

Coexistence holes characterize the assembly and disassembly of multispecies systems

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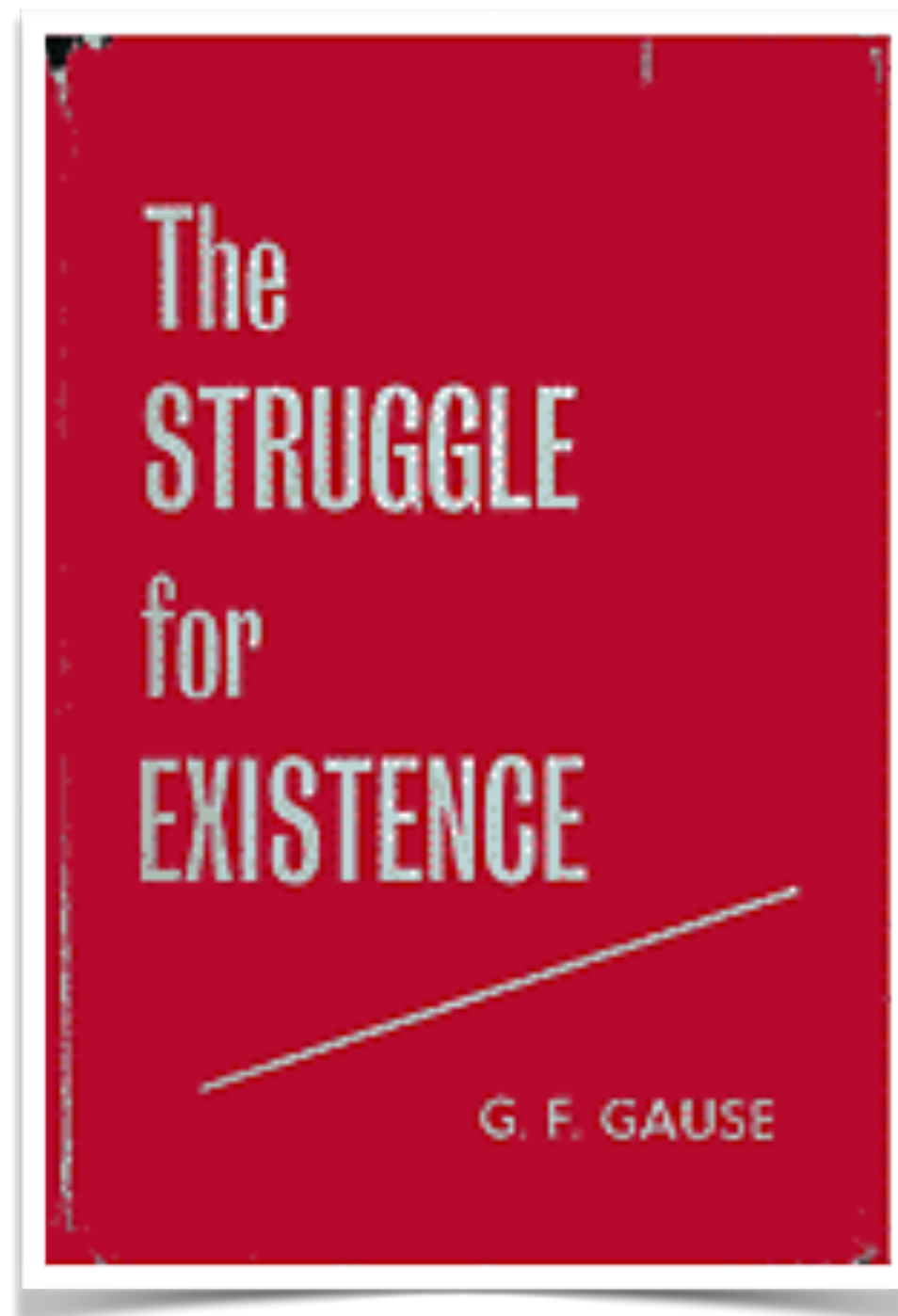
Evolutionary and ecological systems biology talks, Nov 2021

By Andrew L. Nelson

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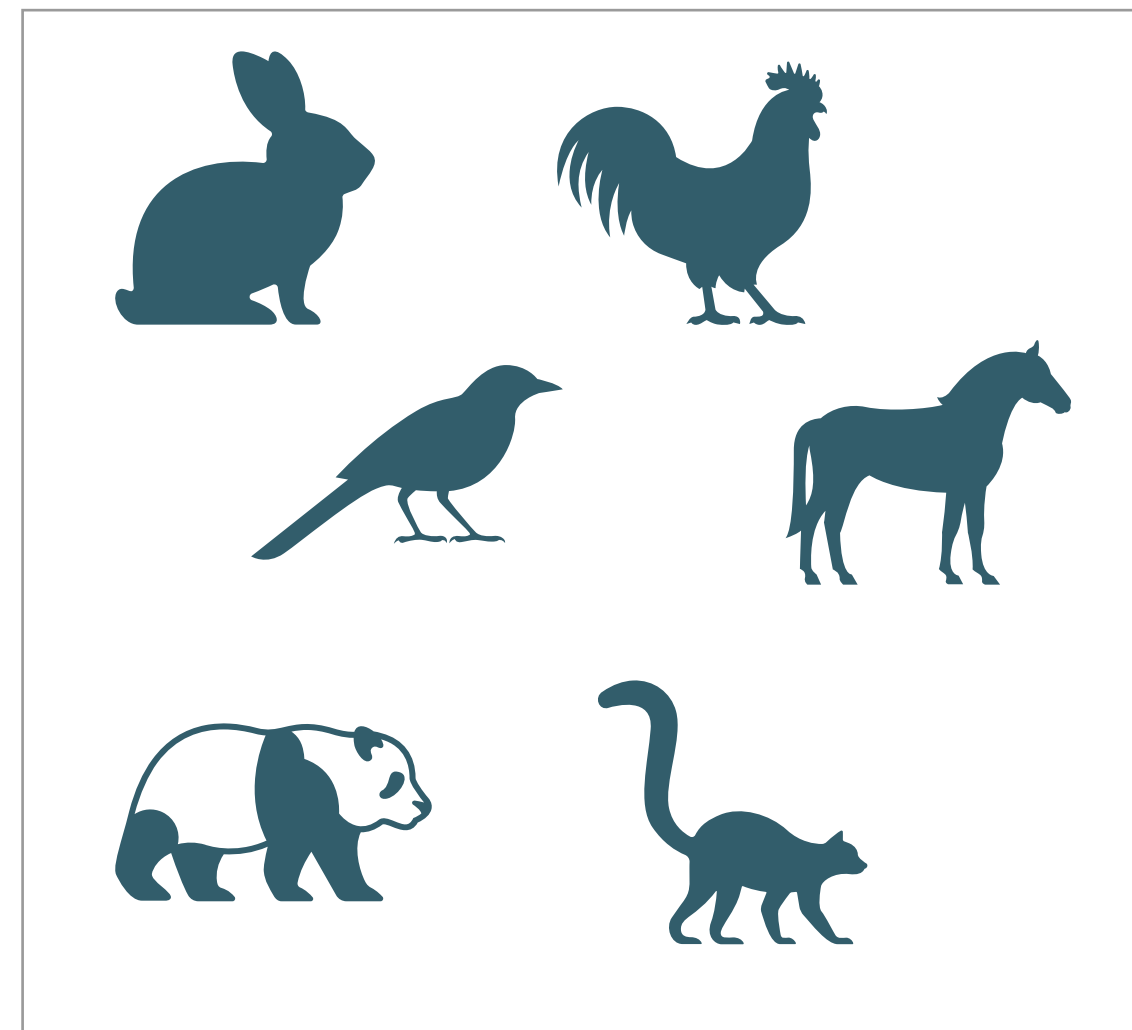
A long search for the **limits** of species coexistence

(maximum number of coexistent species with biotic and abiotic constraints)



