



Deterministic and stochastic effects in microbial community assembly

Jeff Gore

Department of Physics

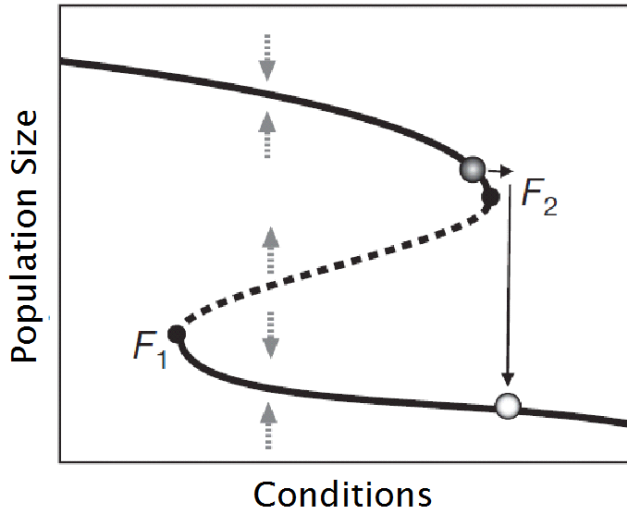
Massachusetts Institute of Technology

SIAM Meeting on Dynamical Systems

May 22, 2017

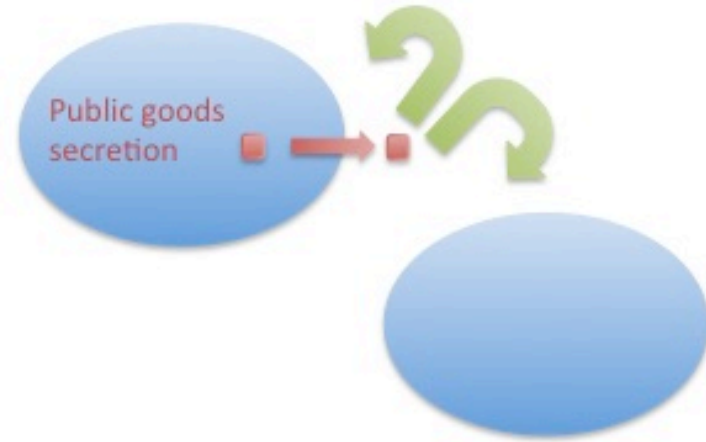
Interactions \leftrightarrow ecological and evolutionary phenomena

Tipping points



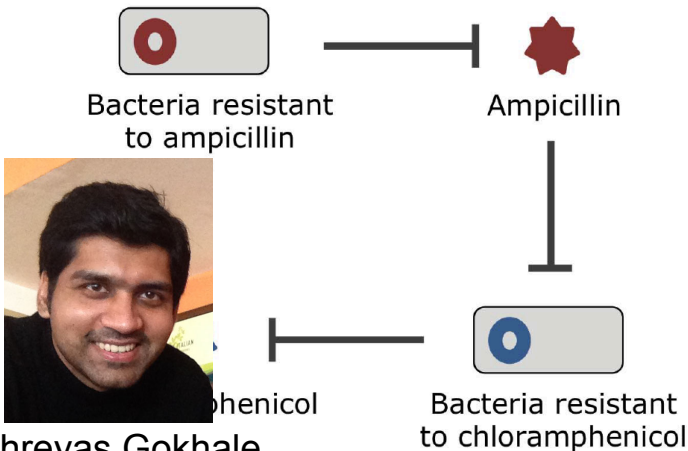
Science (2012), Nature (2013),
Nat Comm (2014), PNAS (2015)

Cooperation and cheating



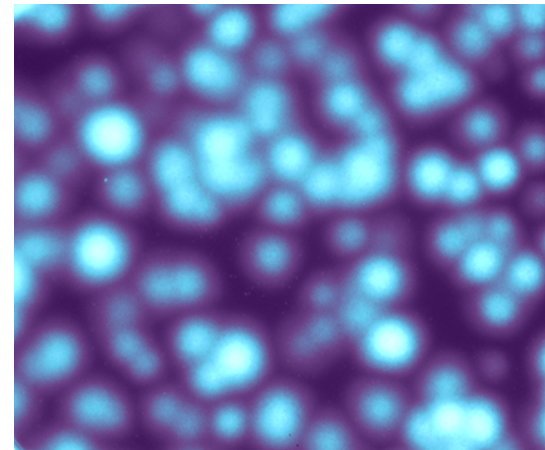
Nature (2009), MSB (2012),
PLOS Bio (2012), eLife (2013),
MSB (2016), PLOS Bio (2016)

Antibiotic cross-protection



MSB (2013), MSB (2015)
PNAS (2016)

Spatial dynamics



PNAS (2012), Nat Micro (2016),
PNAS (2016), Nat Ecol & Evo
(2017)

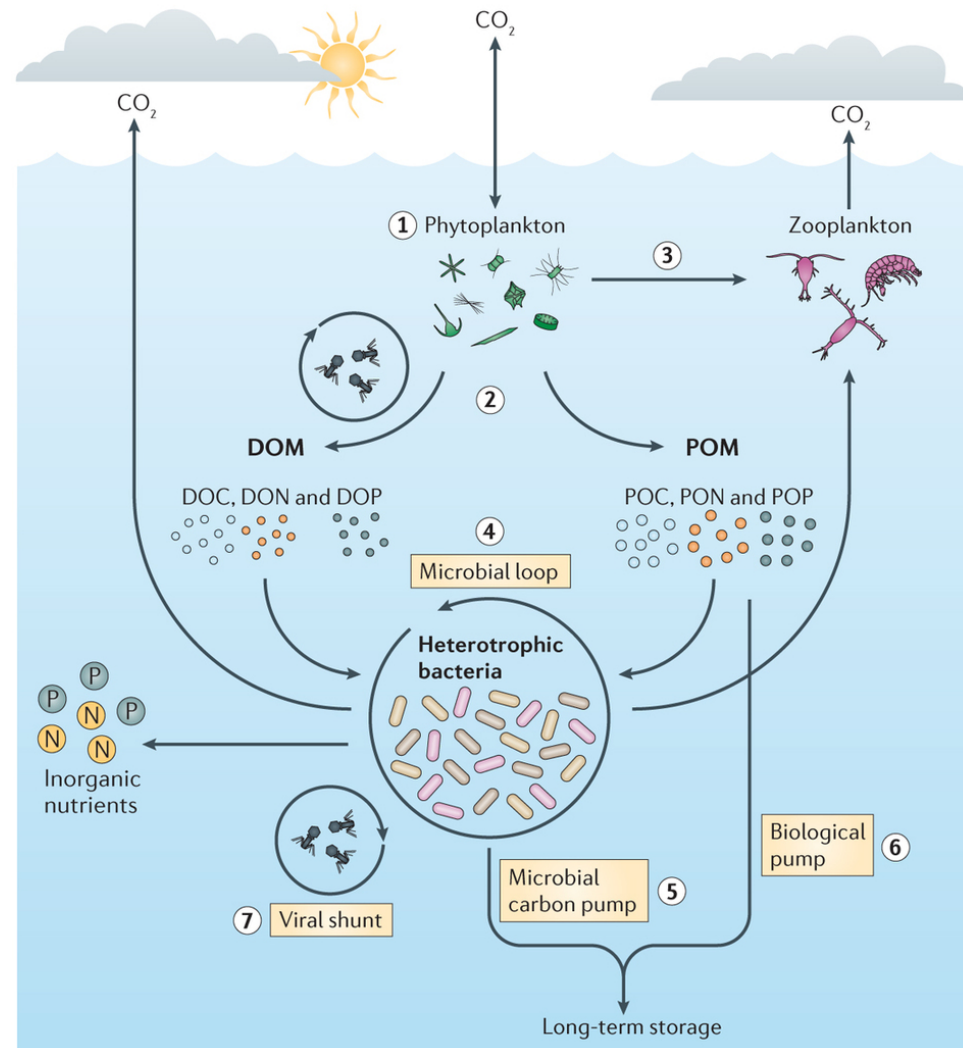


Shreyas Gokhale

Microbes are important for our health...

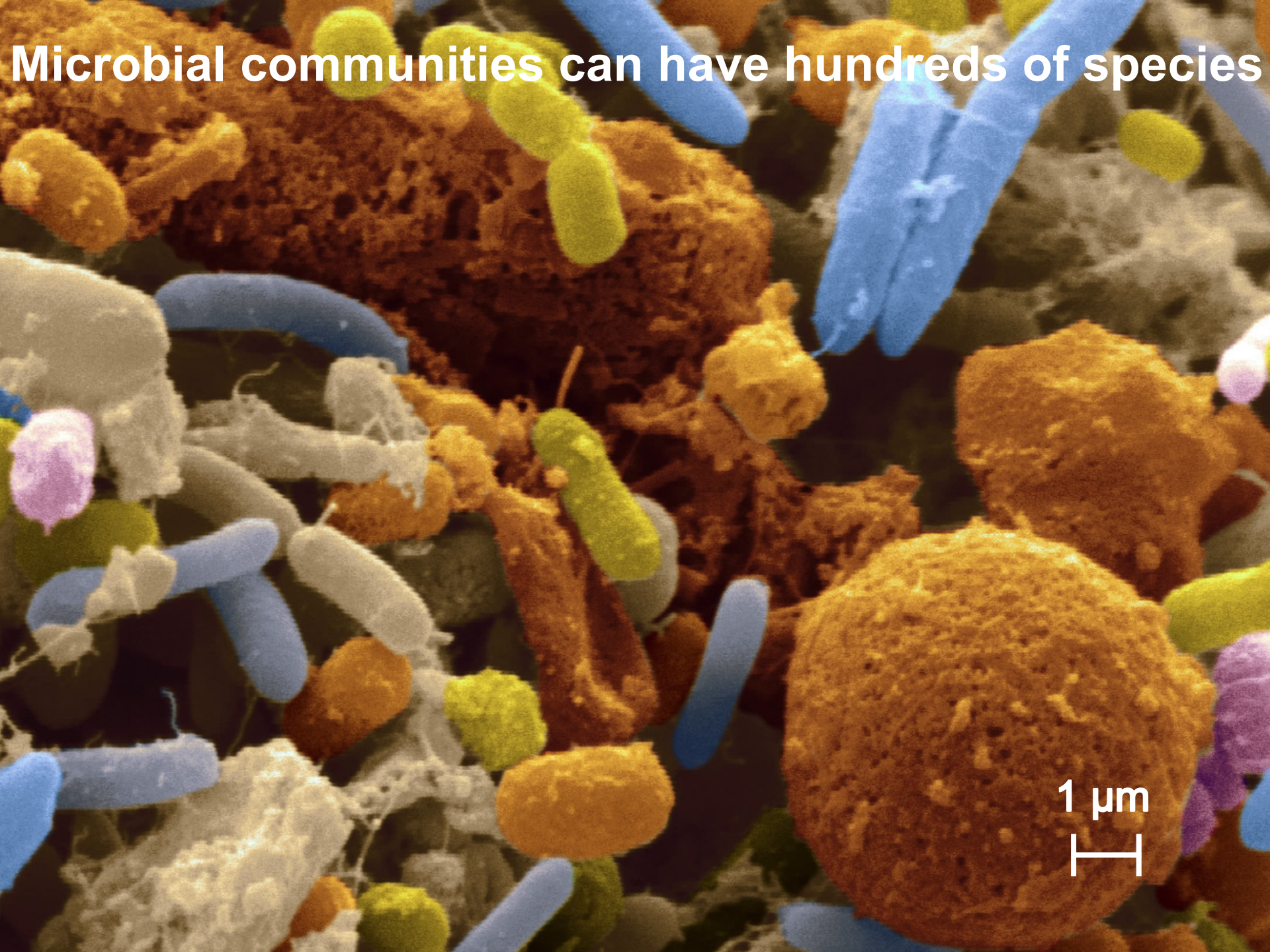


Microbes are important for our health... and planet's health



Nature Reviews | Microbiology

Microbial communities can have hundreds of species

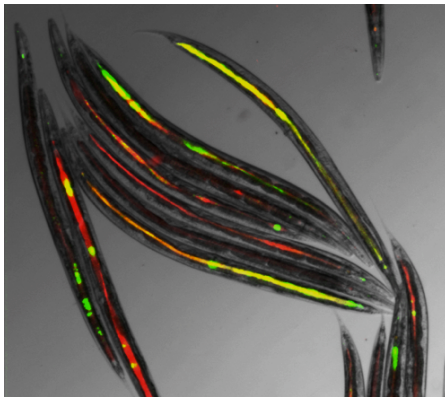


Where we are heading:



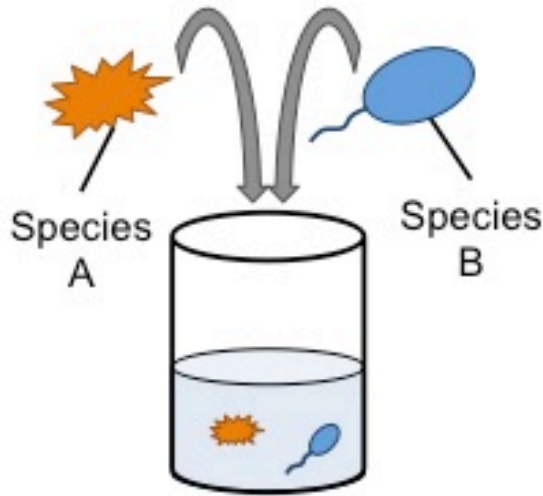
What are typical outcomes of pairwise interspecies competition?

Do pairwise outcomes predict multi-species outcomes?



