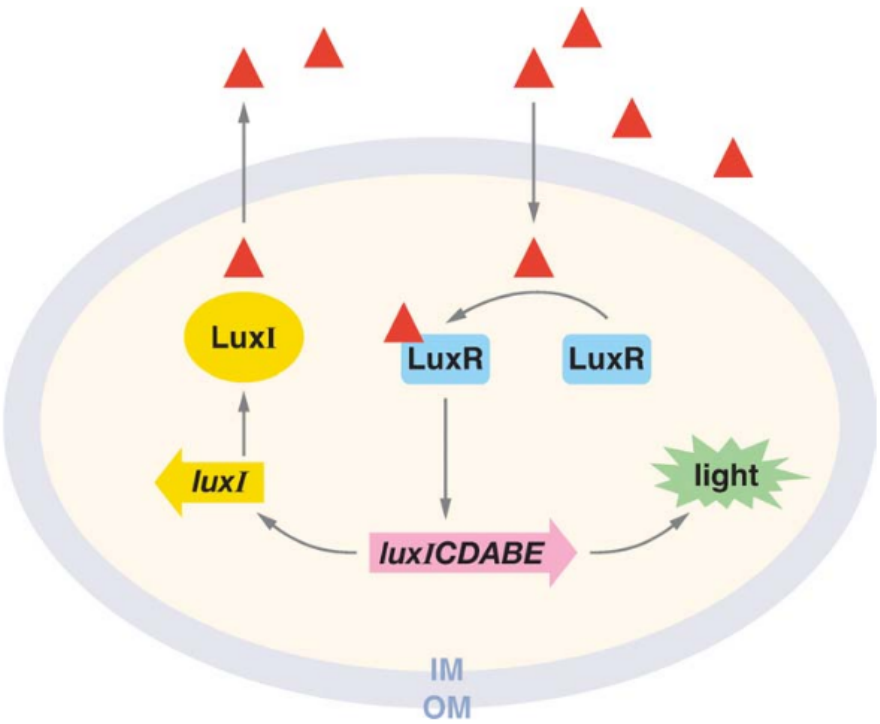
- Once threshold density is reached, enough signal is received to upregulated target genes

Quorum-Sensing Systems



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- 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

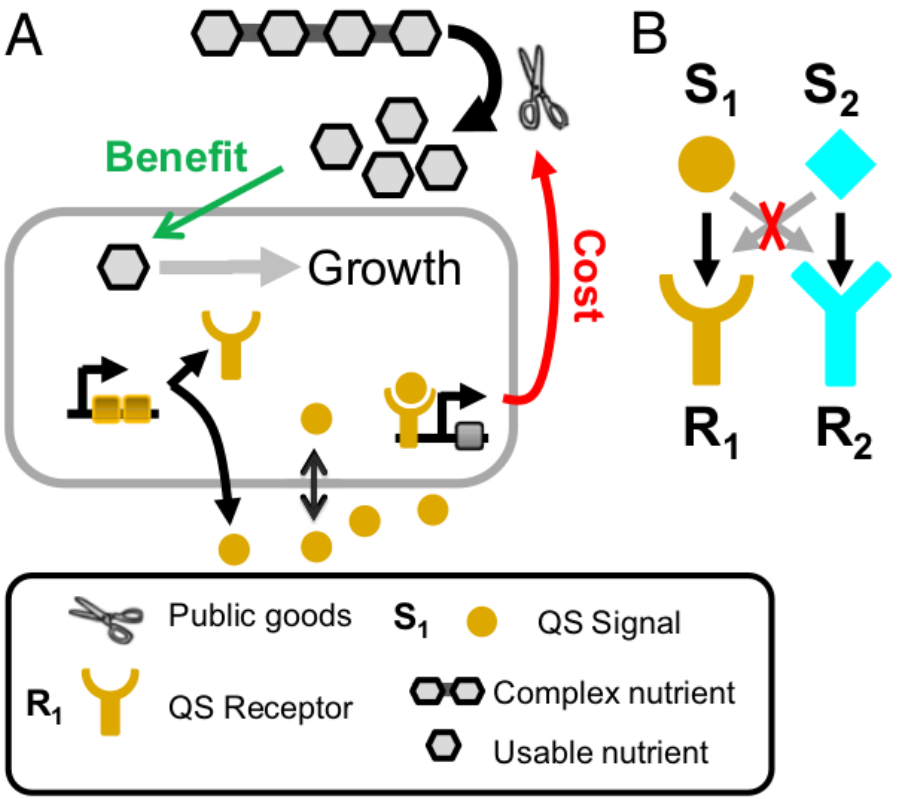

Figure 2: Eldar (2011)