Gause 1926

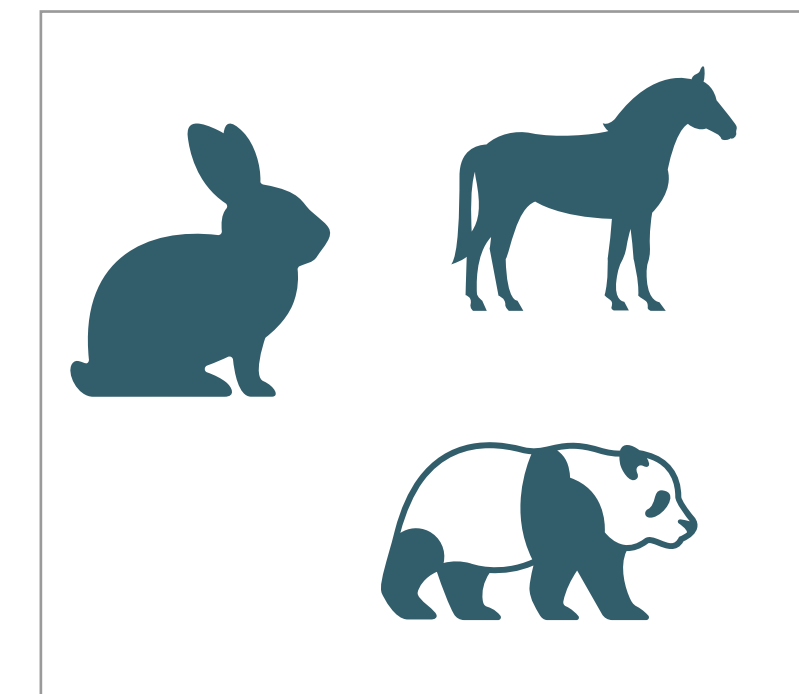
Species pool



biotic and abiotic
constraints



Limits of
species coexistence

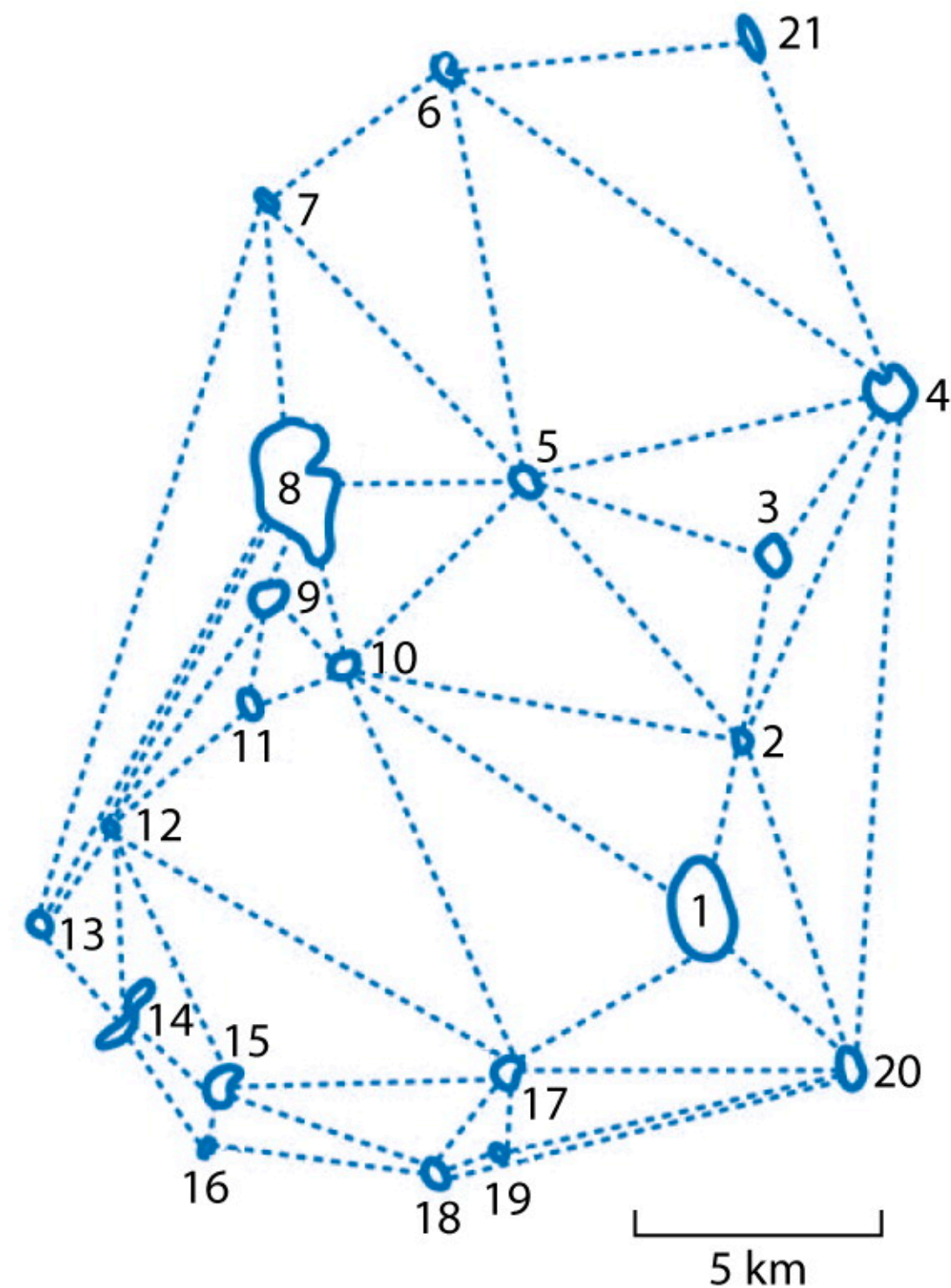


Mother Nature does not assemble her networks by
throwing n species together in one go.

–Karl Sigmund

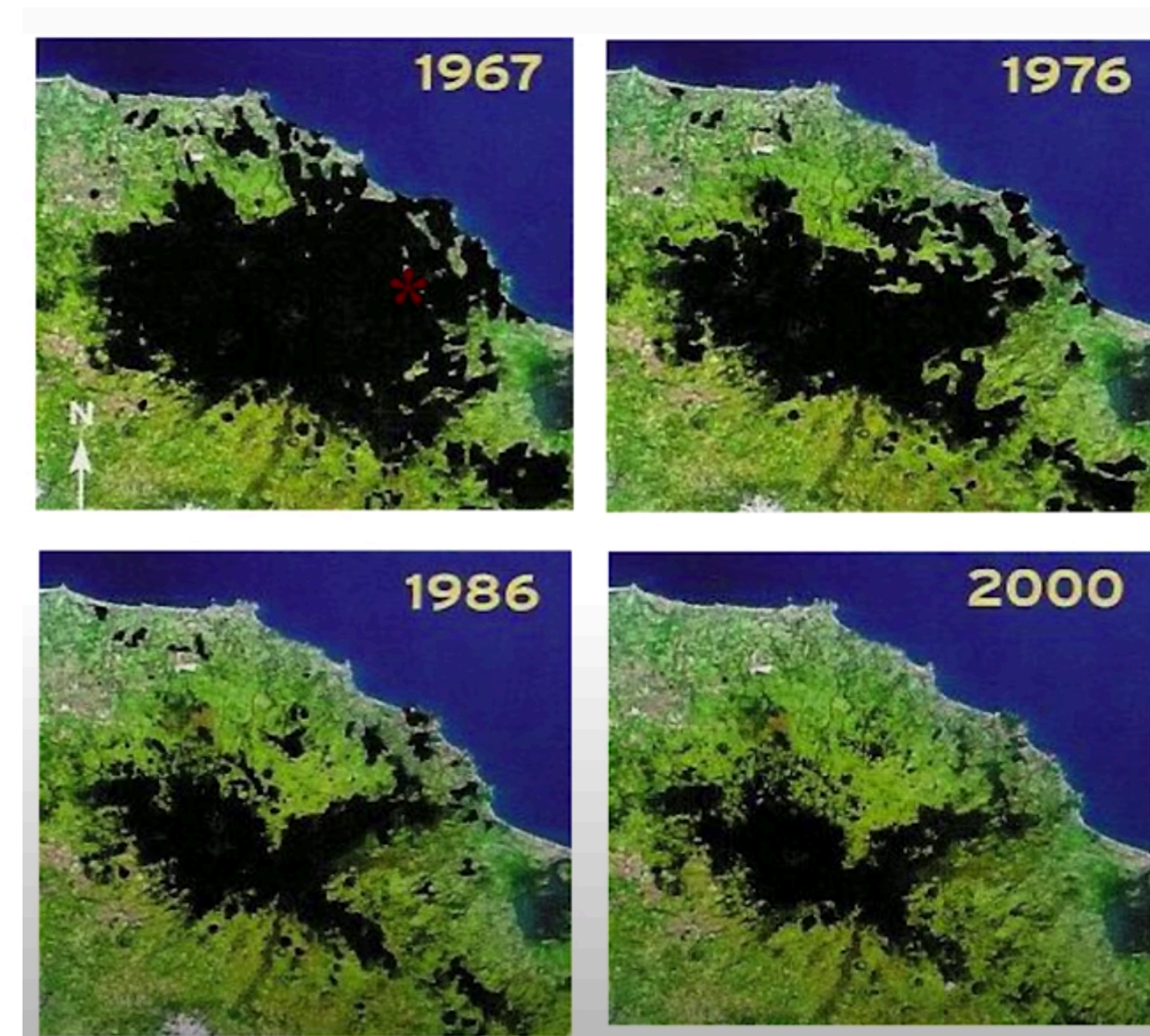
Natural communities are products of assembly and disassembly processes

Assembly (e.g. dispersal)



Dale and Fortin, 2009

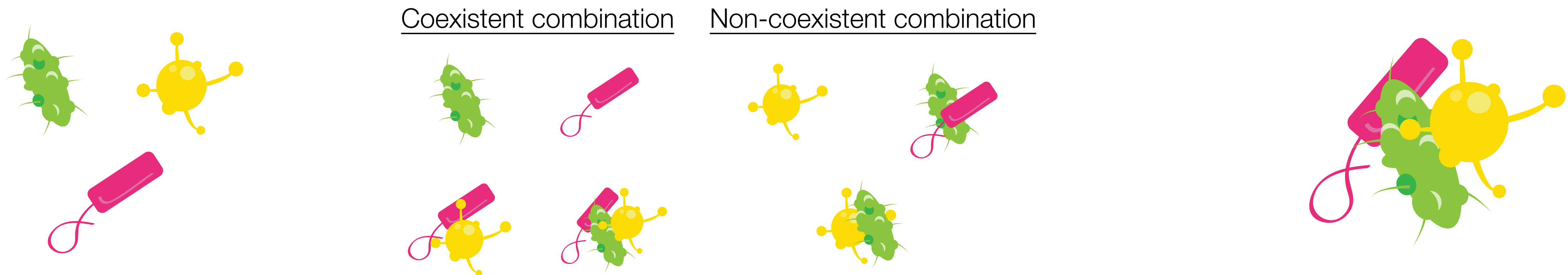
Disassembly (e.g. deforestation)