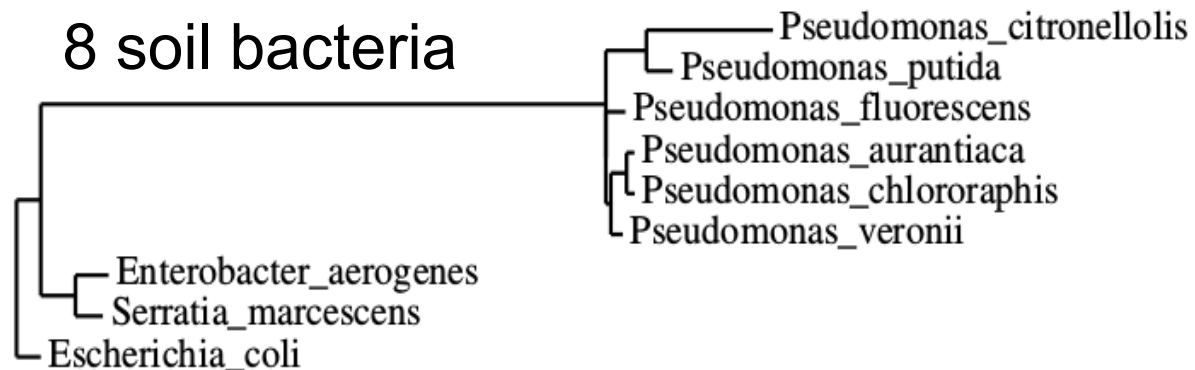
When do stochastic forces dominate community assembly?