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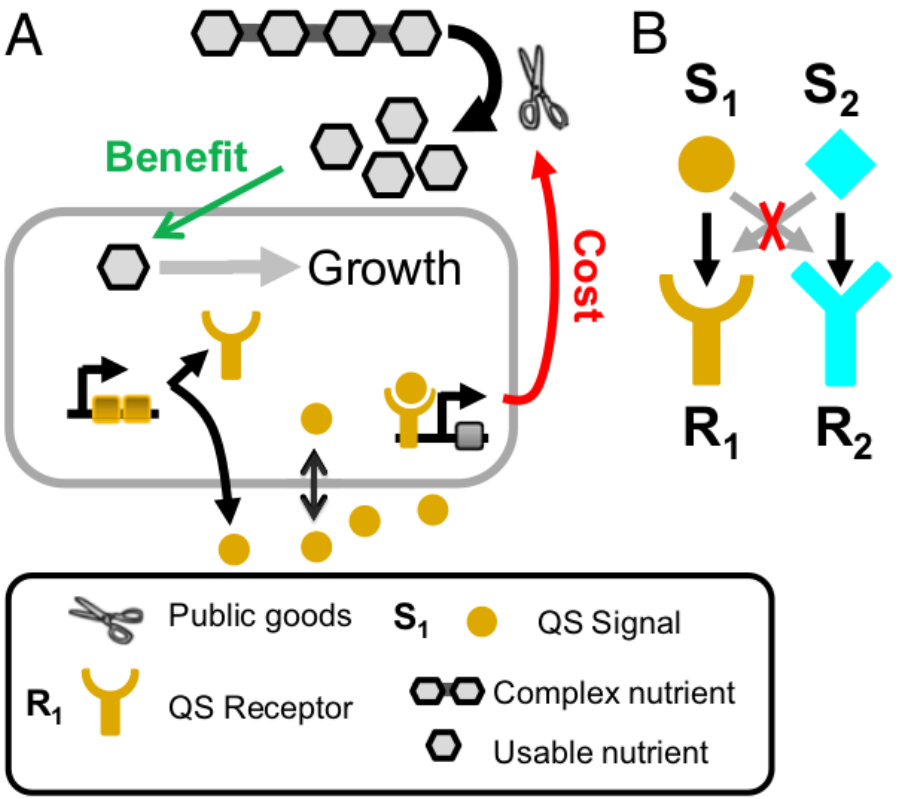

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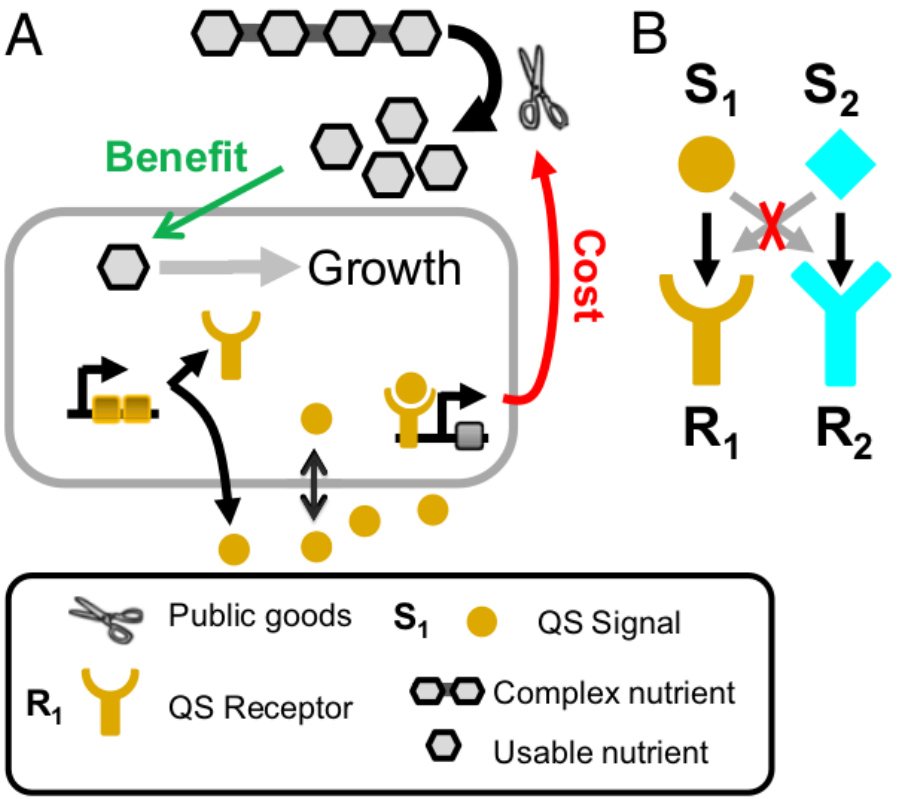