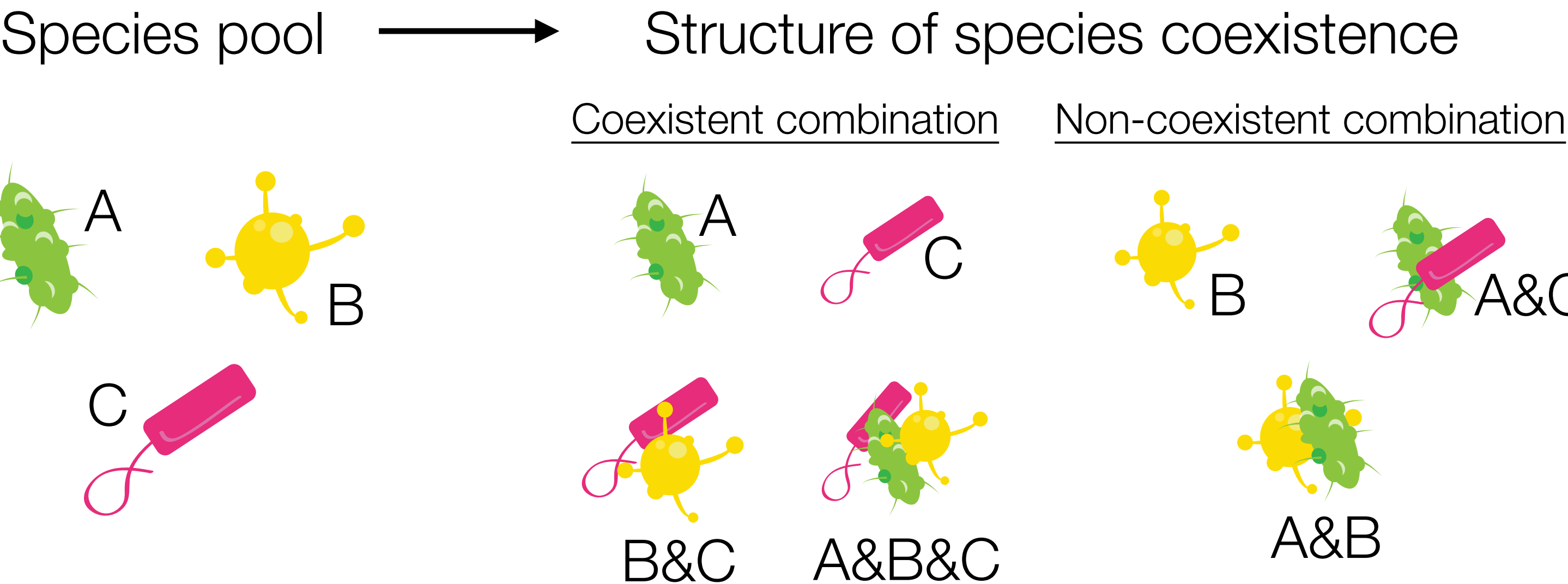
Mendoza & Dirzo, 2005

Structures of species coexistence below the limits

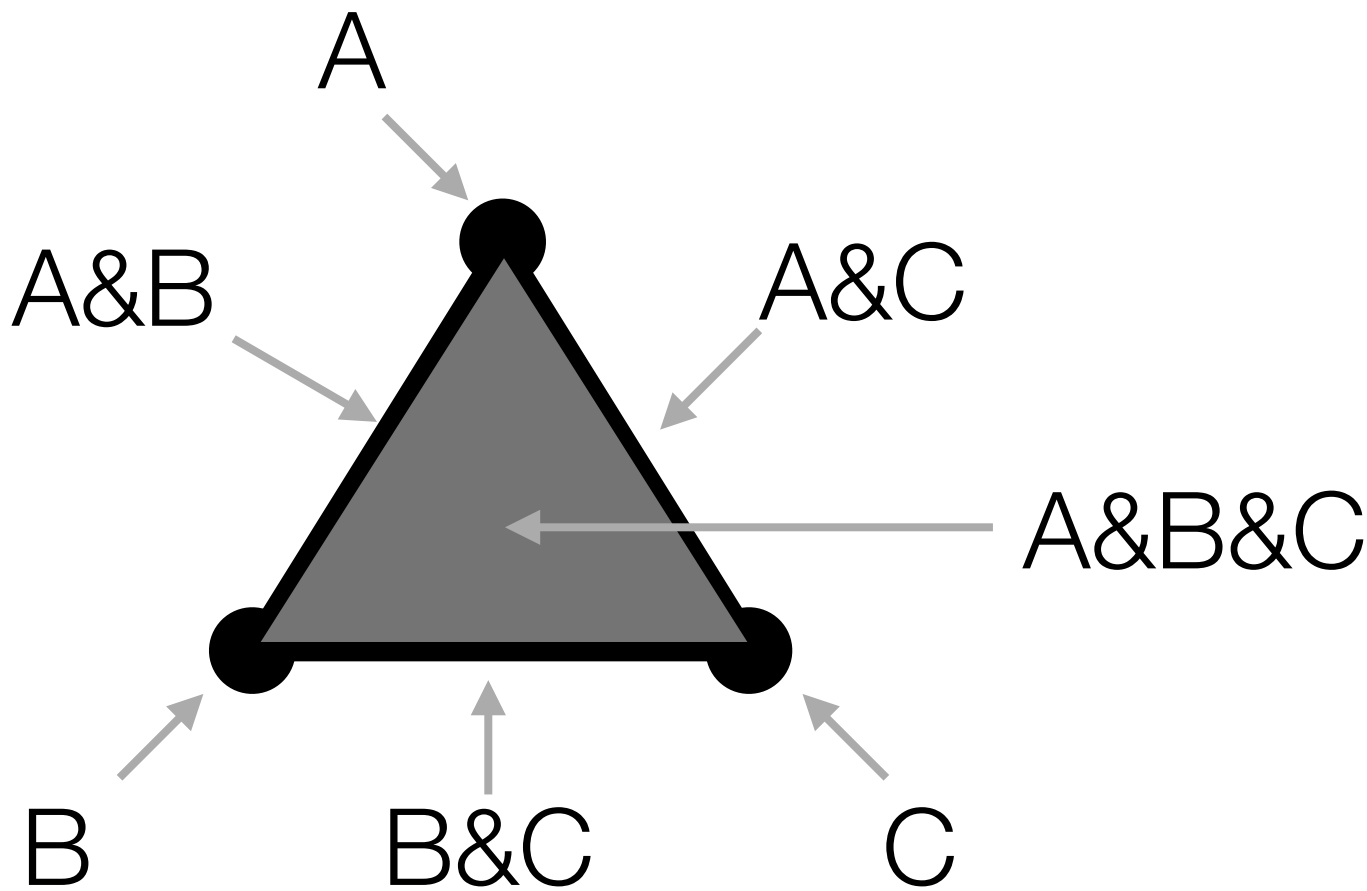
Species pool \longrightarrow **Structure of species coexistence** \longrightarrow Limits of species coexistence



Representing the structure of species coexistence as a hypergraph

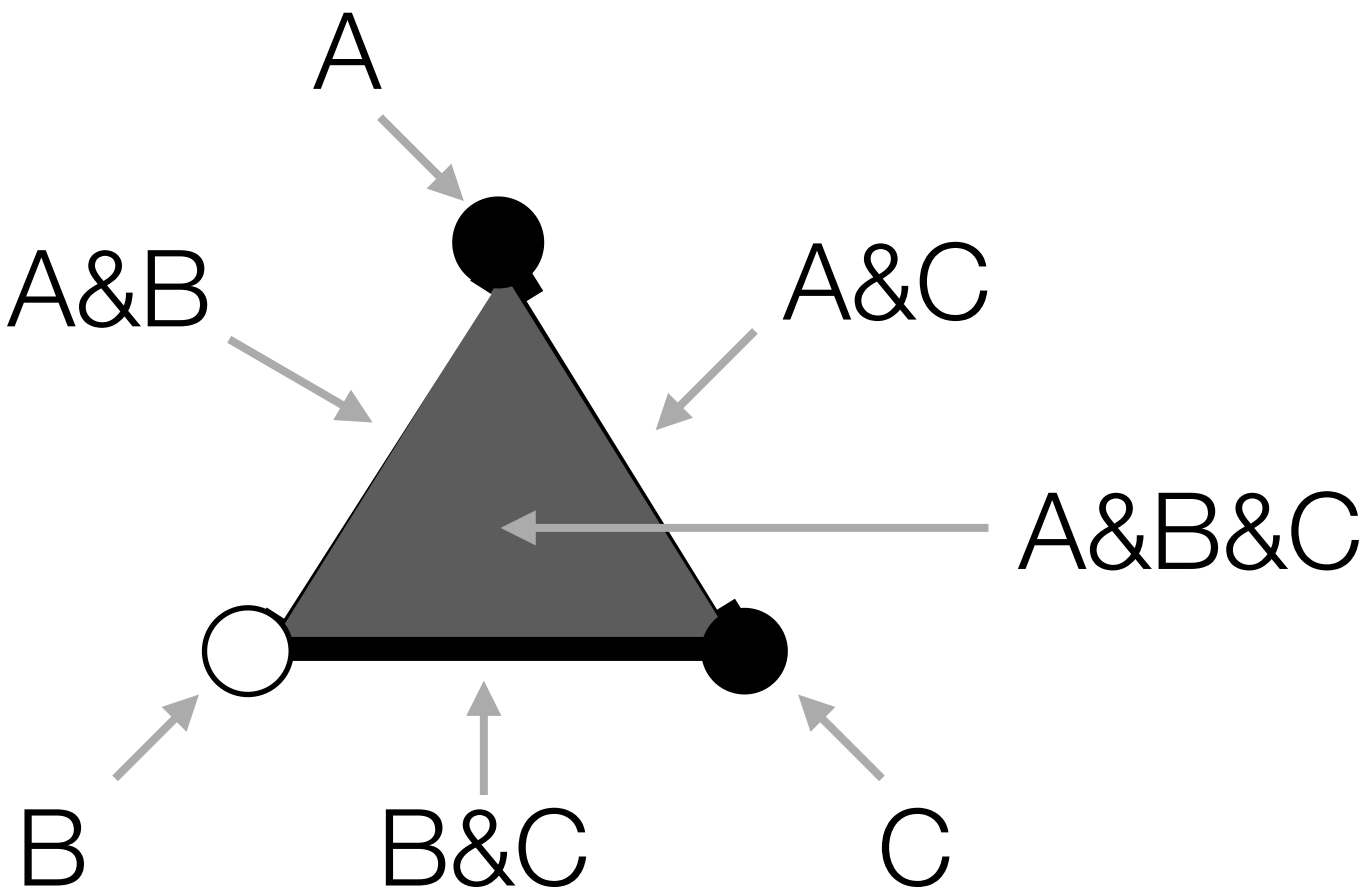


What is an hypergraph?



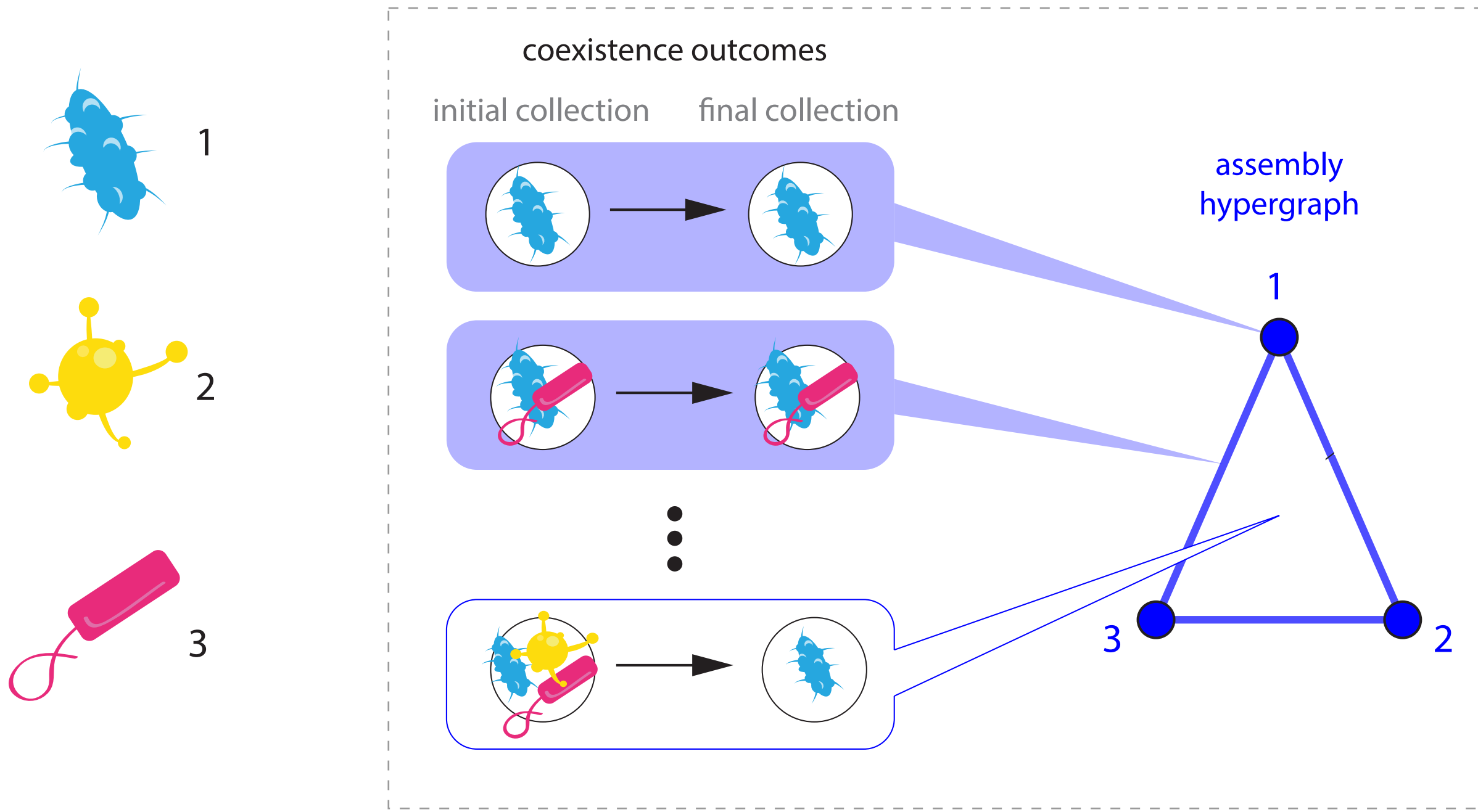
Non-coexistent \rightarrow Hollow
Coexistent \rightarrow Fill