Experimental system for pair-wise competition



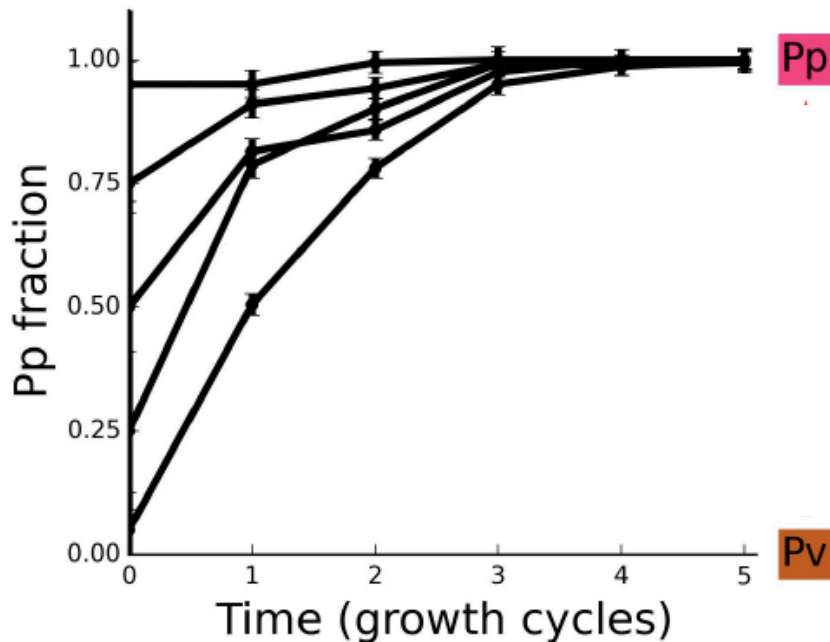
Jonathan Friedman

8 soil bacteria

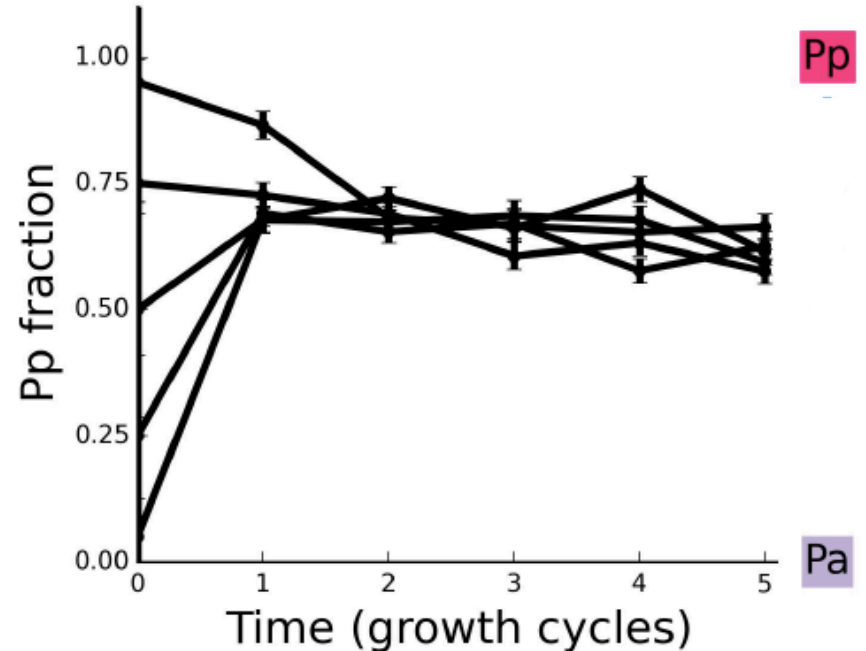


Simple competitive outcomes between pairs

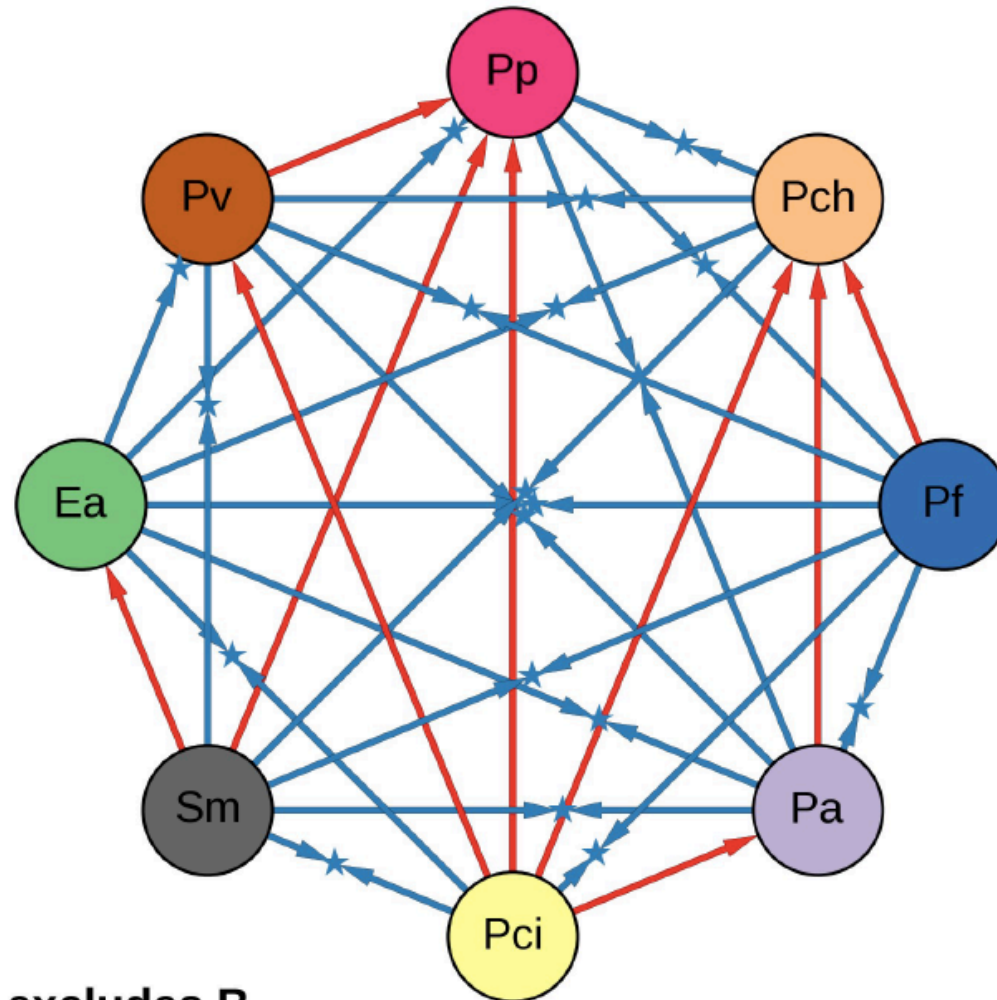
Competitive Exclusion



Coexistence



Network of competitive outcomes between pairs

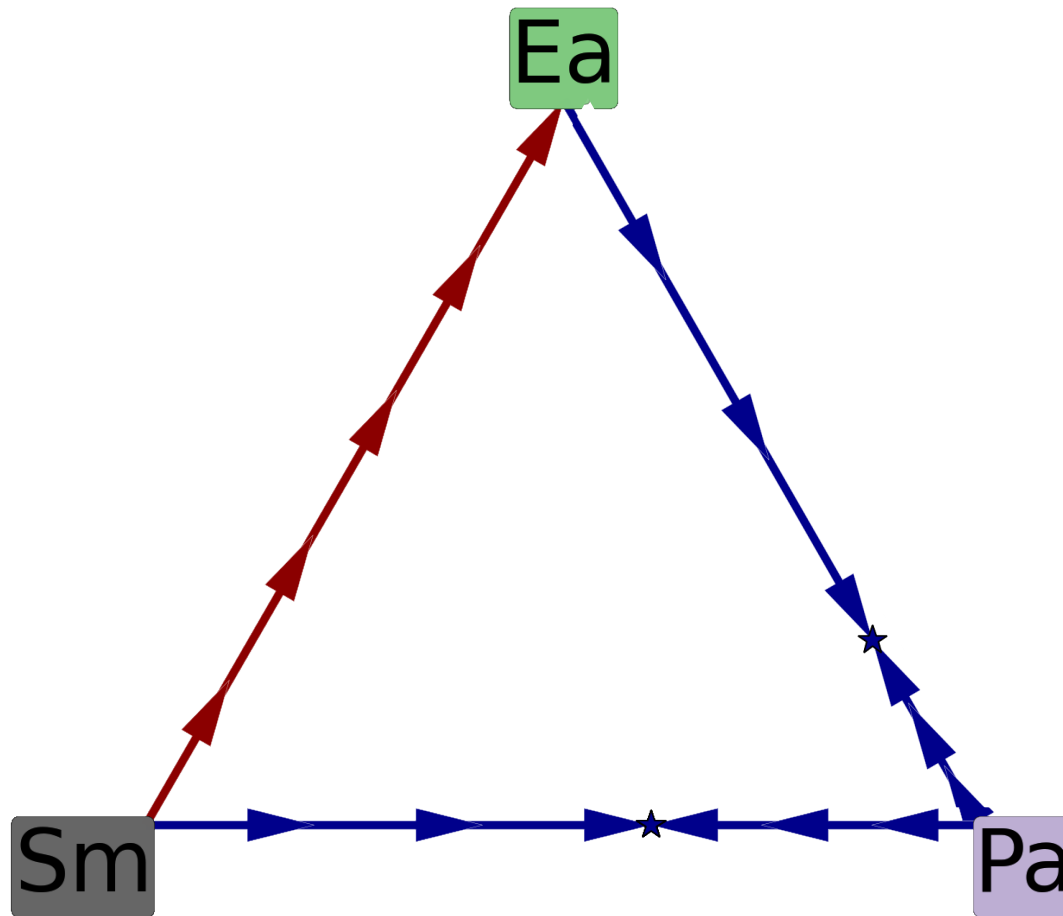


A excludes B

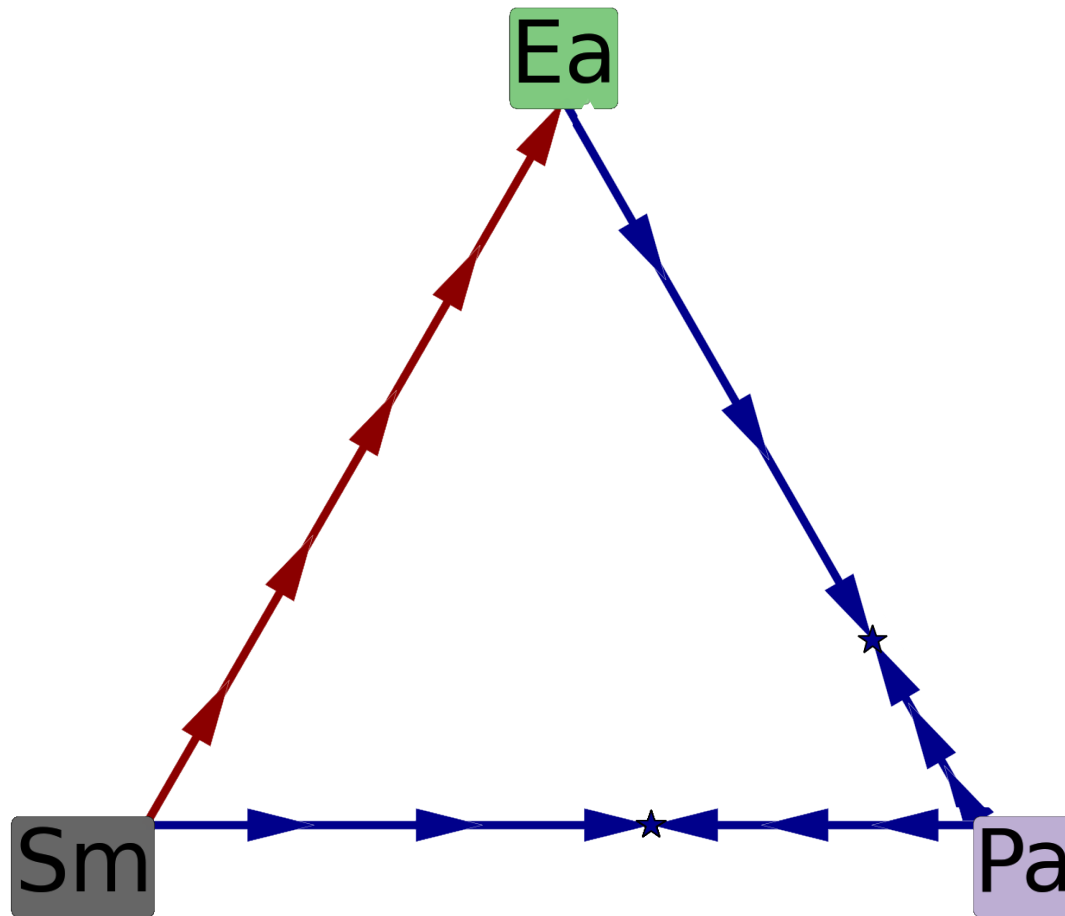


A and B coexist

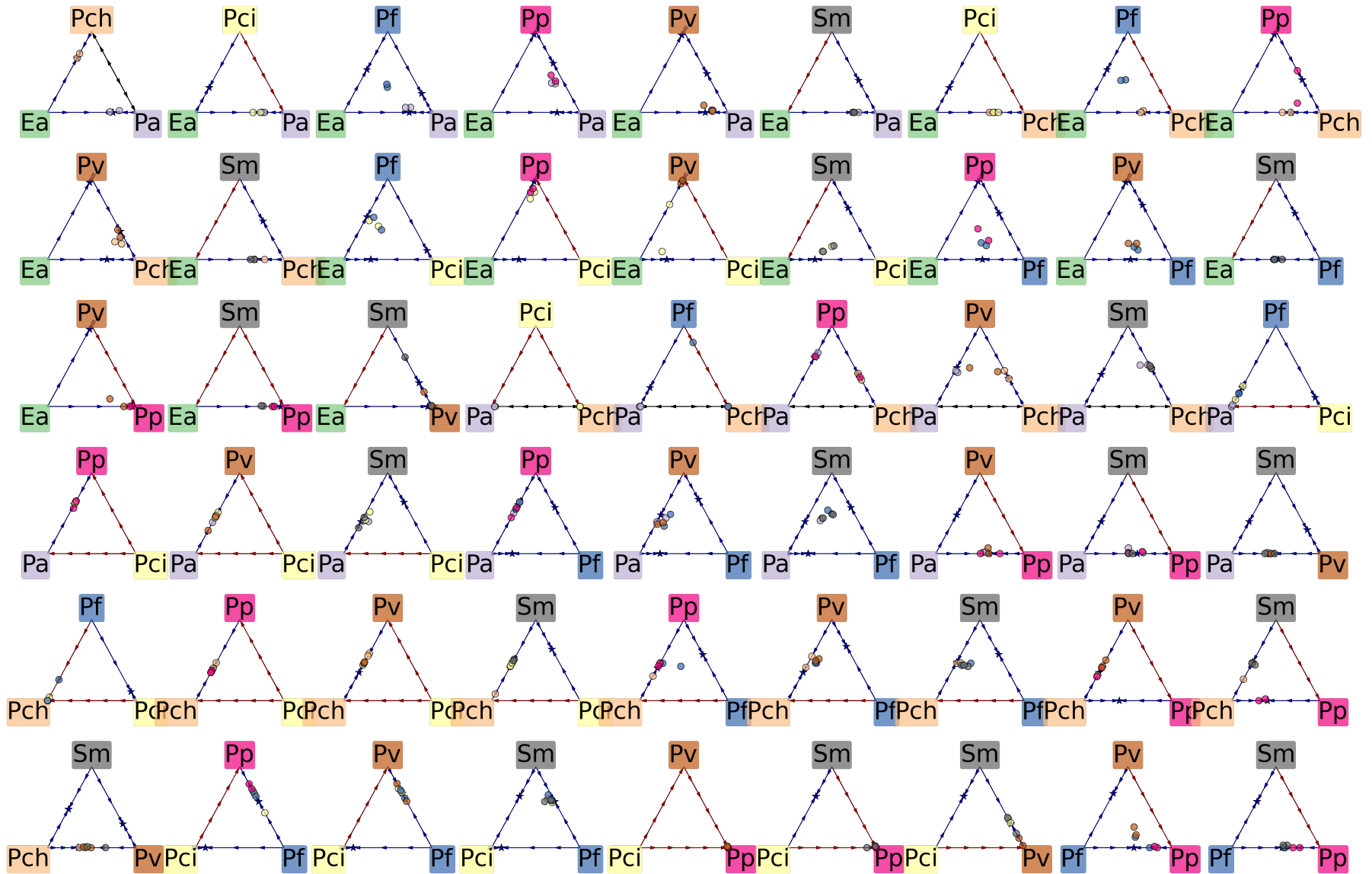
Predict trio outcome from pairwise outcome?



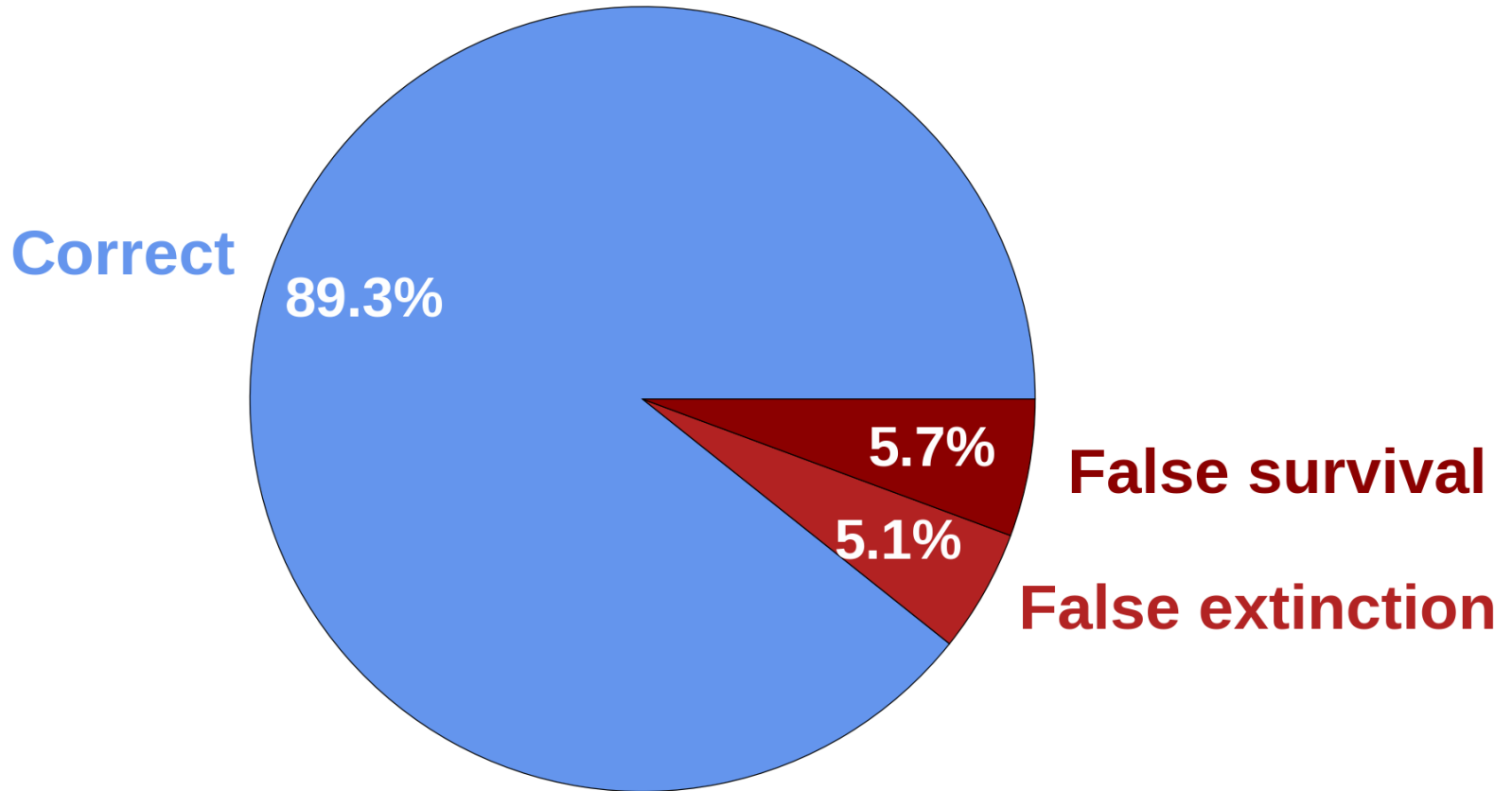
Simple prediction: A species will survive trio competition if and only if it survives in pairs



56 different trio combinations

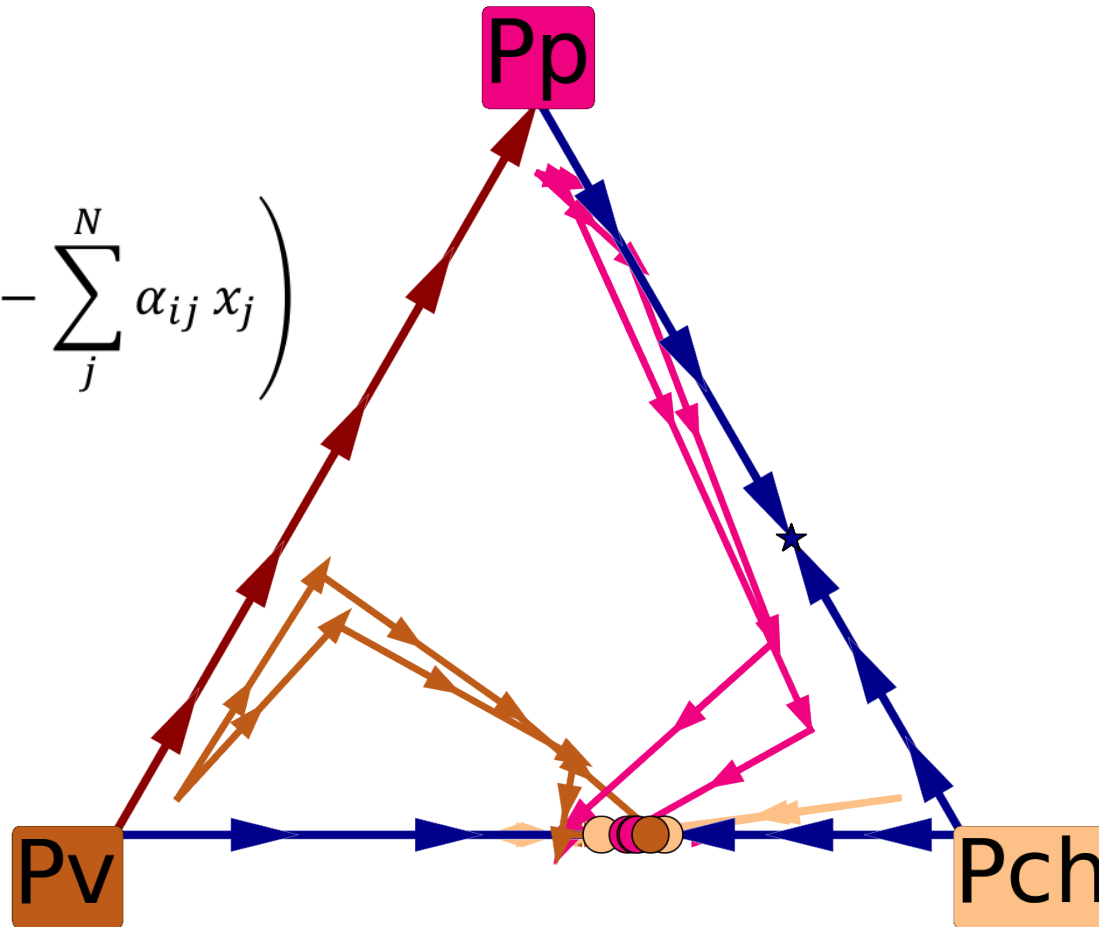


Rule is ~90% accurate in predicting survival in trio



Prediction failures not necessarily due to higher-order interactions

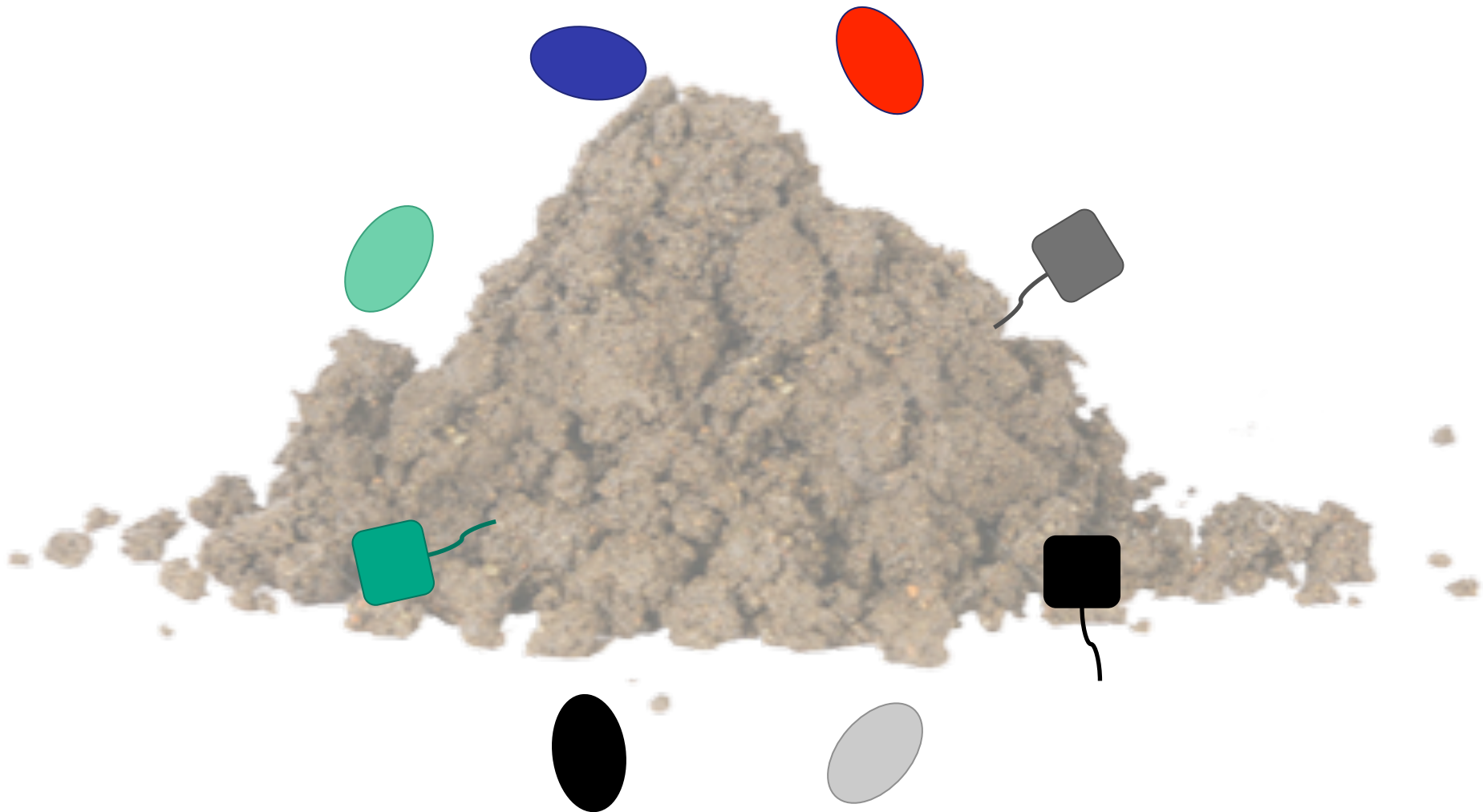
$$\dot{x}_i = r_i x_i \left(1 - \sum_j^N \alpha_{ij} x_j \right)$$