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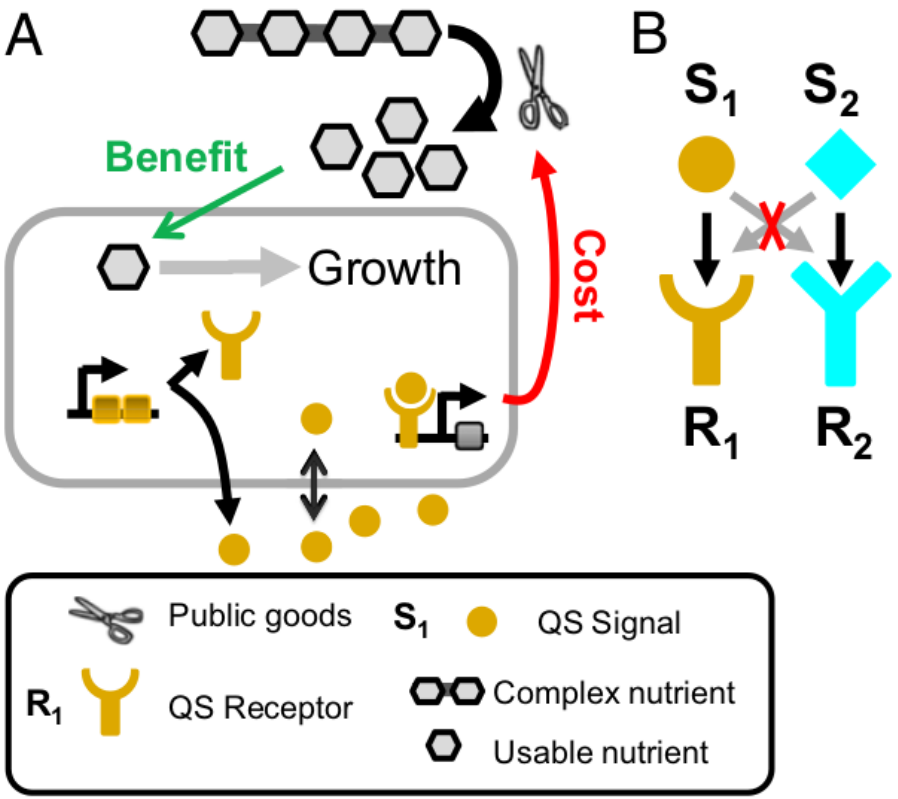

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- Everyone benefits from this even if they don't contribute
- Must produce the receptor, signal molecule and good to contribute
- Cheaters DO prosper (if you are a bacterium)

Who Cares?

- check the discussion from Eldar (2011) for references

Maintaining Freeloaders as a Diversity Reservoir

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Kin Recognition for Strains

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Maintaining Freeloaders as a Diversity Reservoir

Kin Recognition for Strains

Designing Cheaters to Disrupt Pathogen Growth

Methods

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

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Model Equations

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

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

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

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

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_iS_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