Hypergraph representation

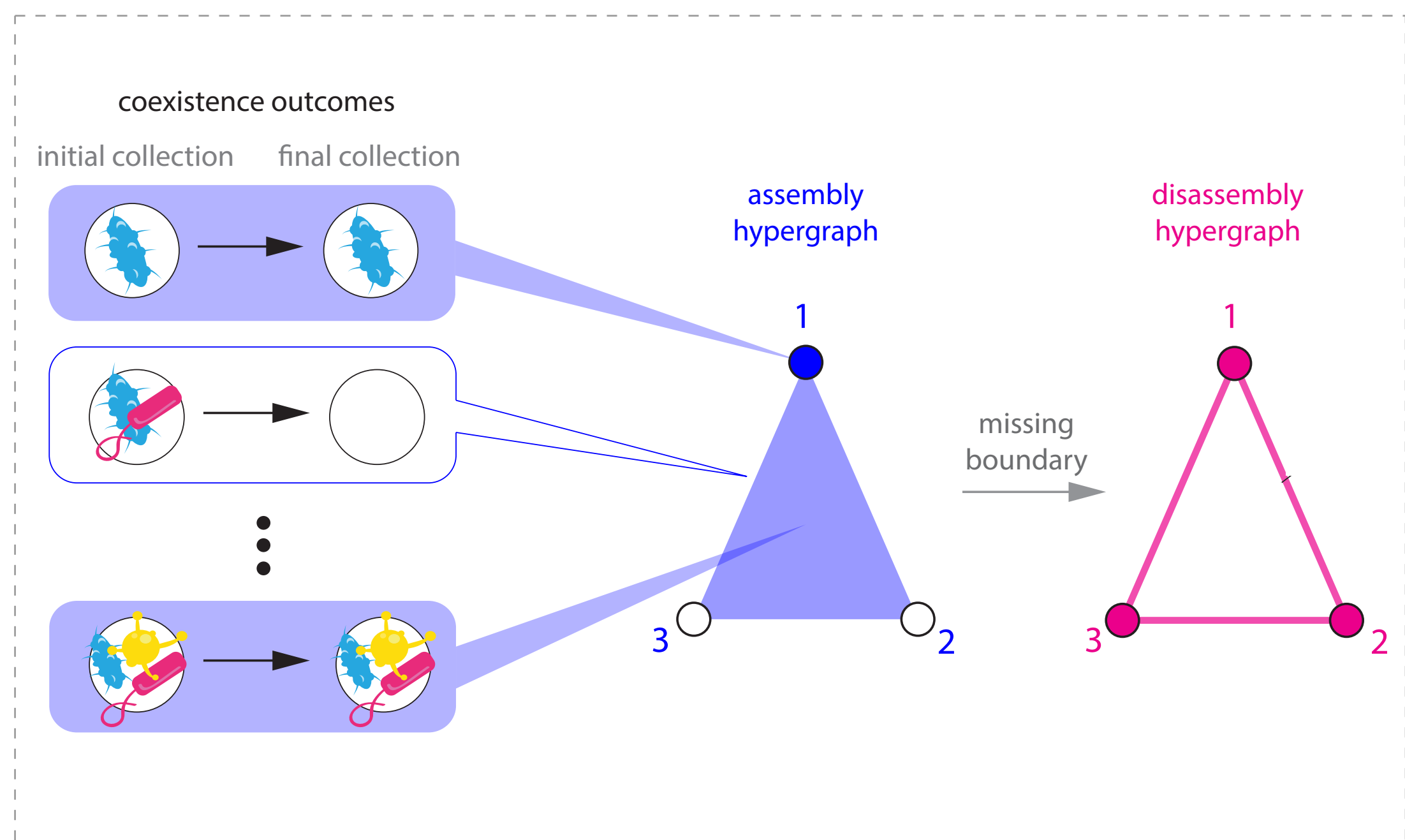


Coexistent species compositions form an **assembly** hypergraph
Non-coexistent species compositions form a **disassembly** hypergraph

Example of **assembly** hypergraph



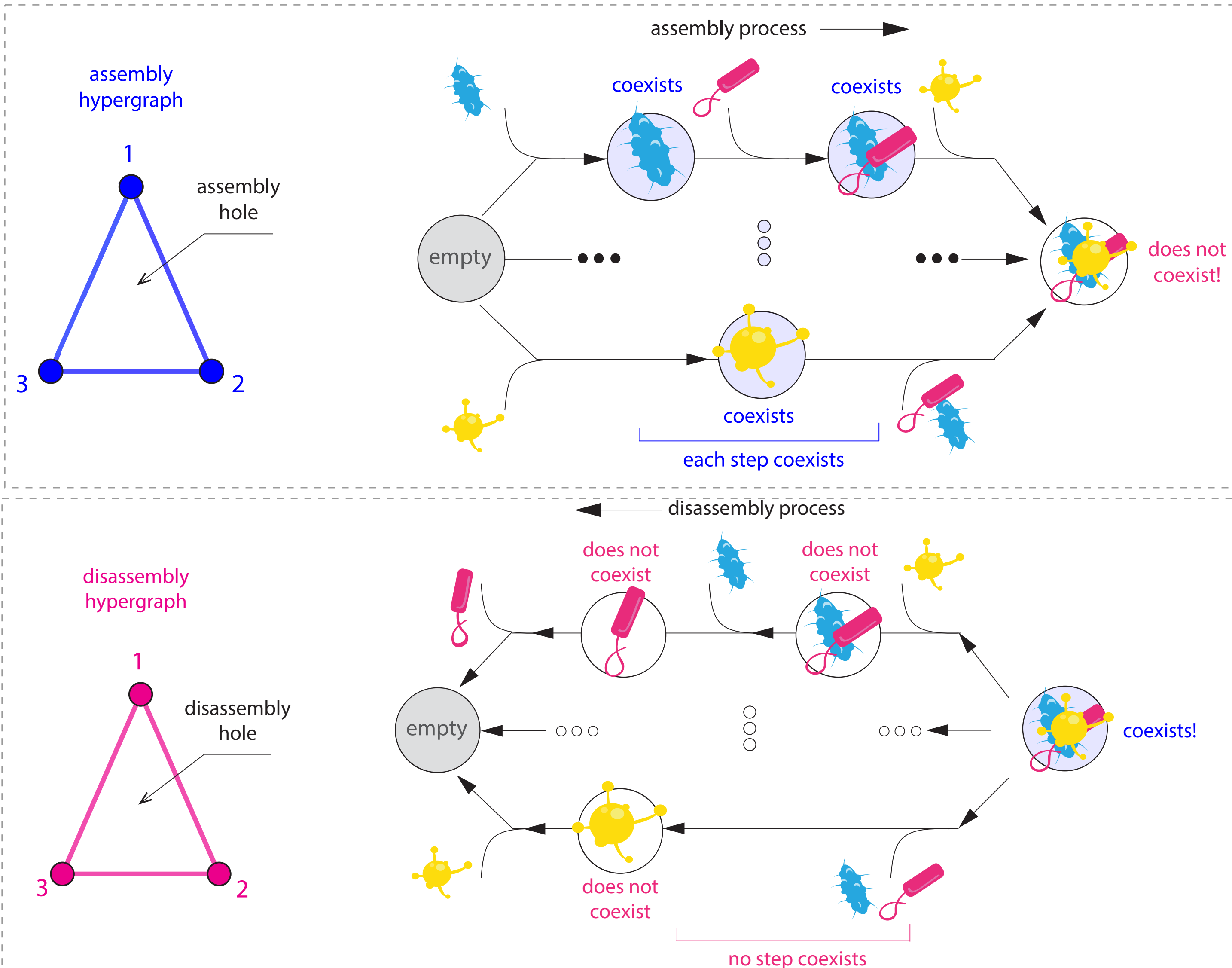
Example of **disassembly** hypergraph



Coexistence holes characterize **unexpected breakdowns** in the assembly/disassembly process

Assembly holes
in assembly process

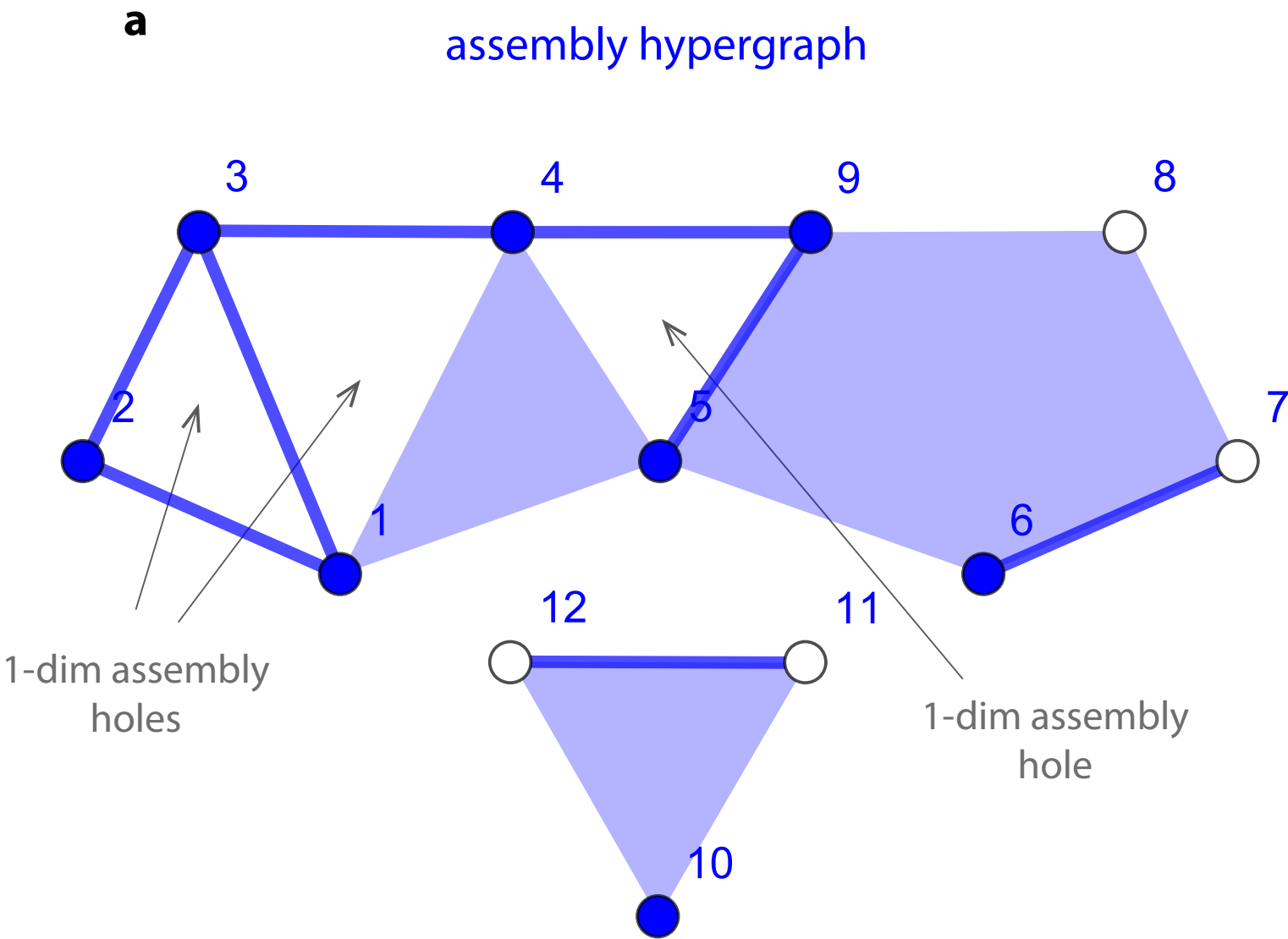
Disassembly holes
in disassembly process