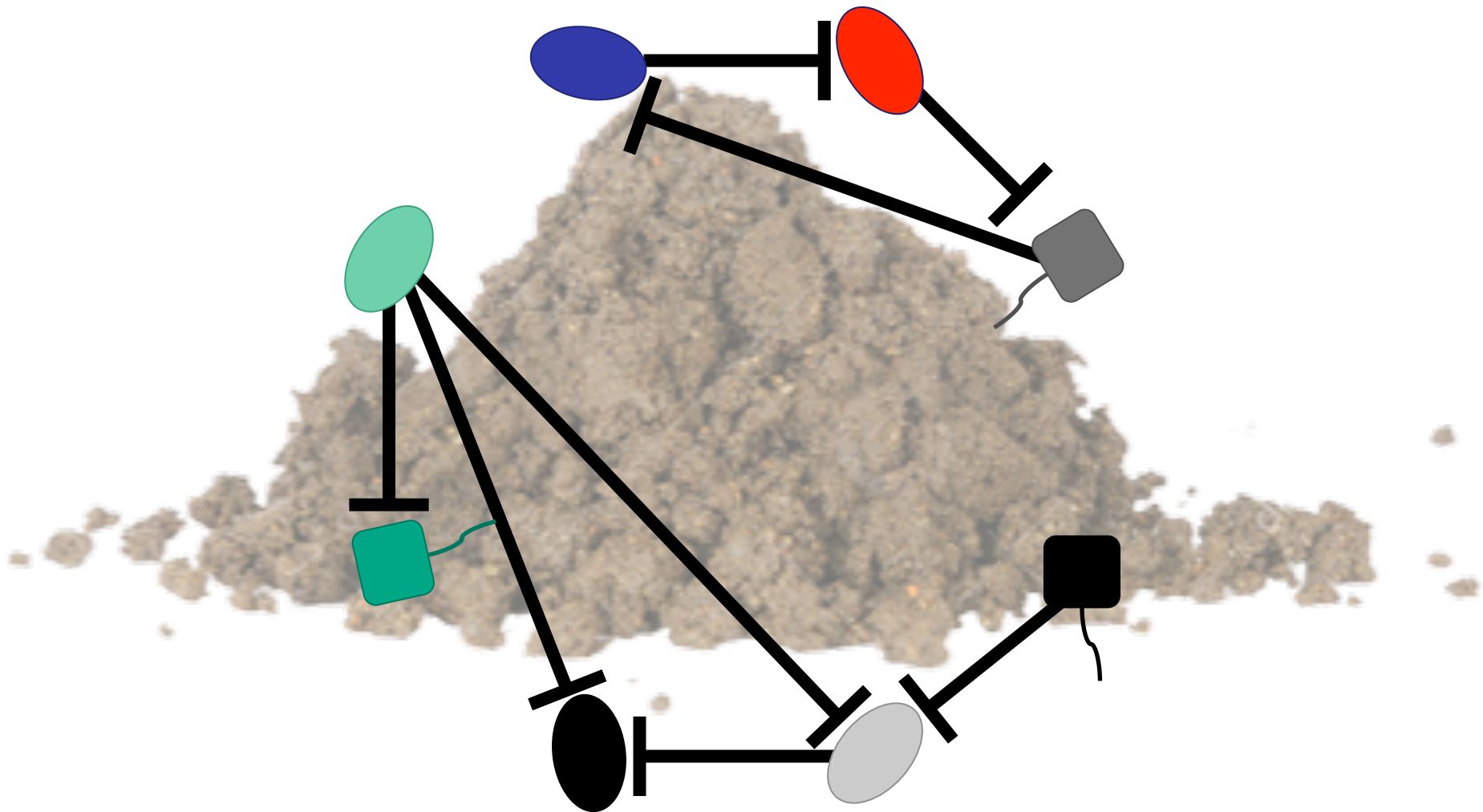
What does this network look like in a natural community?



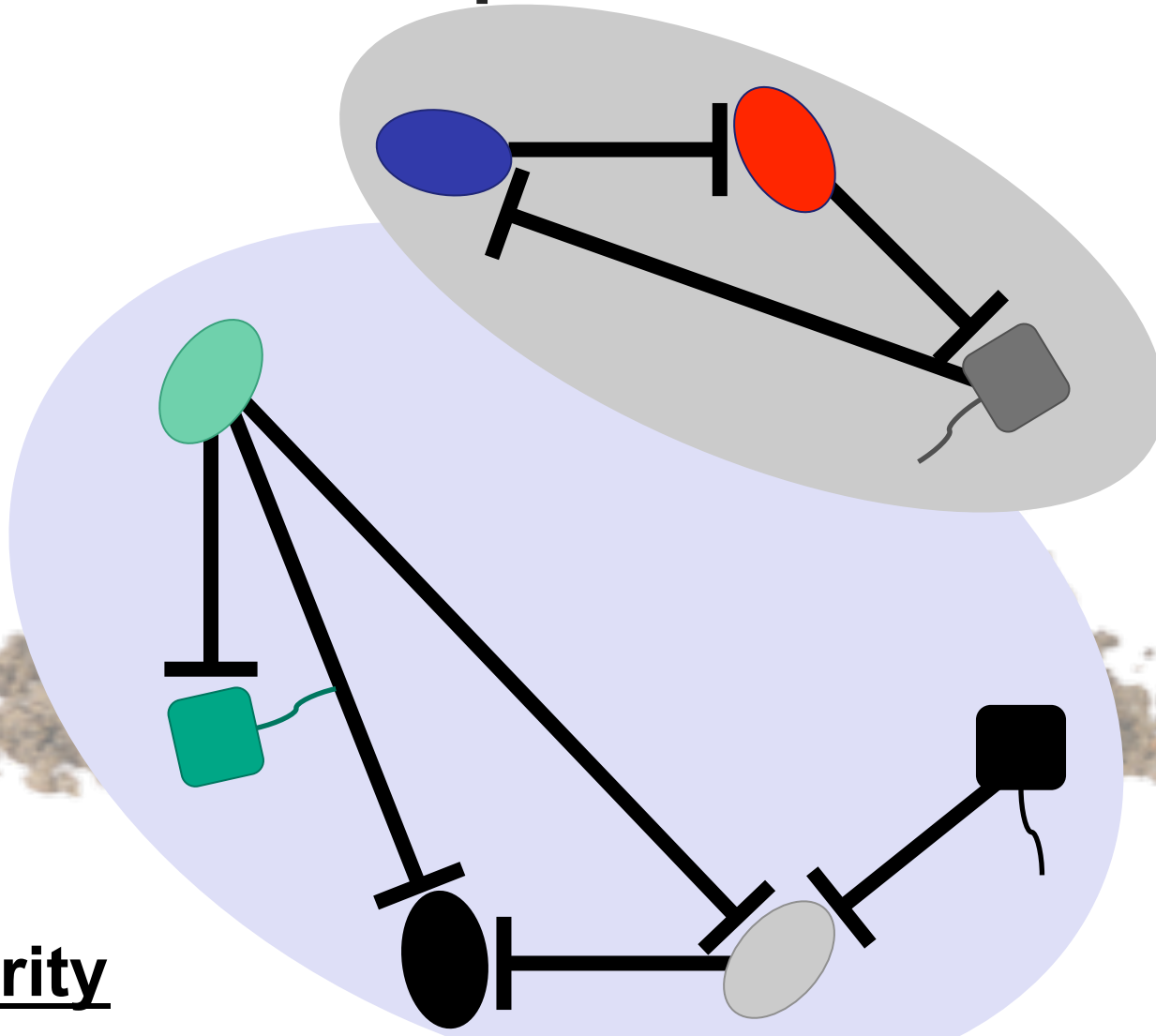
Community complexity may be reflected in the network of pairwise interactions