Matrix for 2 strains R_1S_1 and R_0S_0

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Custom Matrix

Matrix for 2 strains $R_1R_2S_1$ and R_2S_2

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

Our Work

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

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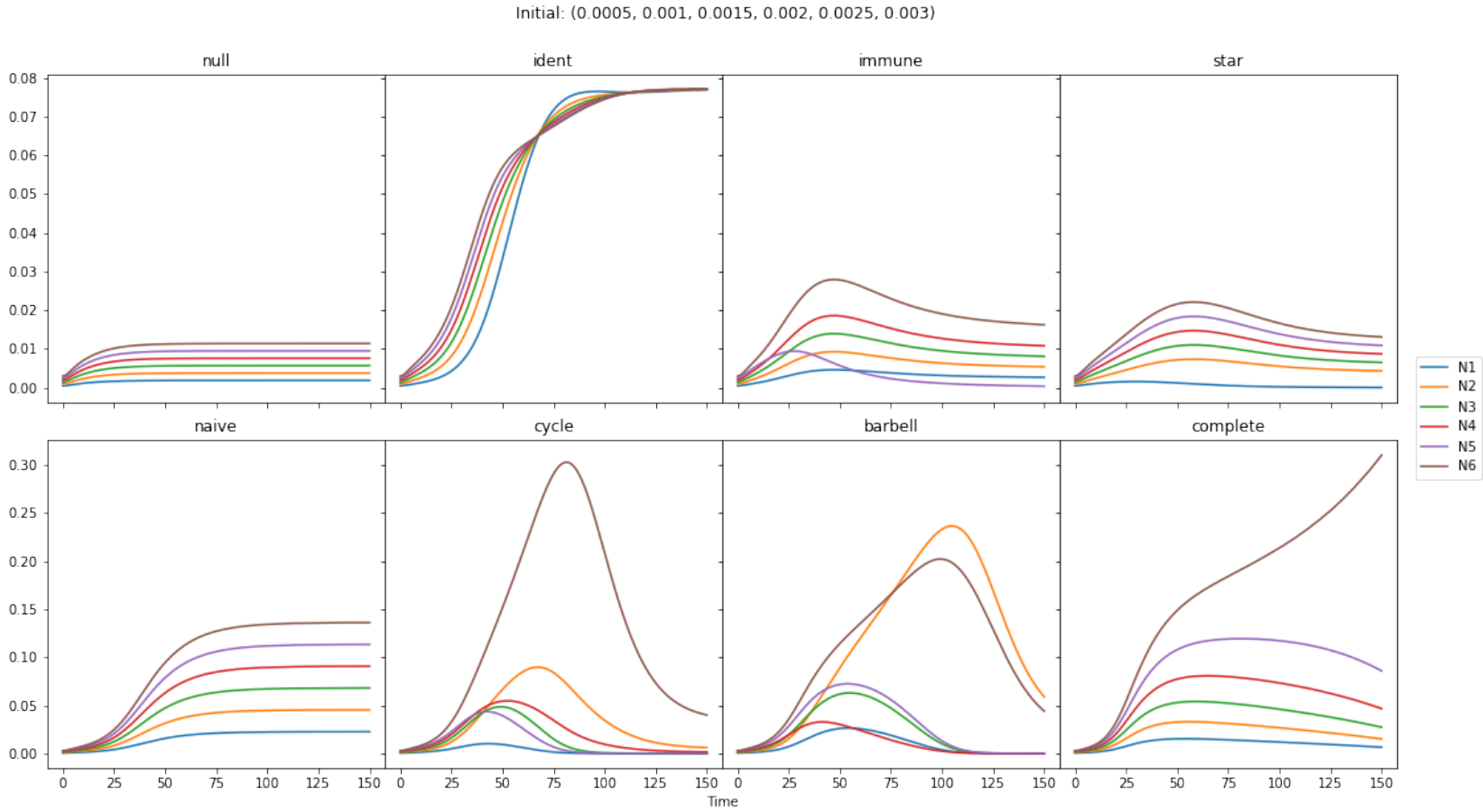
- Generated different K_{ac} matrices and run simulations
  - Specific patterns and randomly generated K_{ac}
- Examine population structure and model dynamics
- Simulate using gut microbiome data as initial state
- All code/results easily available to use on Github

Results

Comparing Different K_{ac} Matrices



How K_{ac} Sparsity Affects Population Structure

Simulating With Human Gut Microbiome Data

Discussion

Moral of the Study

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Cheating works...

Moral of the Study

Cheating works...

(for bacteria)

Moral of the Study

Cheating works...

(for bacteria)

but cooperating is better!

Bibliography I

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