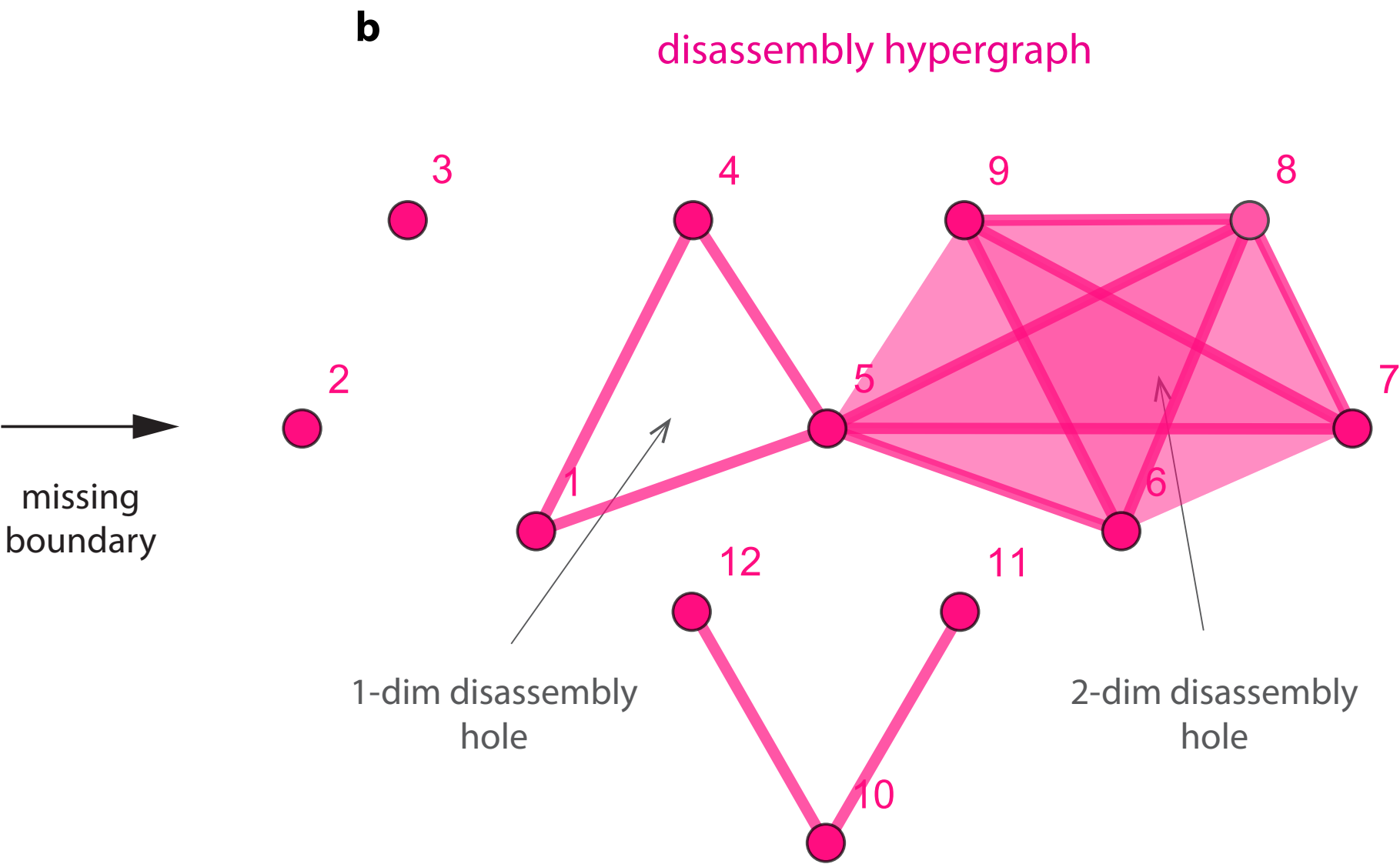
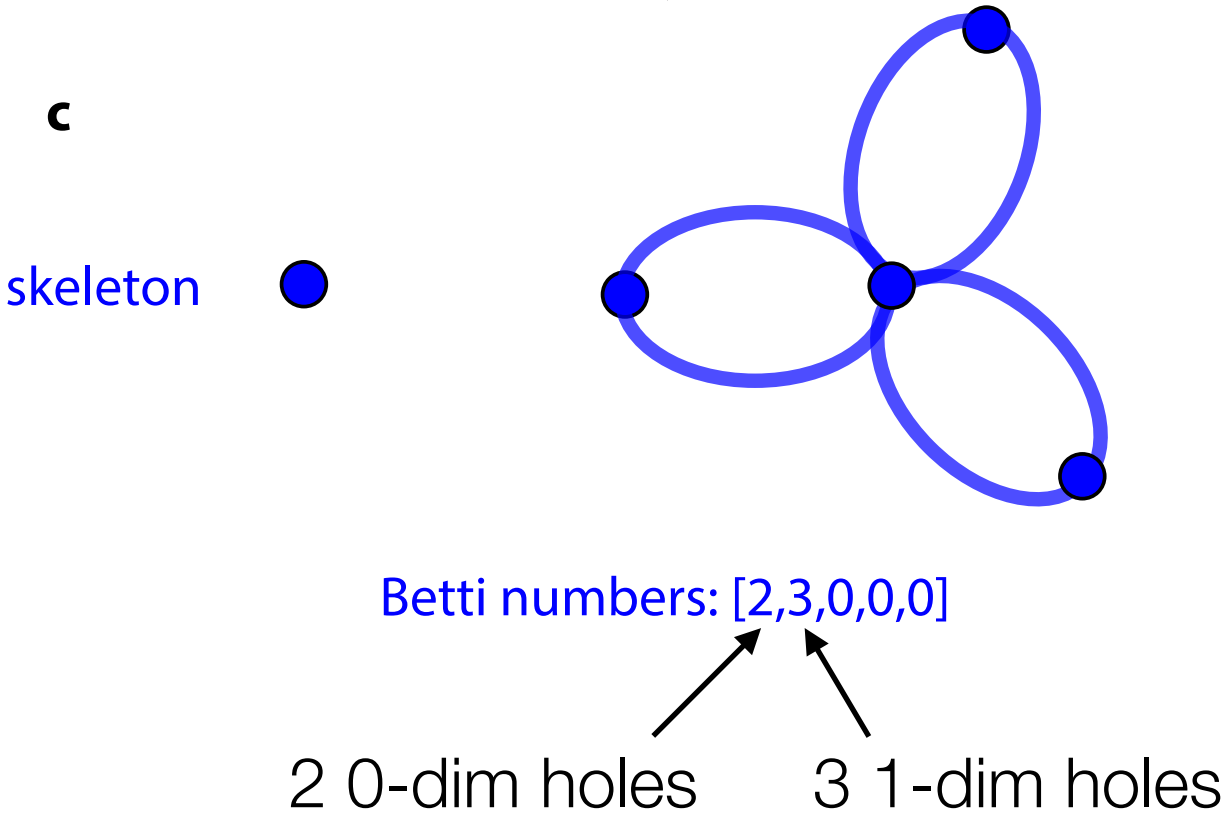
e.g. 3 species competing for 2 resources

e.g. rock-paper-scissor dynamics

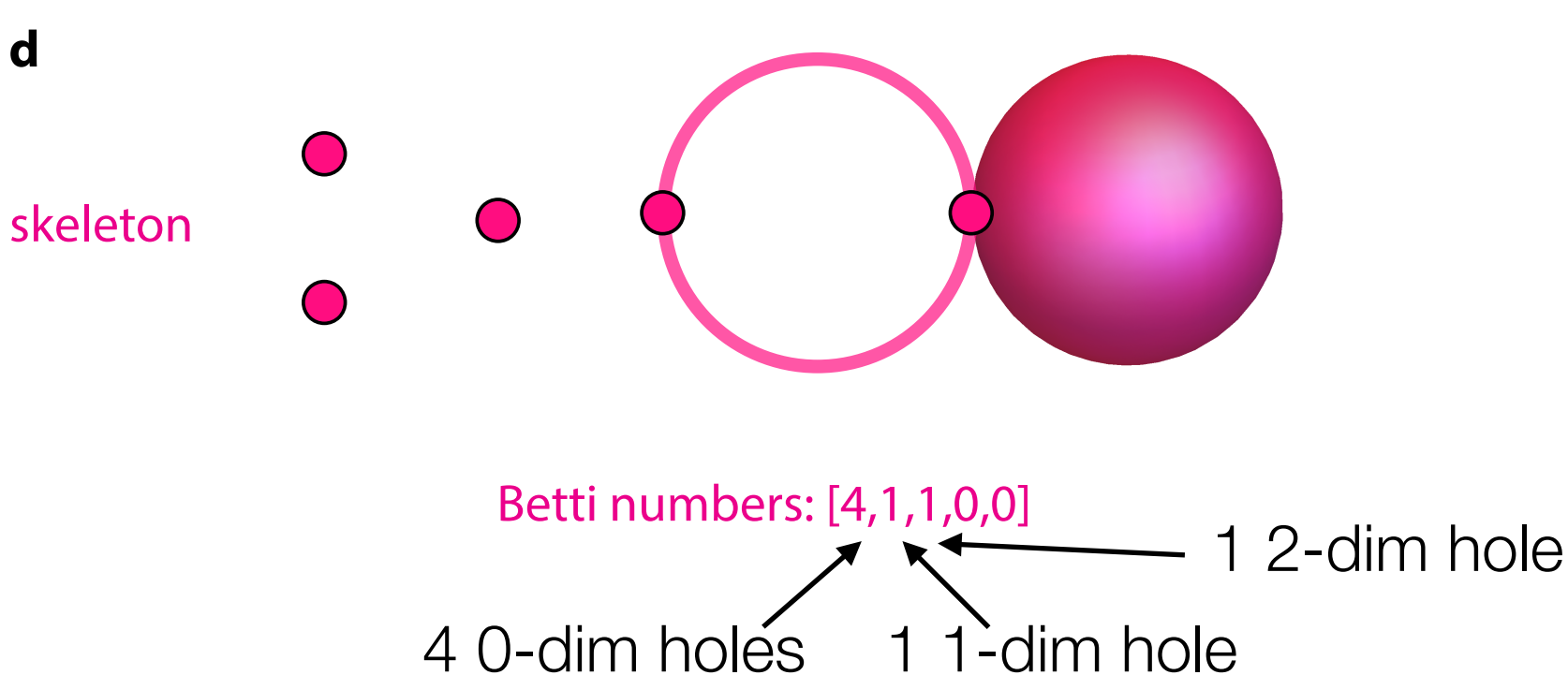
Charactering coexistence holes as Betti numbers from homology theory in algebraic topology