Community complexity may be reflected in the network of pairwise interactions

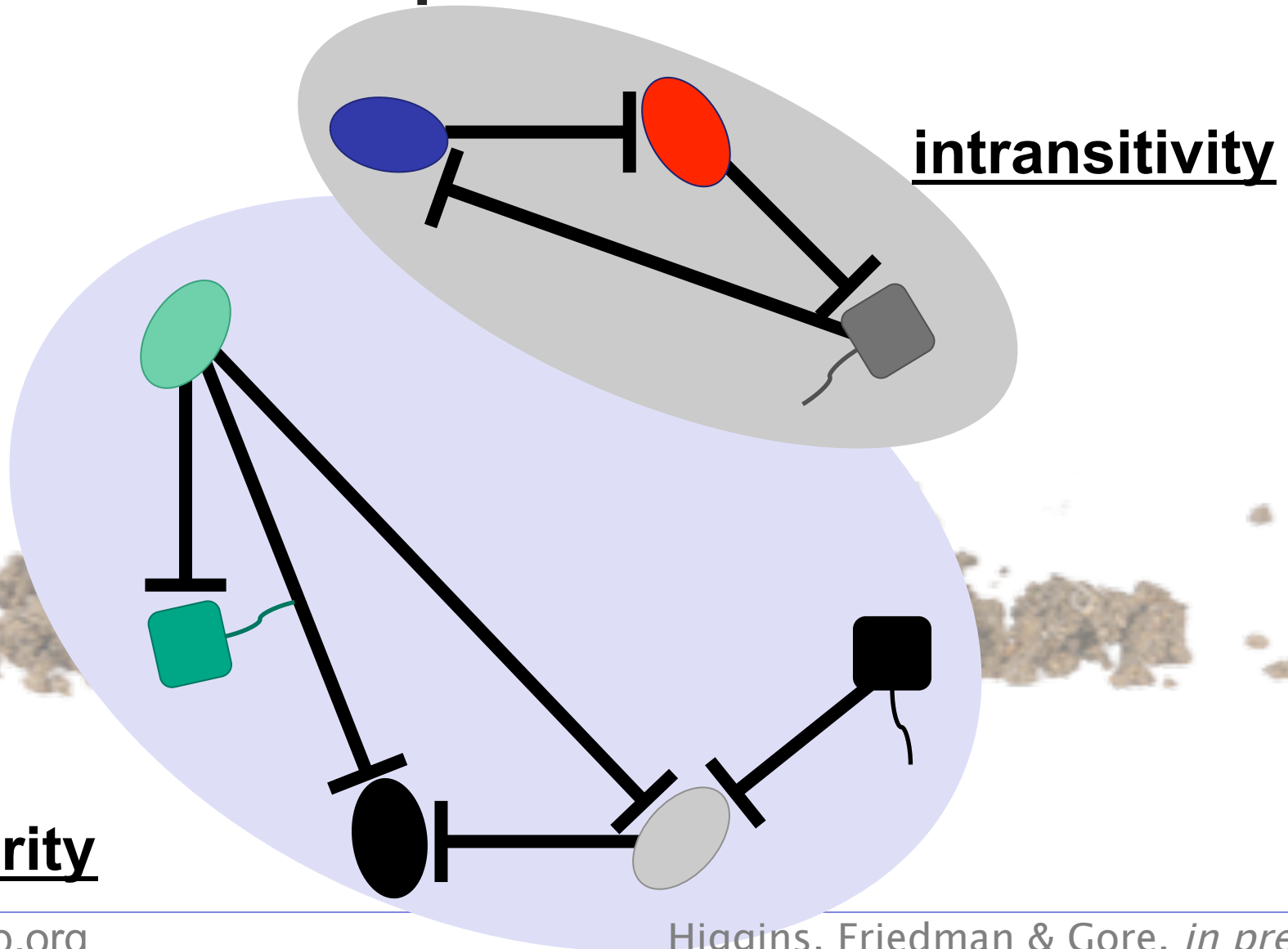


Community complexity may be reflected in the network of pairwise interactions

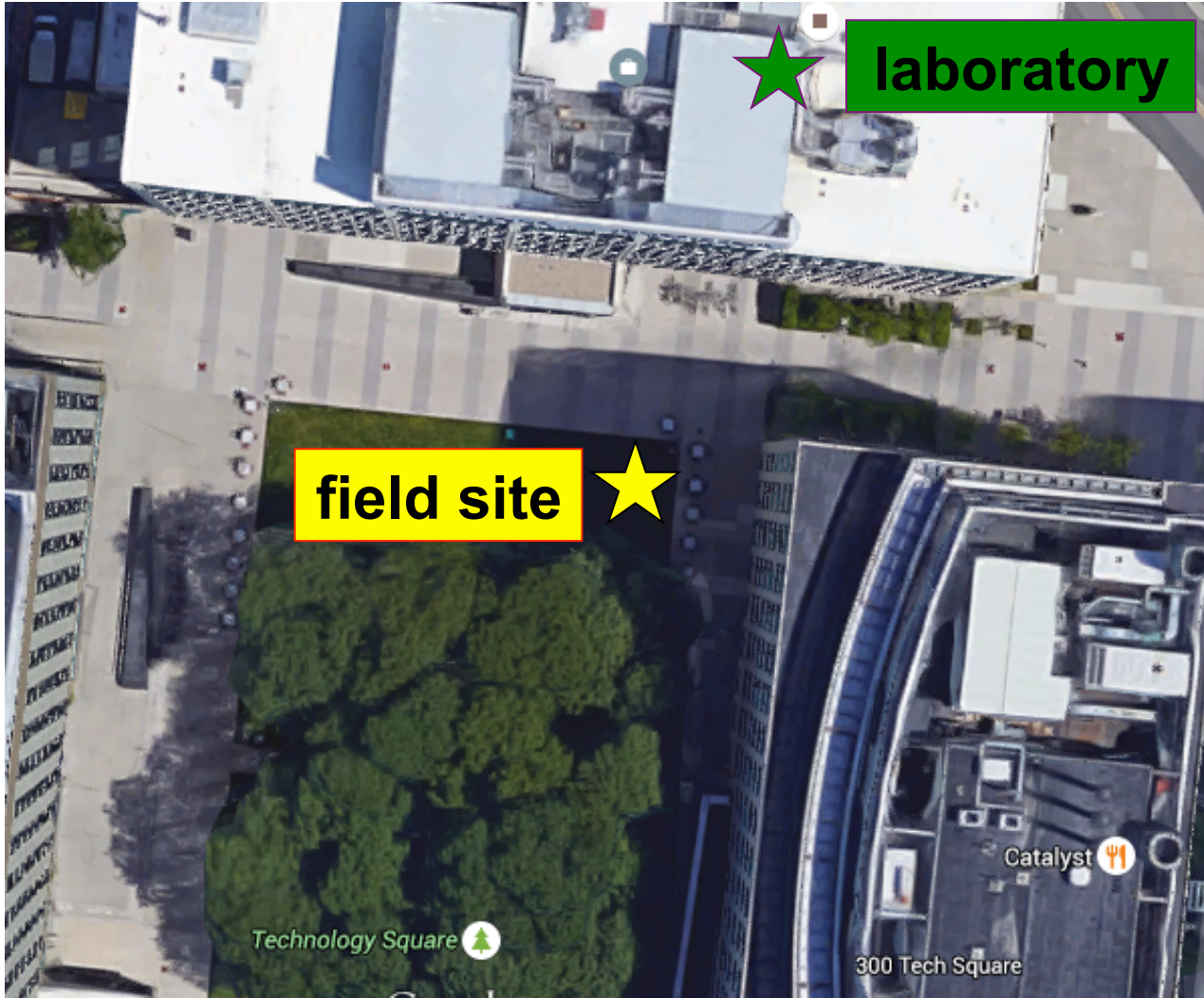


modularity

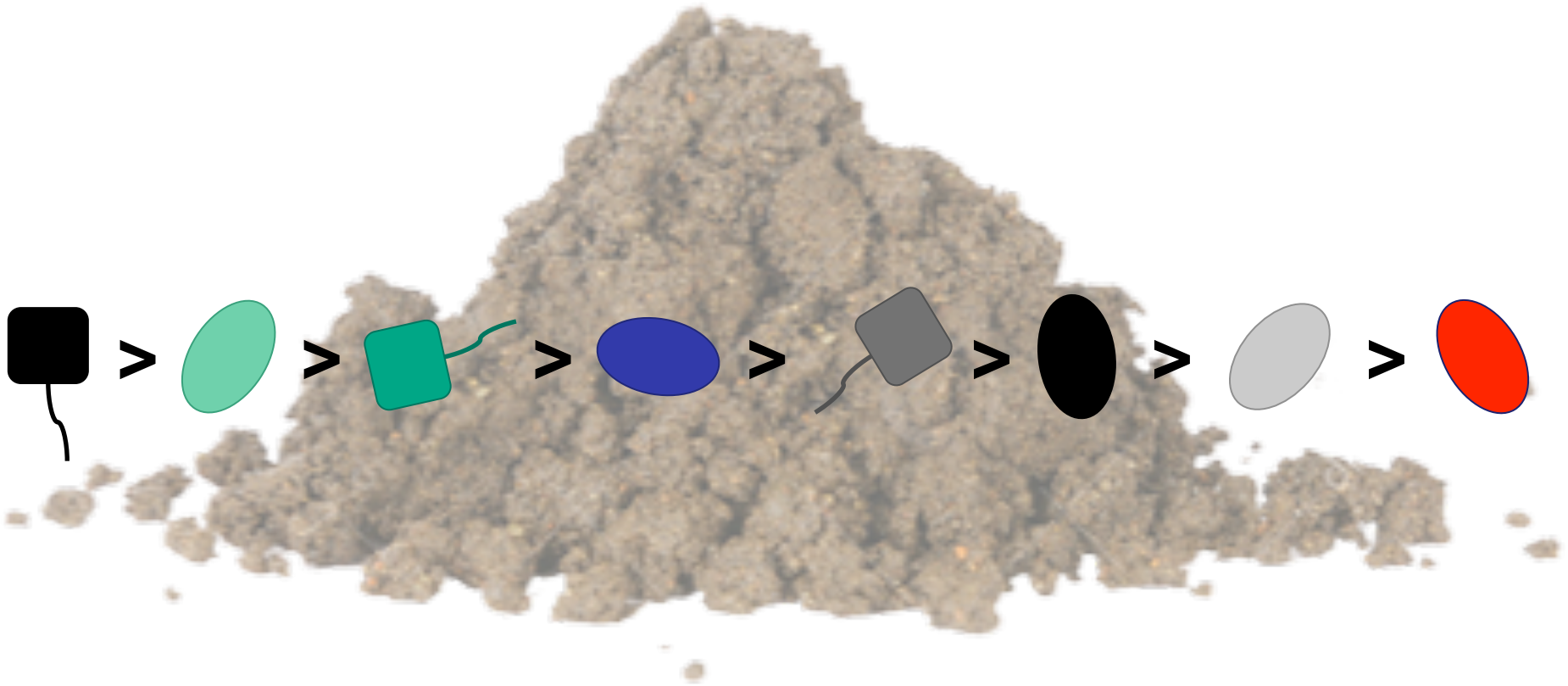
Community complexity may be reflected in the network of pairwise interactions



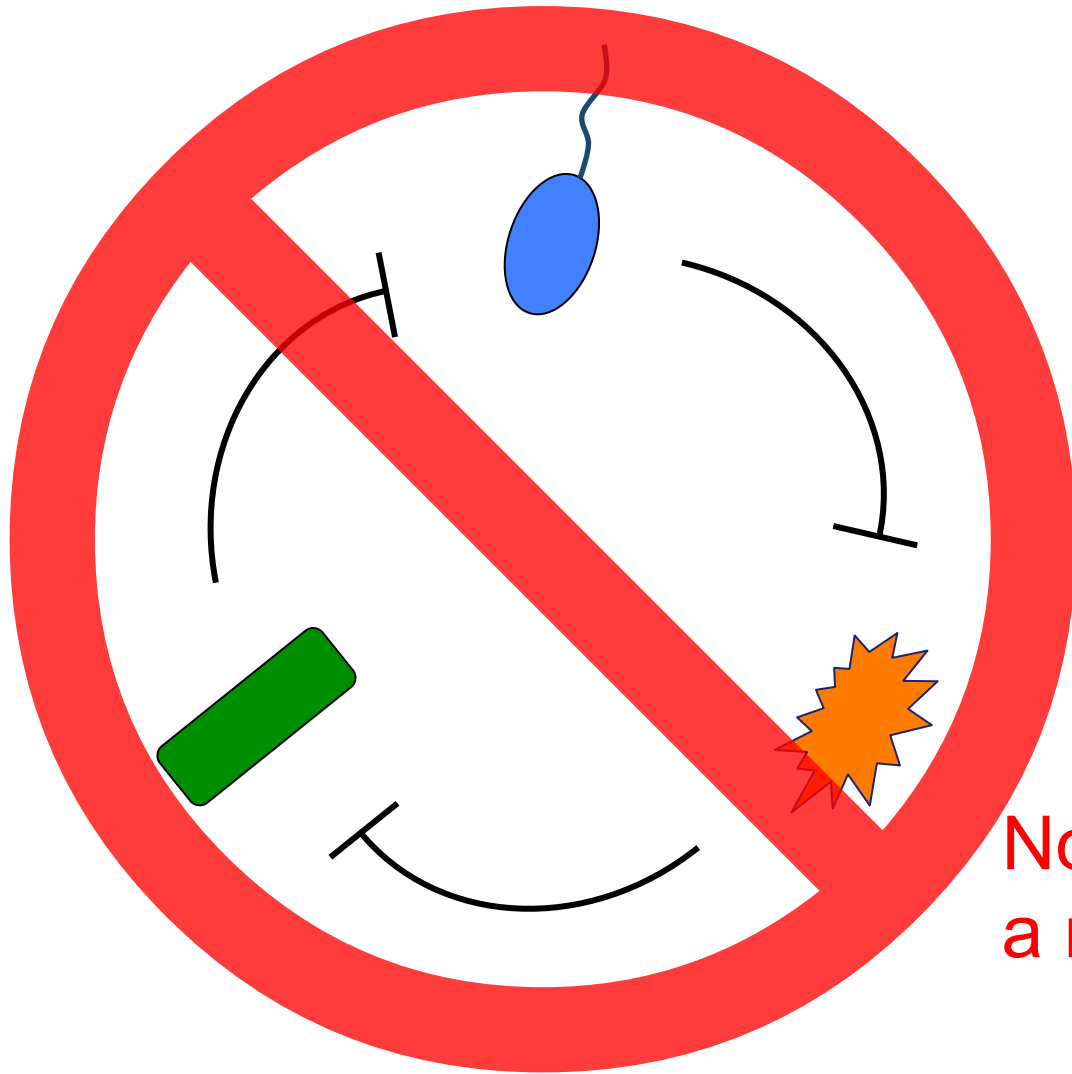
20 bacterial species from a single grain of soil



Our community is strongly hierarchical



RPS rare, so impact on diversity small



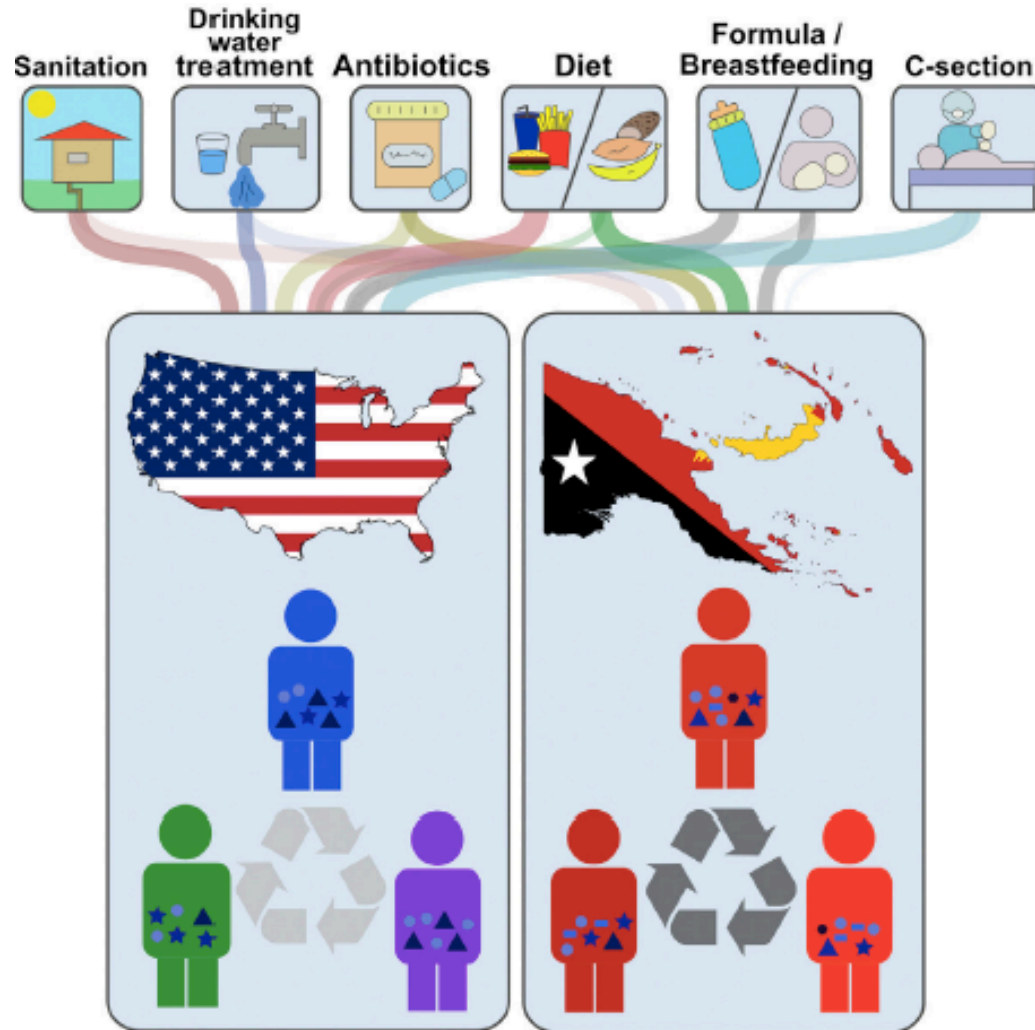
20 species



1,140 trios

None of these trios were
a rock-paper-scissors!