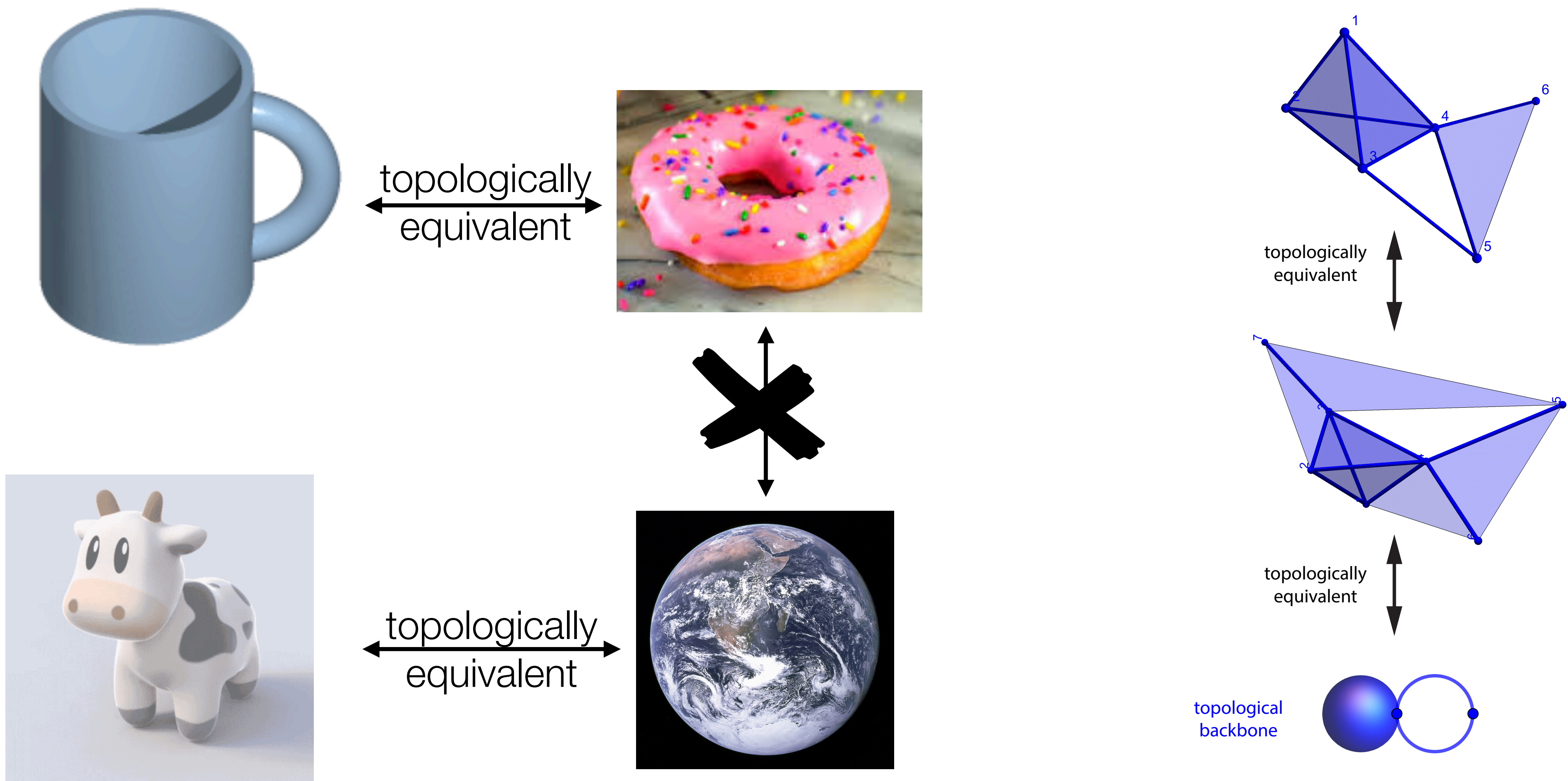
Topologically equivalent



Topologically equivalent

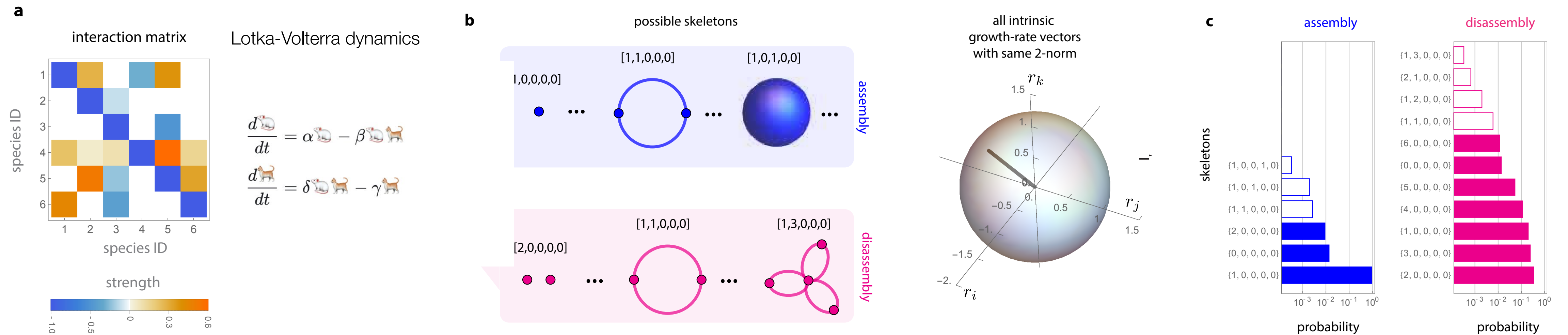


Uncovering similarities and differences in assembly and disassembly processes across systems



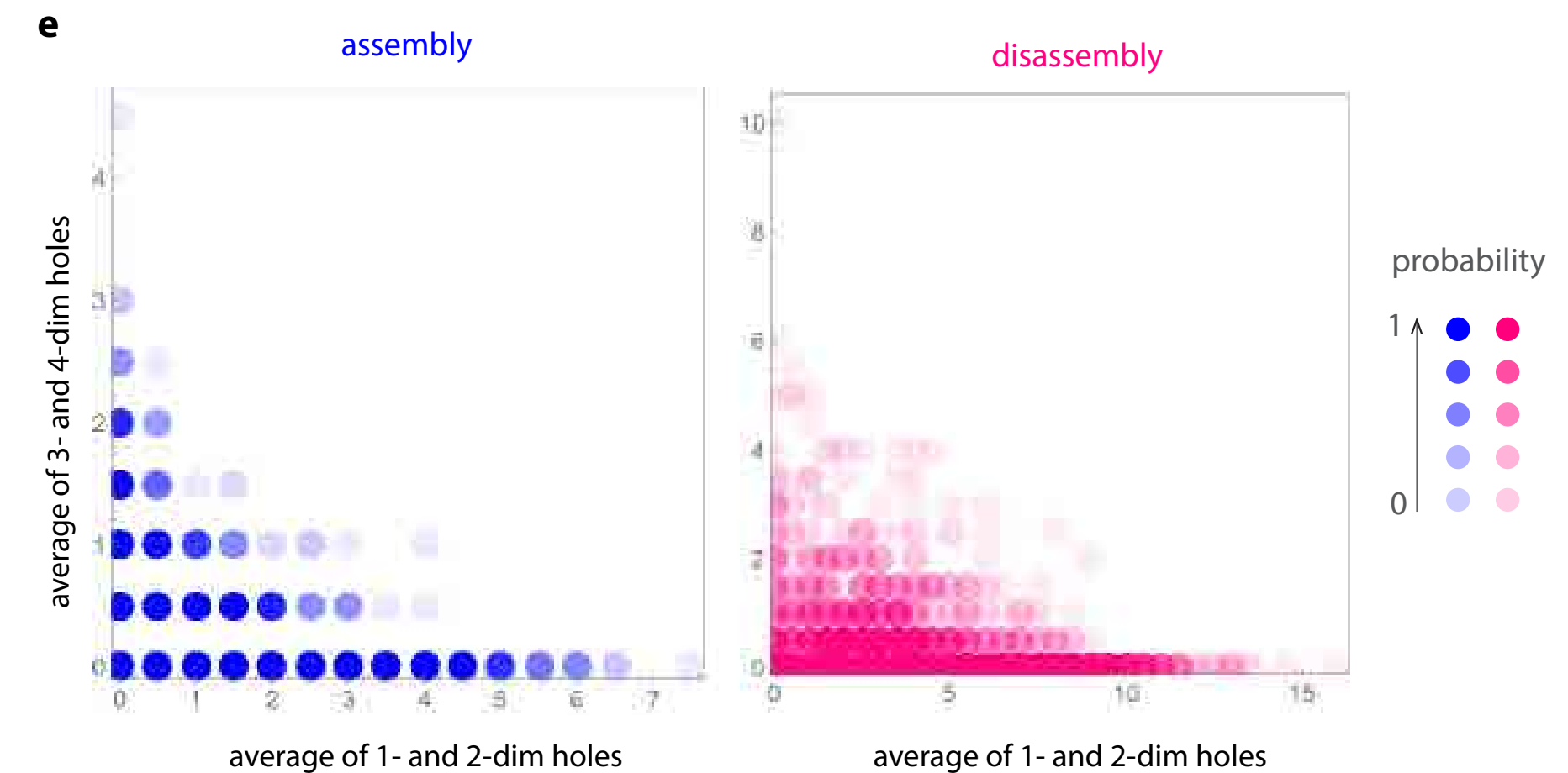
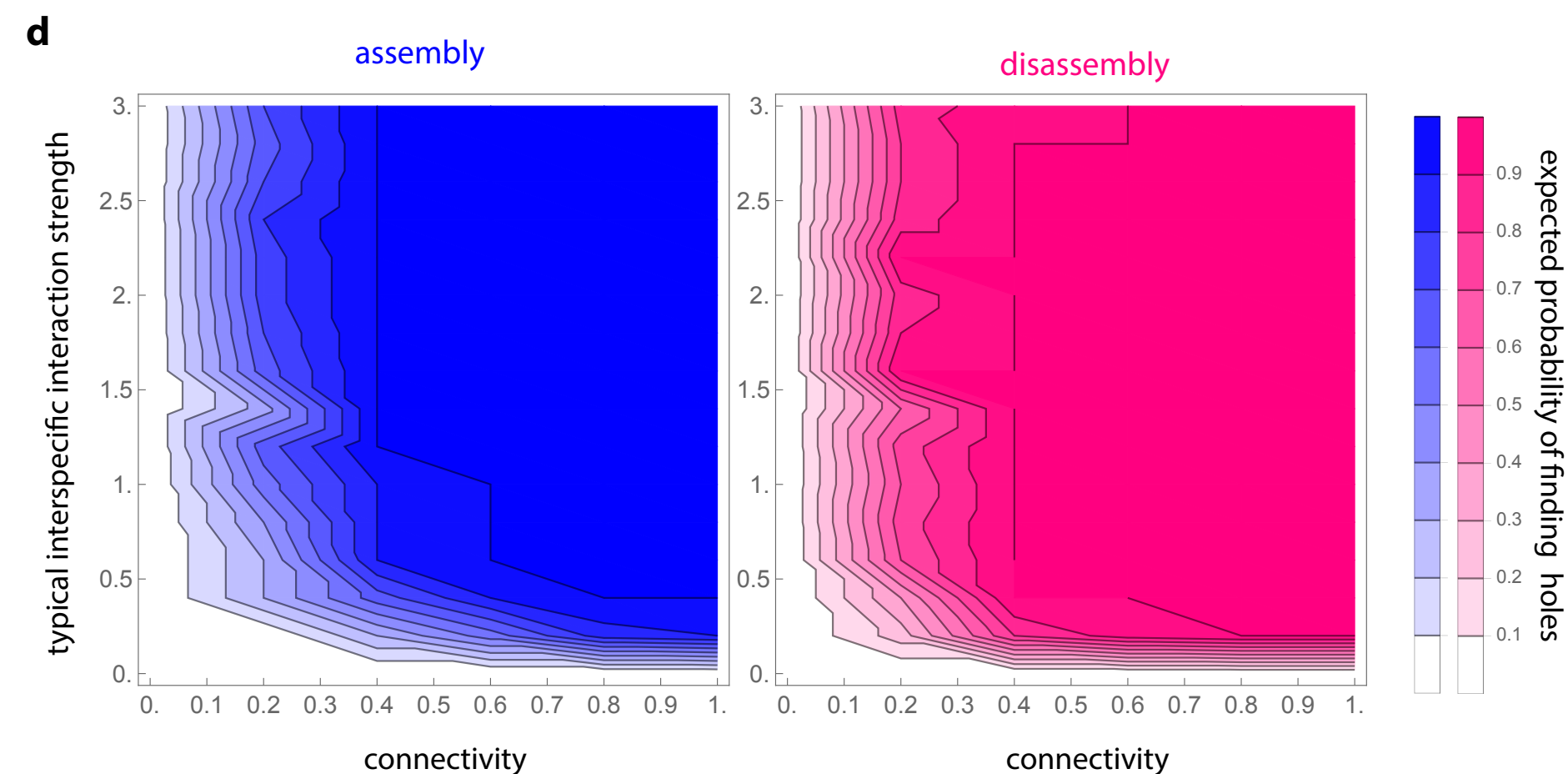
<https://en.wikipedia.org/wiki/Topology>

Two general constraints of coexistence holes *in silico*



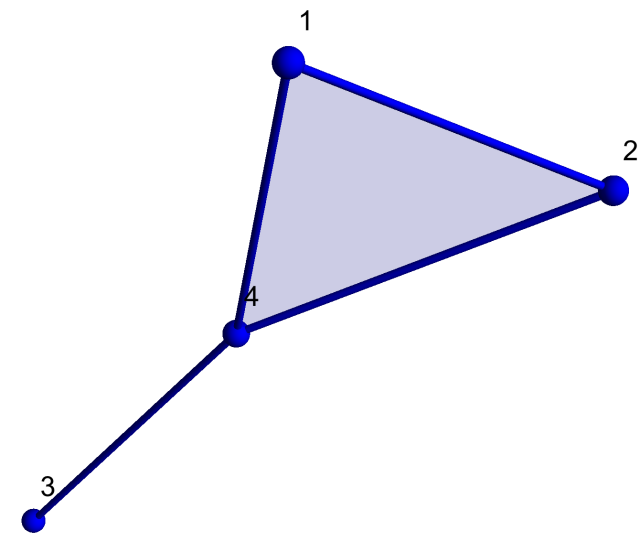
Coexistence holes emerge in complex systems

Trade-off between low- and high-dimensional holes



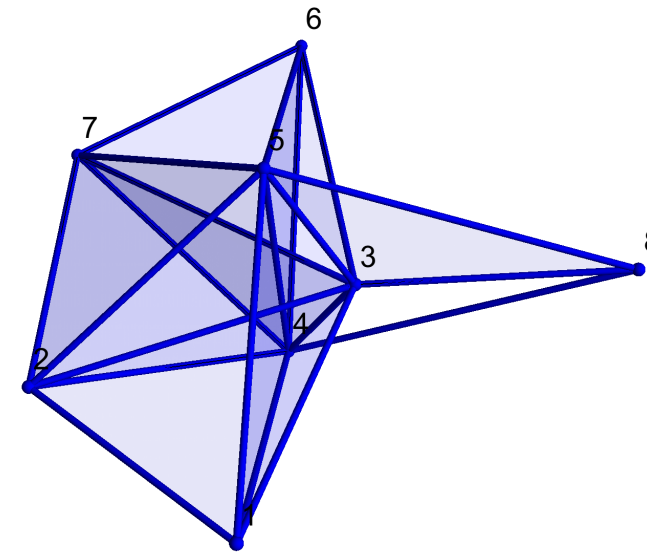
Empirical ecological systems are enriched with assembly/disassembly holes

a Vandermeer (4 species)



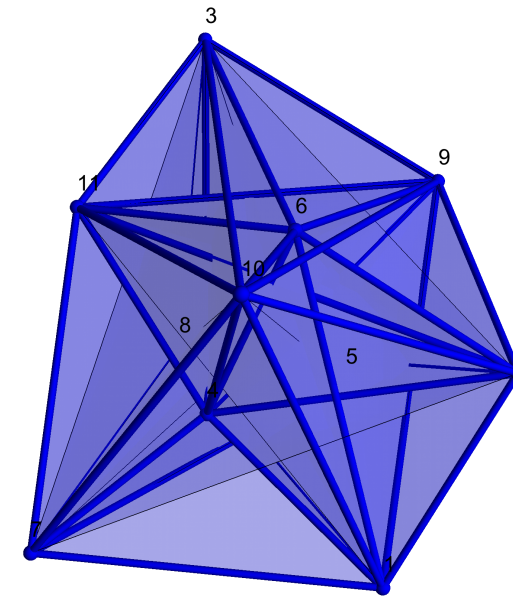
[1,0,0,0,0]
9 hyperedges, dim = 2

b Friedman (8 species)



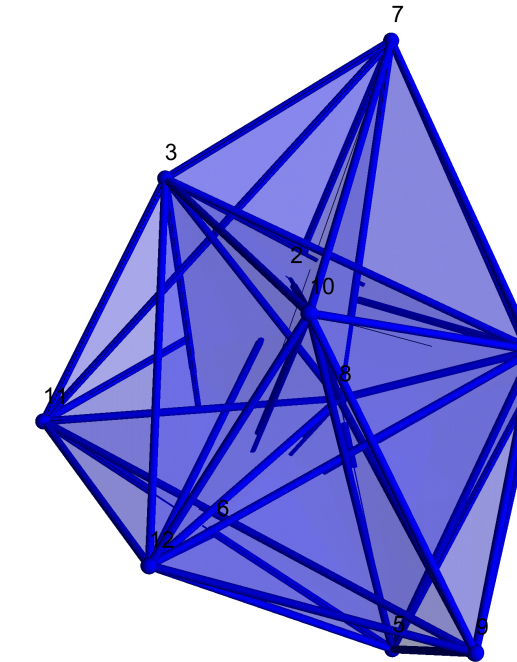
[1,2,0,0,0]
41 hyperedges, dim = 2

c Stein (11 species)



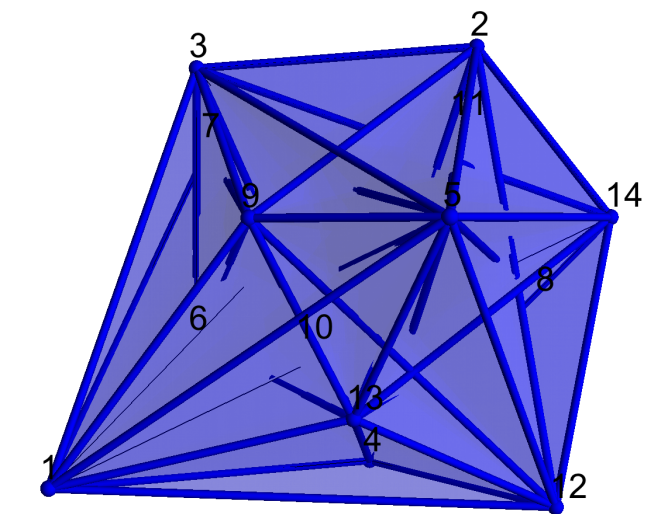
[1,0,1,6,2]
528 hyperedges

d Venturelli (12 species)

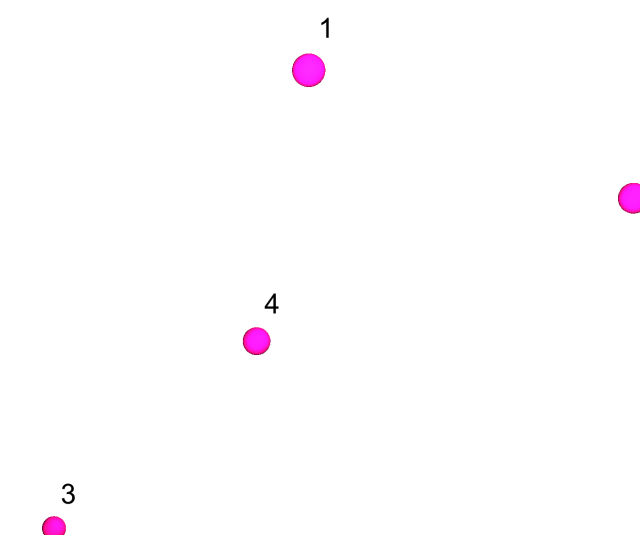


[1,0,9,0,0]
204 hyperedges, dim = 5

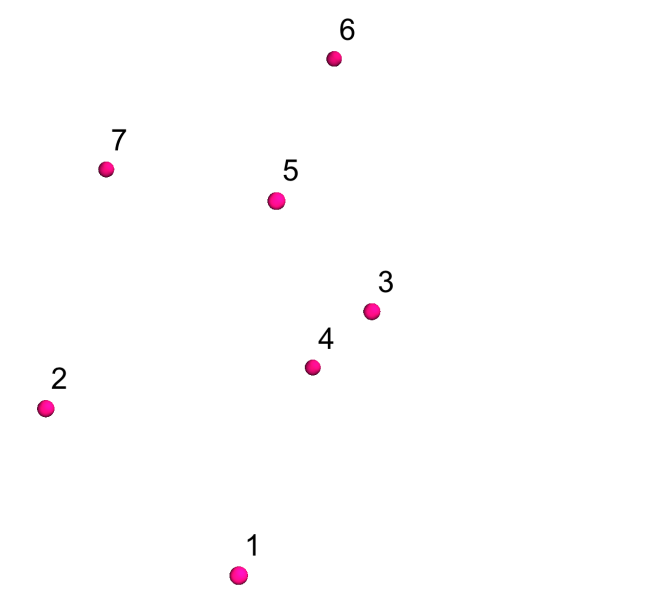
e MDSine (14 species)