Different individuals have different microbiomes

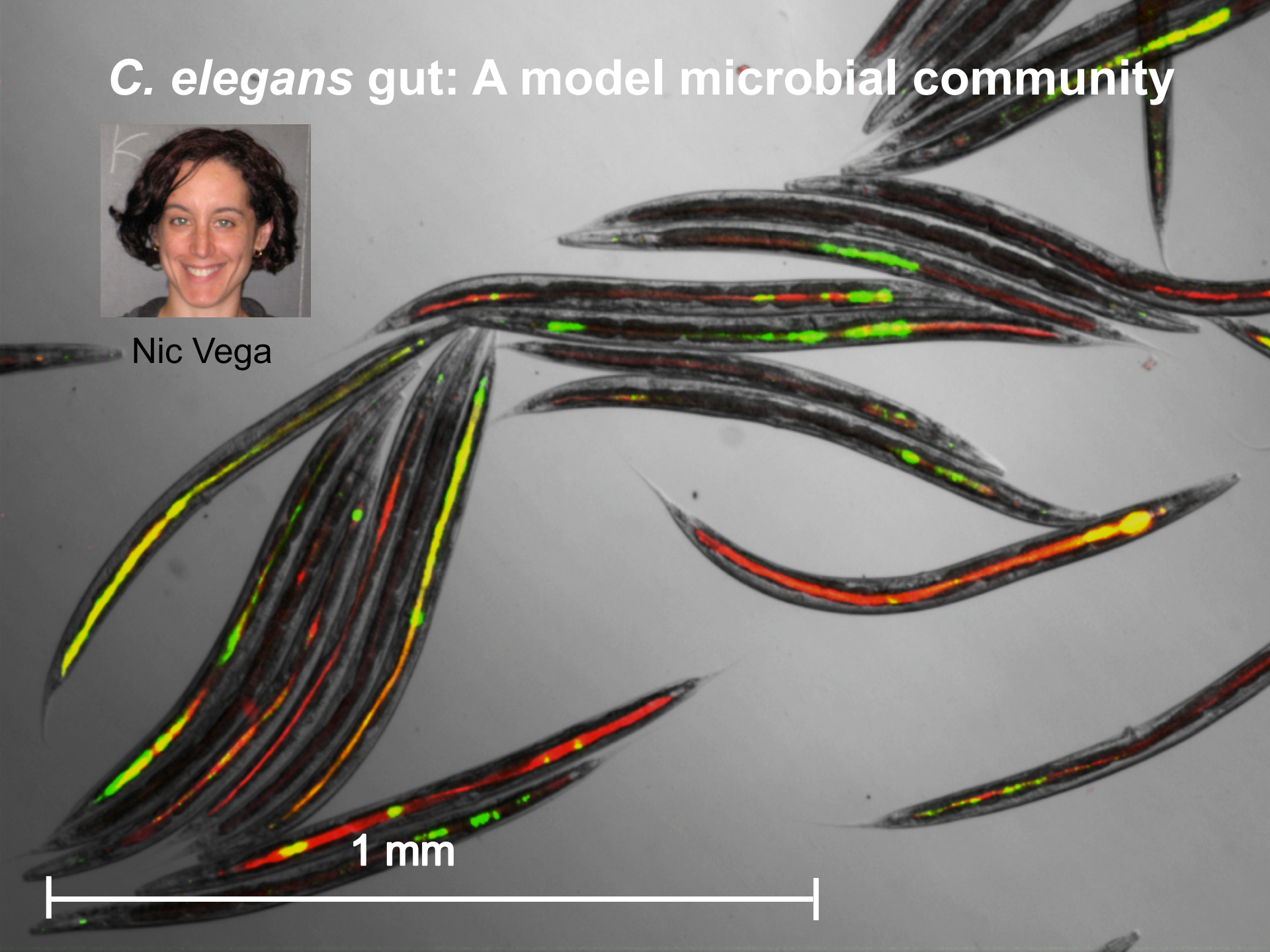


Martinez et al, *Cell Reports* (2015)

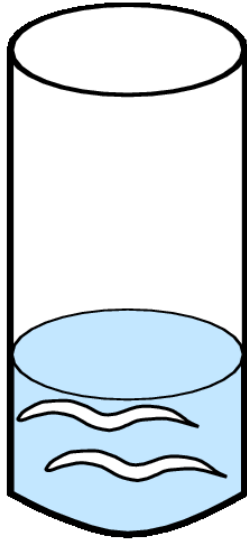
C. elegans gut: A model microbial community



Nic Vega

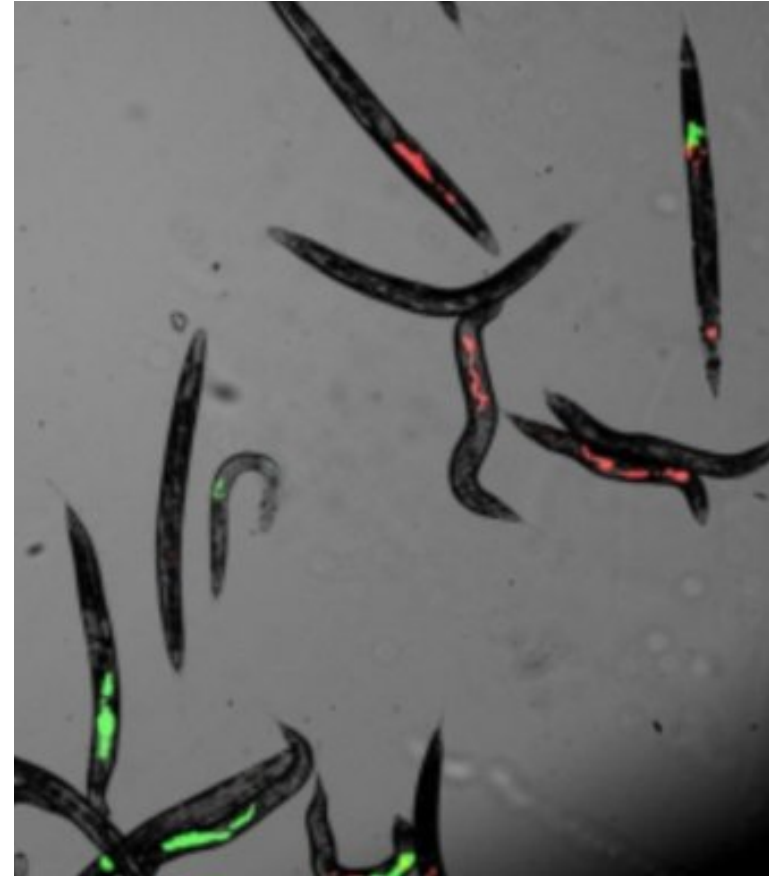
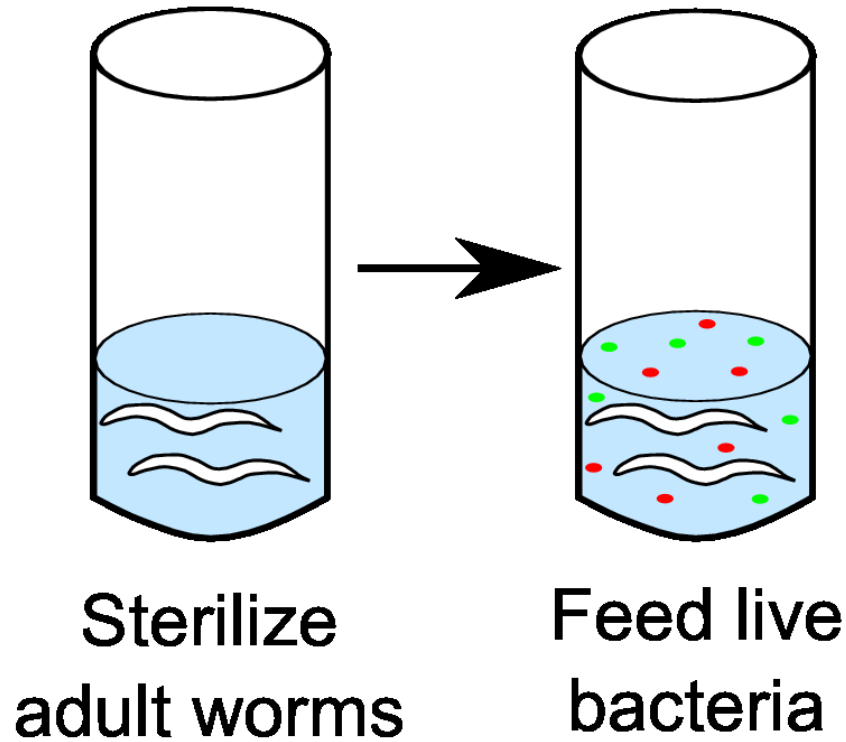


Worm microbiome has surprising heterogeneity

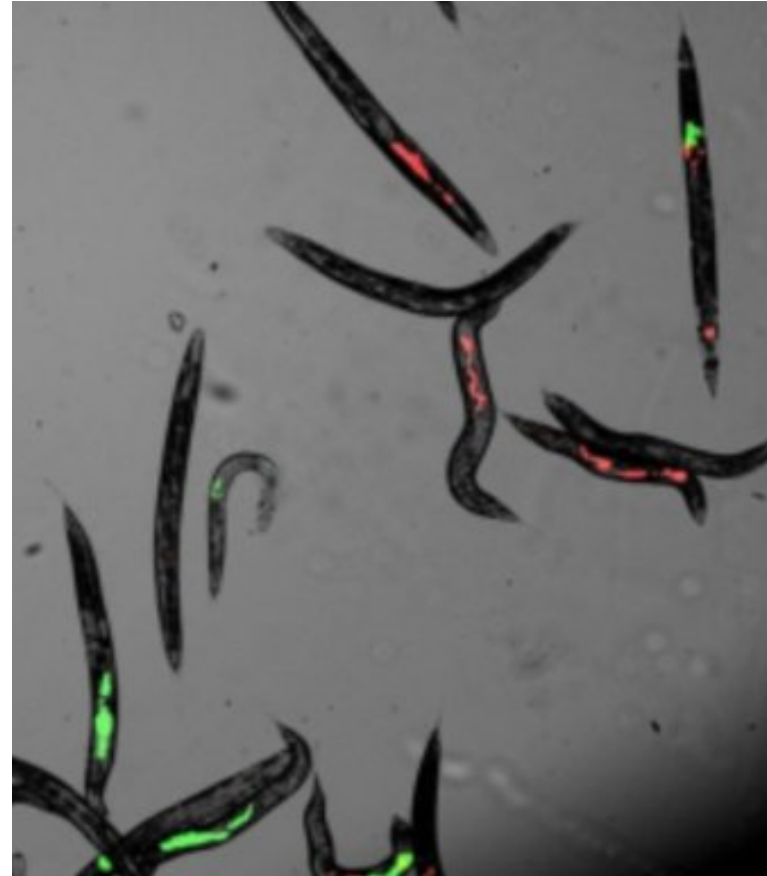
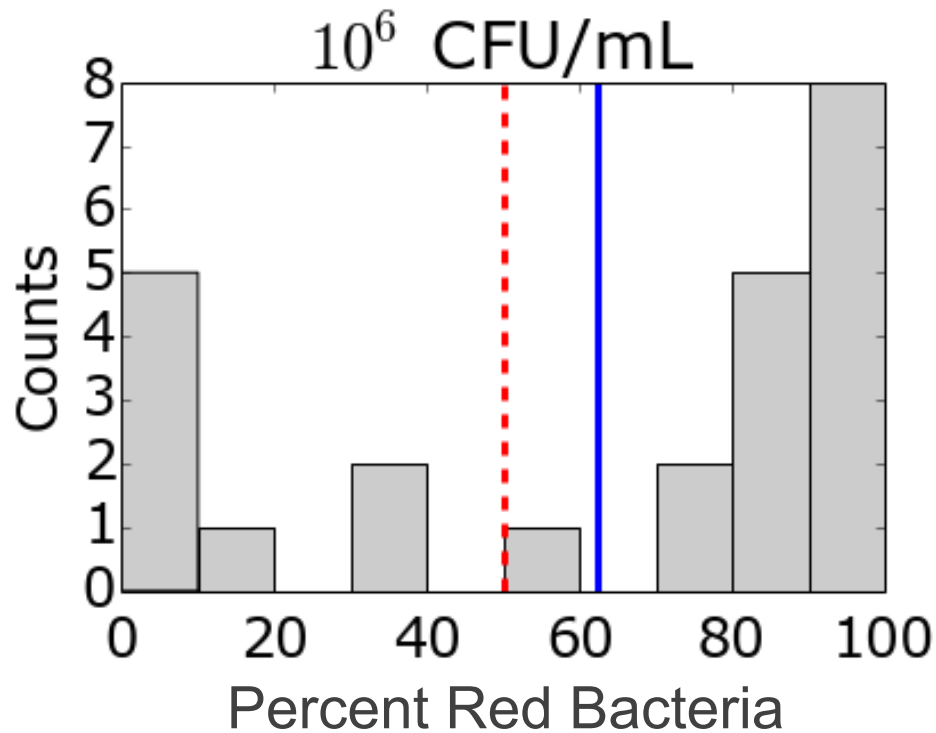


**Sterilize
adult worms**

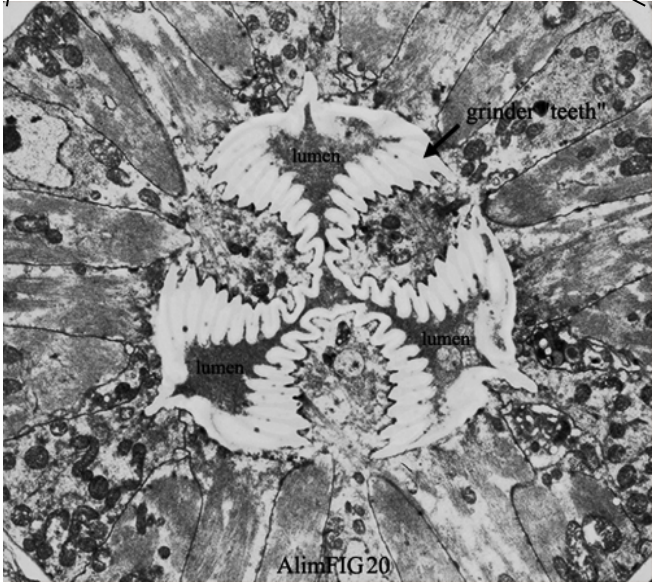
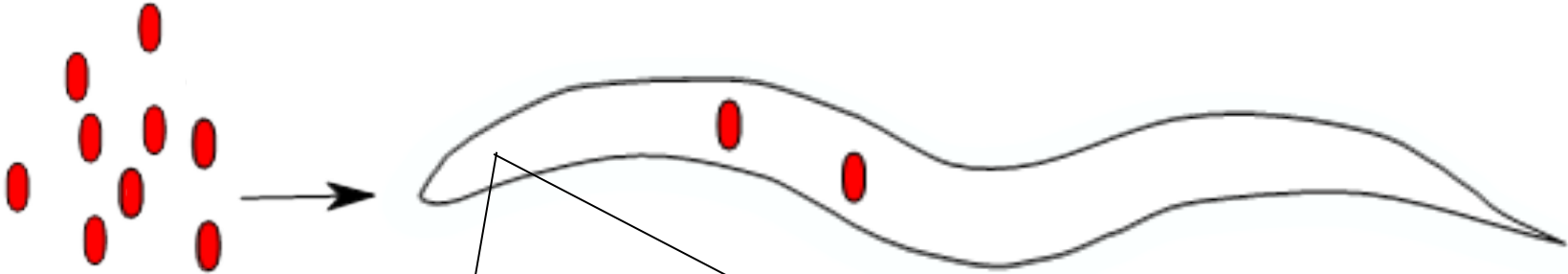
Worm microbiome has surprising heterogeneity



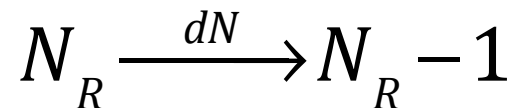
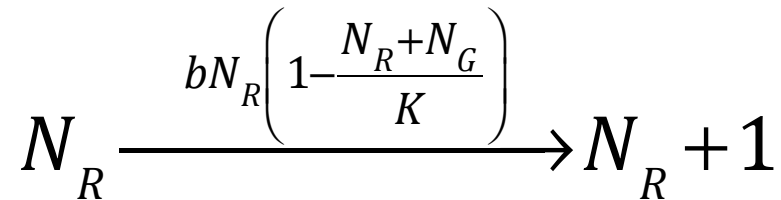
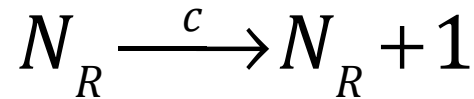
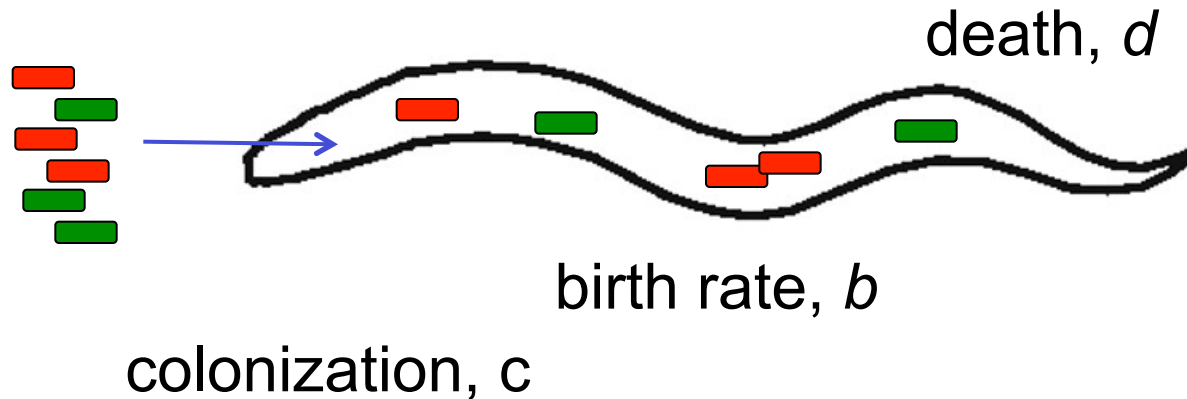
Worm microbiome has surprising heterogeneity



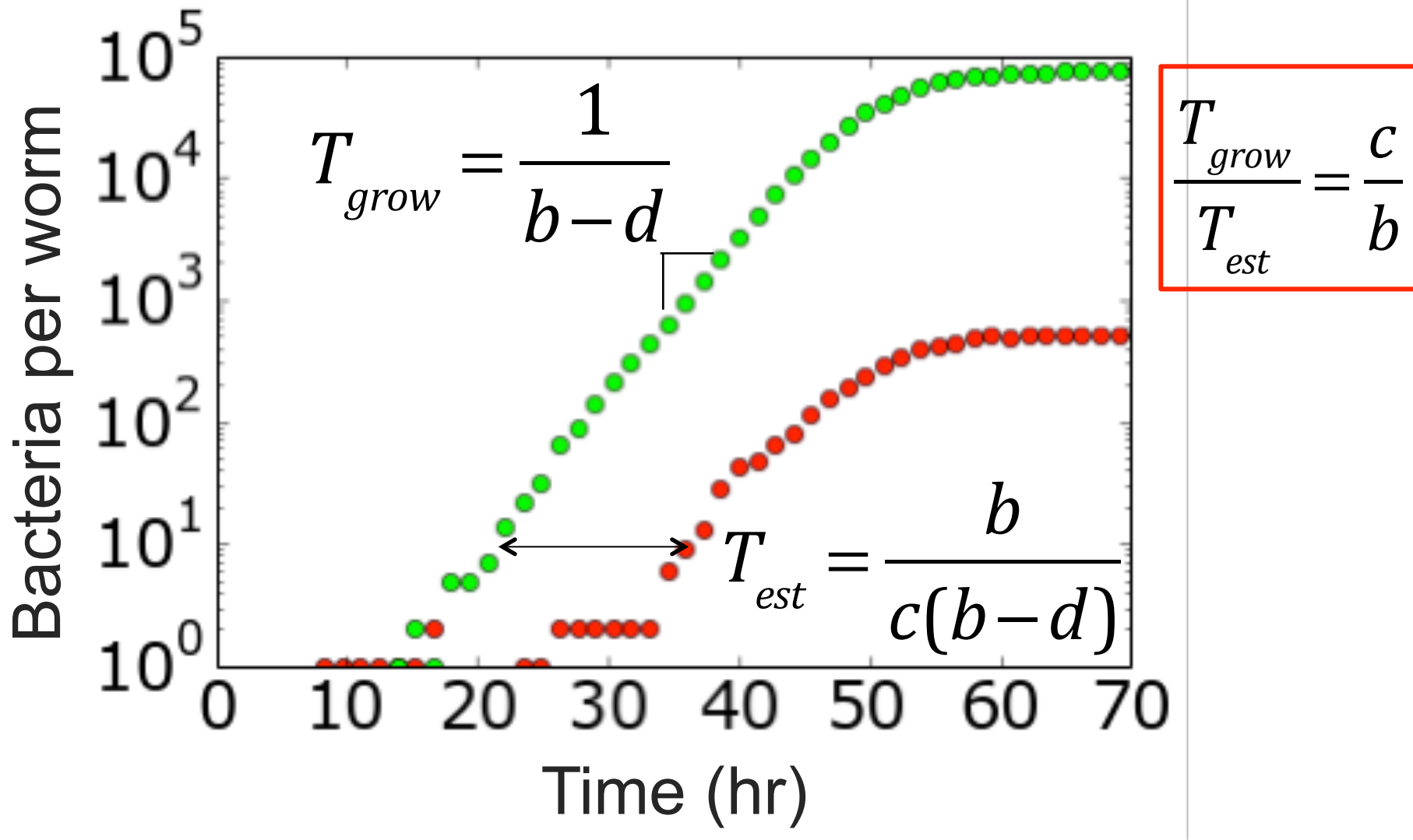
Most bacteria killed when eaten, so colonization rare



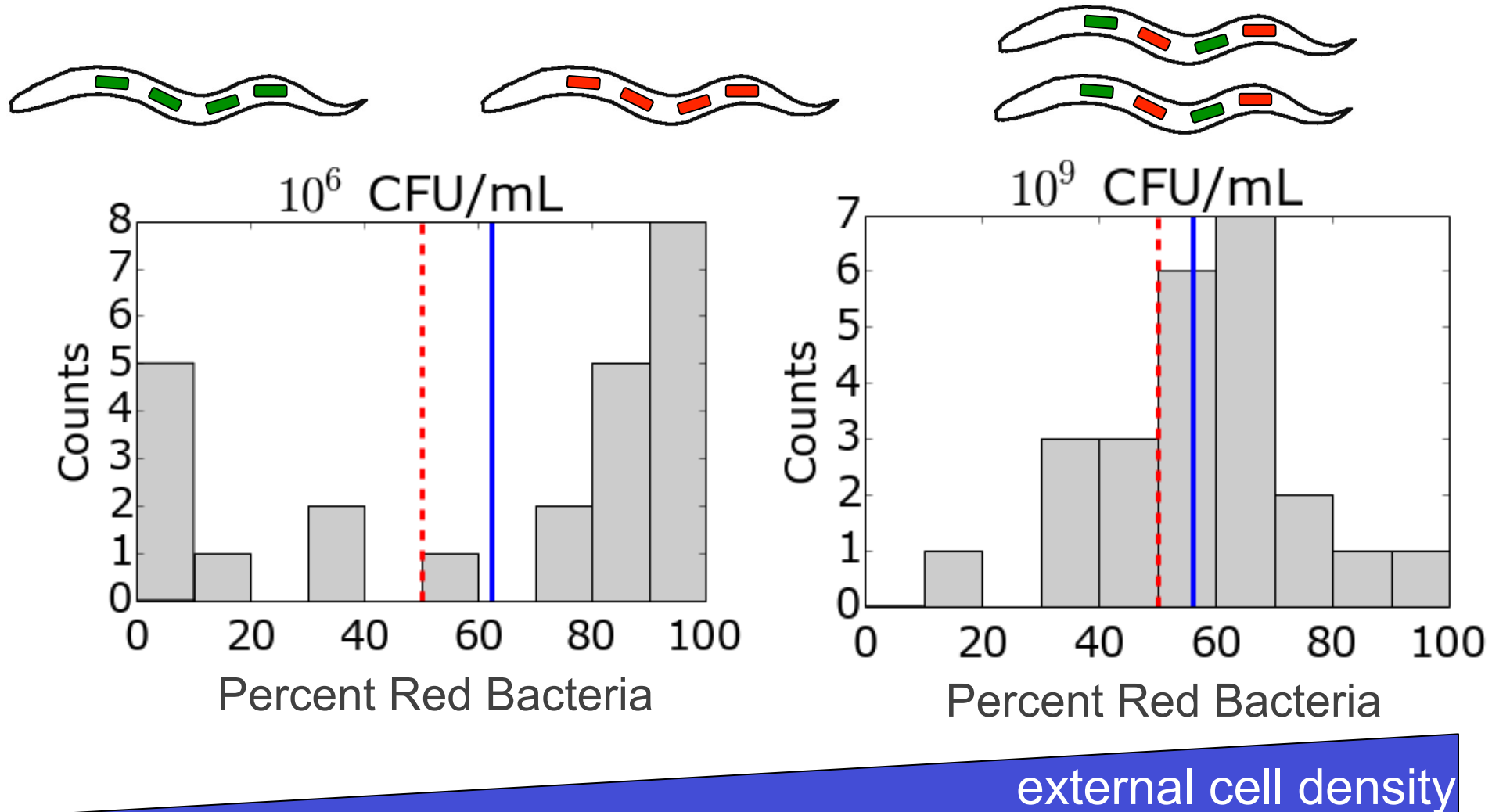
Simple stochastic model of colonization and growth



Simple stochastic model predicts heterogeneity determined by ratio of two timescales

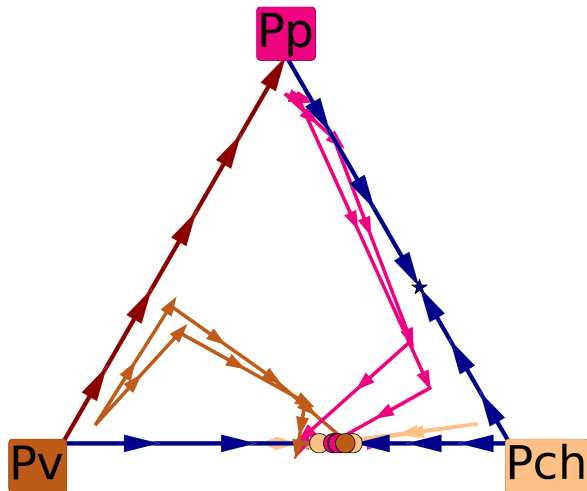
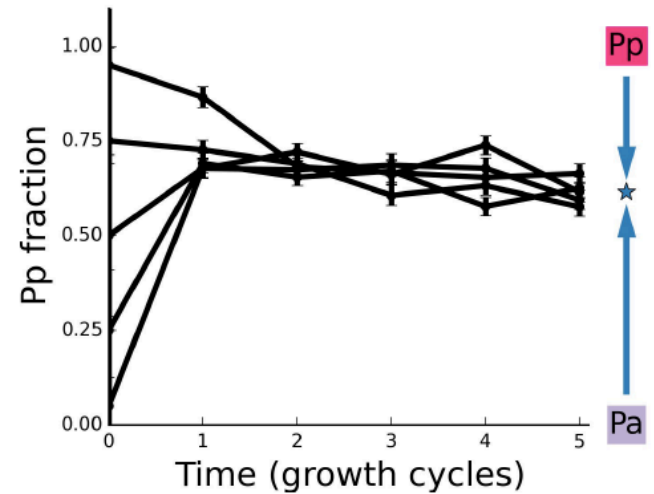


Worms fed high density bacteria display a unimodal distribution of community composition