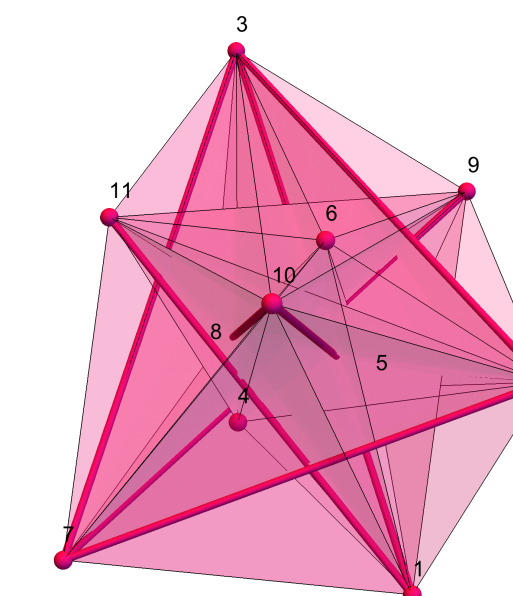
[1,0,0]
4927 hyperedges, dim = 11



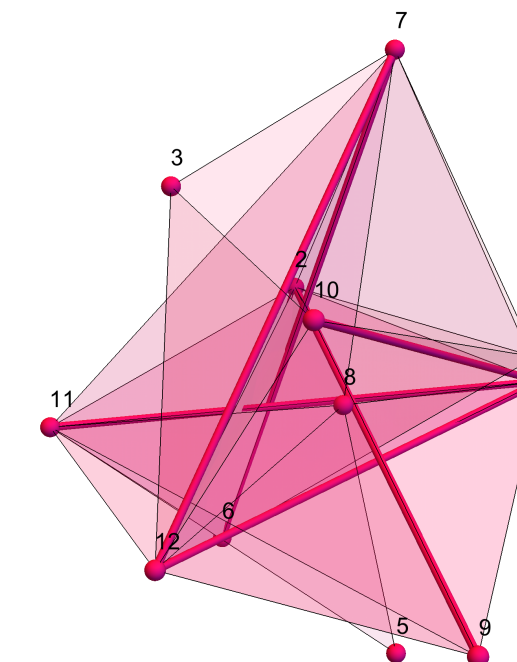
[4,0,0,0,0]
4 hyperedges, dim = 0



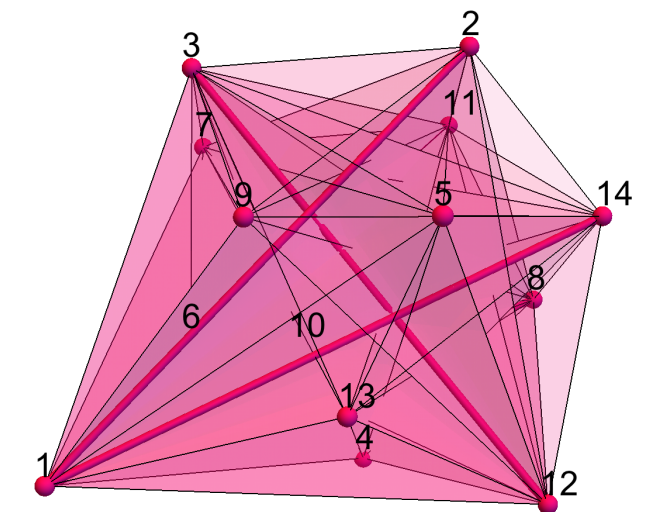
[8,0,0,0,0]
8 hyperedges, dim = 0



[1,5,64,7,1]
573 hyperedges



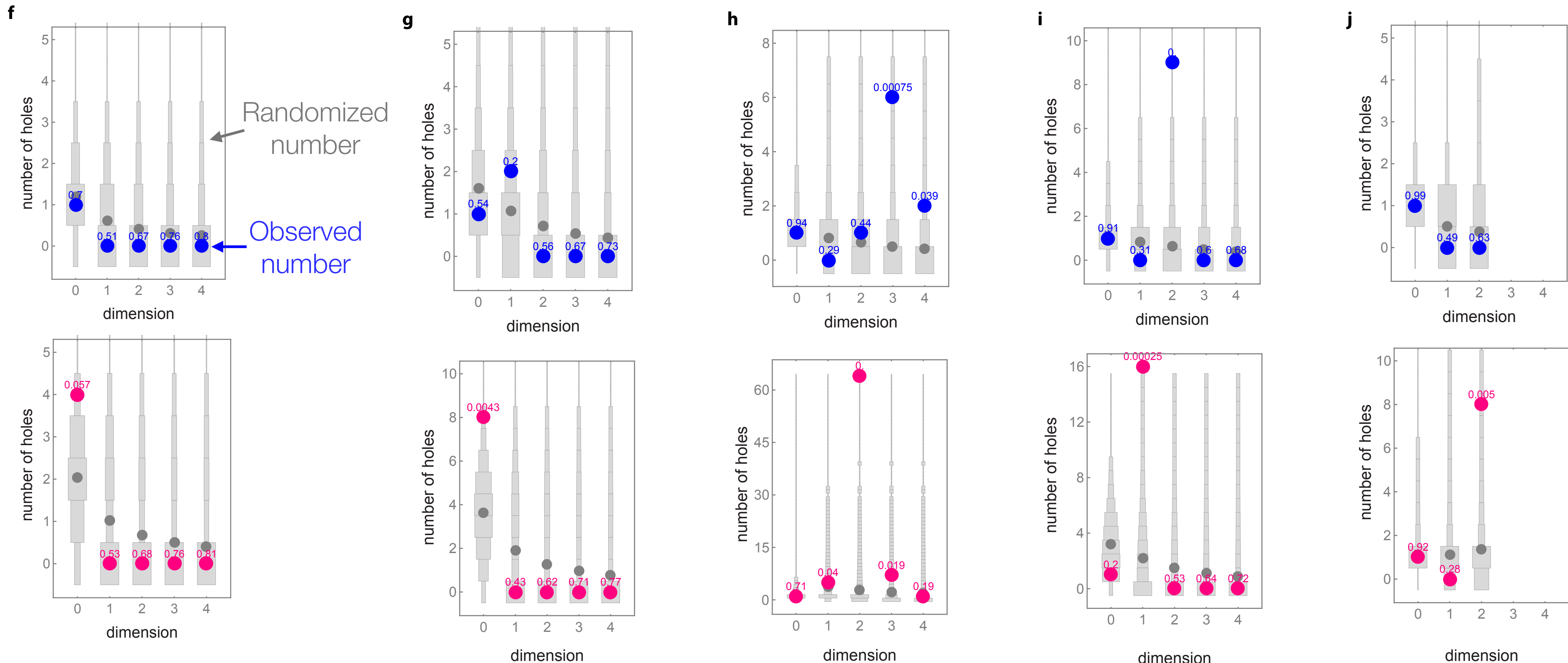
[1,16,0,0,0]
57 hyperedges, dim = 4



[1,0,8]
4161 hyperedges, dim = 10

Biotic and abiotic constraints of empirical systems produce an over-representation of coexistence holes in some dimensions

Vandermeer (4 species) Friedman (8 species) Stein (11 species) Venturelli (12 species) MDSine (14 species)



Take-home message

- We introduce a novel hypergraph-based formalism that fully captures the structure of coexistence in multispecies systems.
- Coexistence holes characterize the unexpected breakdowns in assembly/disassembly processes.
- Coexistence holes obey predictable patterns (unavoidable in complex systems & trade-off between low- and high- dimension).
- Empirical communities are enriched with overrepresented number of coexistence holes.
- Assembly and disassembly processes are not continuous but filled with discontinuities.

Thanks!

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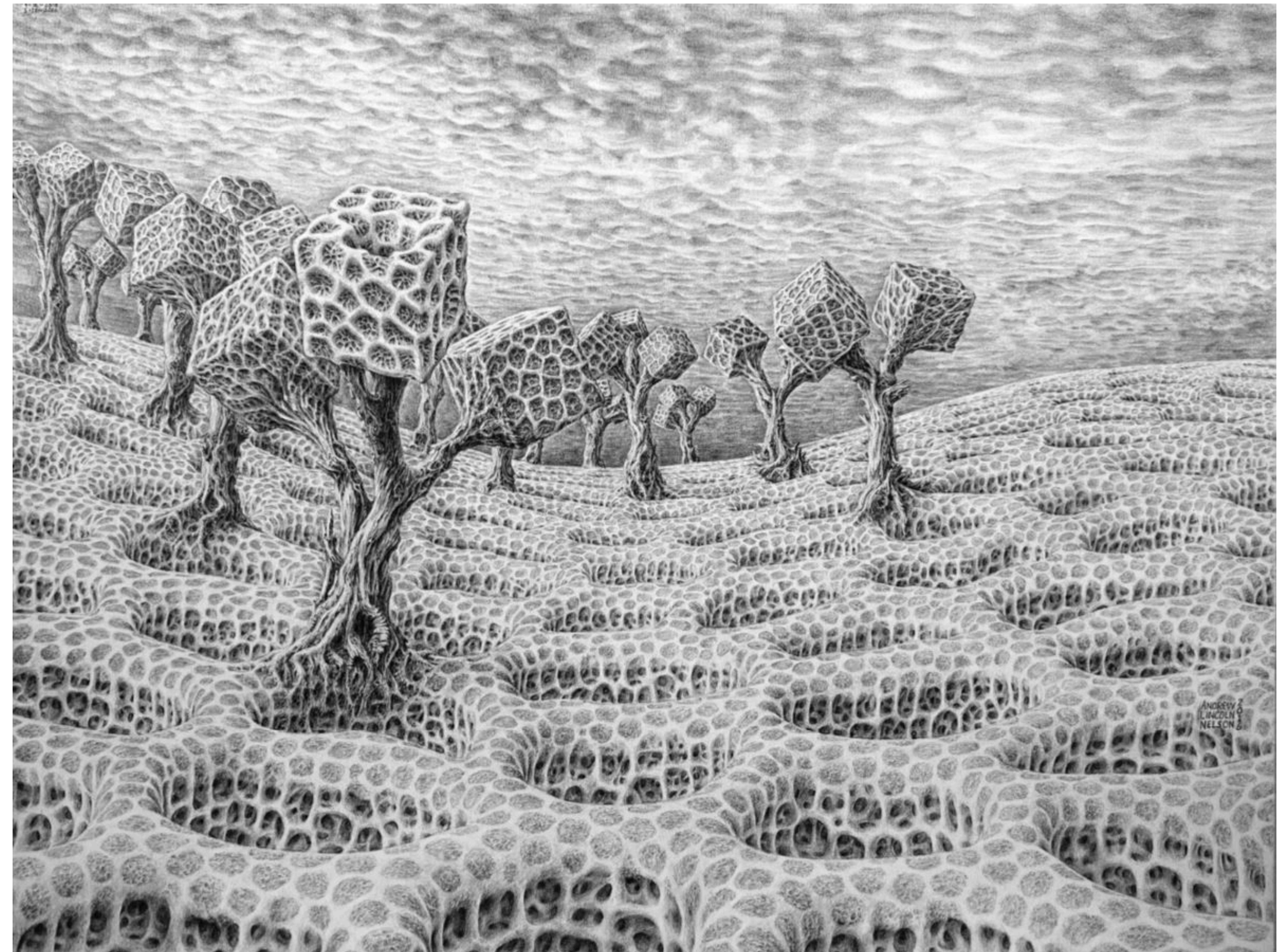


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