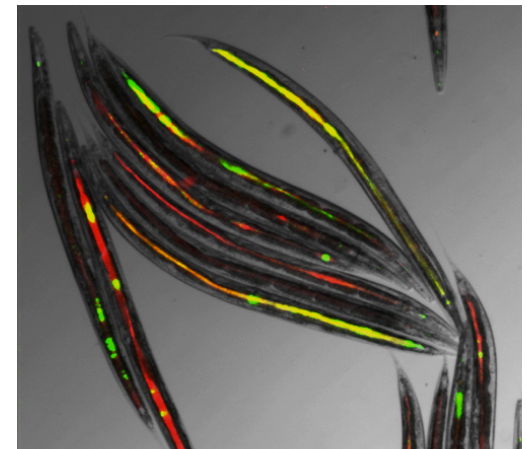
Summary

Pair-wise competition results in simple outcomes



Pairwise outcomes **predict** survival in trio 90% of the time

Stochastic colonization can dominate community assembly of the worm gut



Acknowledgements

Postdoctoral Scholars



Nic Vega



Christoph Ratzke



Shreyas Gokhale



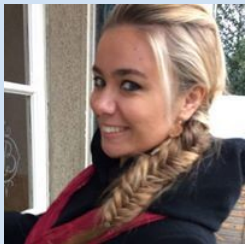
Jonathan Friedman



Avihu Yona



Tommaso Biancalani



Martina dal Bello

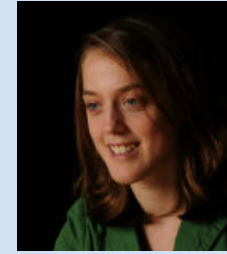


Alfonso Perez Escudero

Graduate Students



Clare Abreu



Arolyn Conwill



Logan Higgins



Saurabh Gandhi

Anthony Ortiz

Former



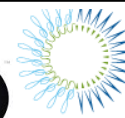
Lei Dai: UCLA



Kirill Korolev: BU



Alvaro Sanchez
Yale



THE PAUL G. ALLEN
FAMILY foundation



GORDON AND BETTY
MOORE
FOUNDATION



Postdoctoral Fellows

Faculty

Physics of
Living Systems



Todd Gingrich
Non-eq stat mech



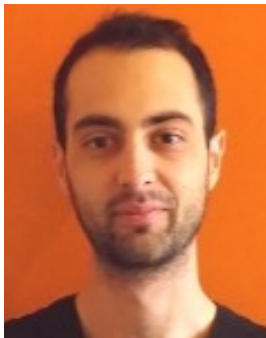
Peter Foster
Active matter exp



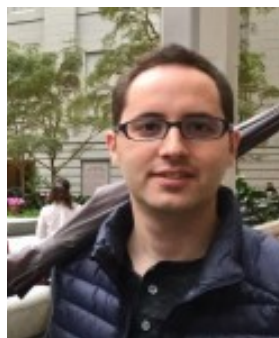
Arup Chakraborty
Viral evolution



Ibrahim Cisse
Live super-resolution



Alexandre Solon
Active matter



Jordan Horowitz
Non-eq stat mech



Jeremy England
Non-eq stat mech



Nikta Fakhri
Active matter



Jeff Gore
Population dynamics



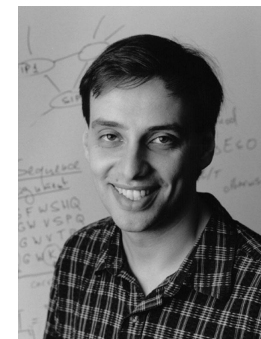
Sarah Marzen
Information Theory



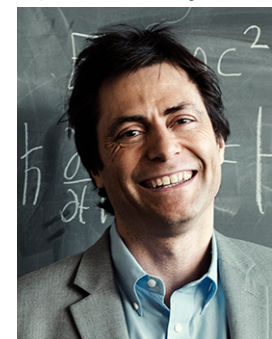
Dino Osmanovic
Biophysics theory



Mehran Kardar
Statistical physics



Leonid Mirny
Genome conformation



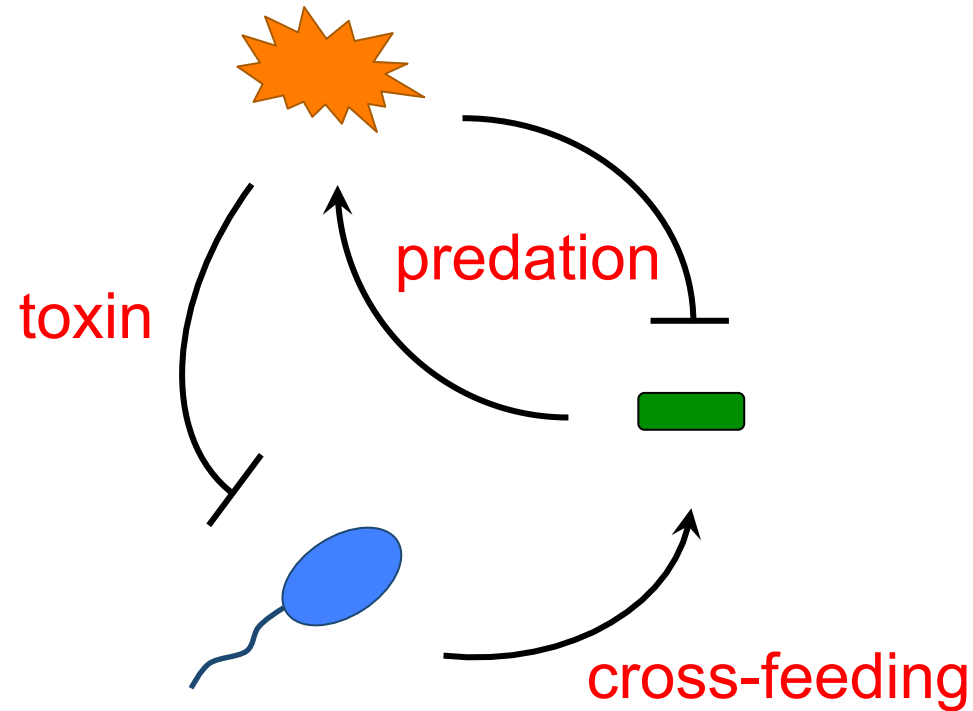
Max Tegmark
Neural dynamics



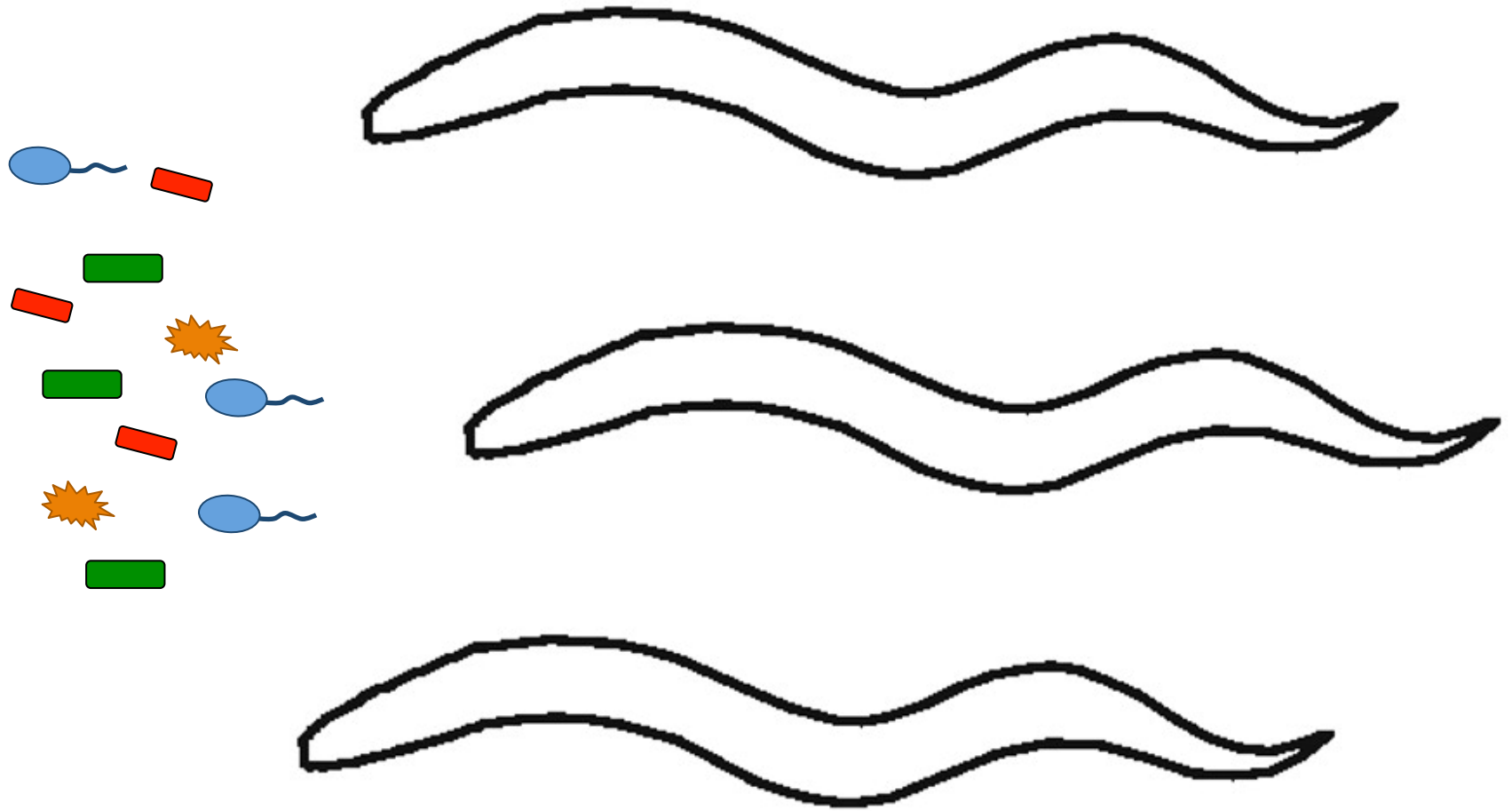
Microbial communities are complex and strongly-interacting



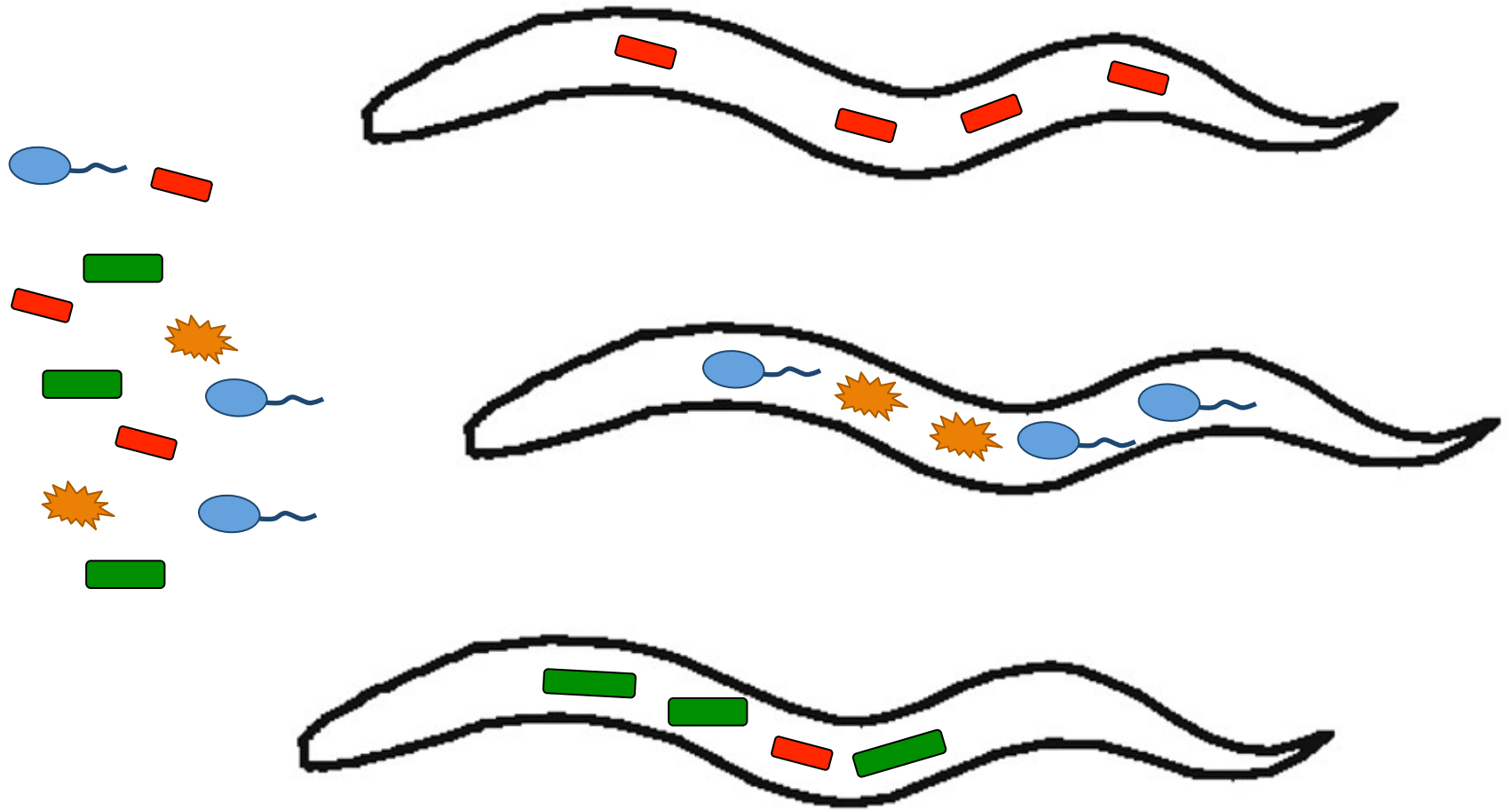
What factors stabilize the remarkable diversity of natural communities?



Stochastic colonization makes worms different



Stochastic colonization makes worms different



Heterogeneity may have dramatic health effects

