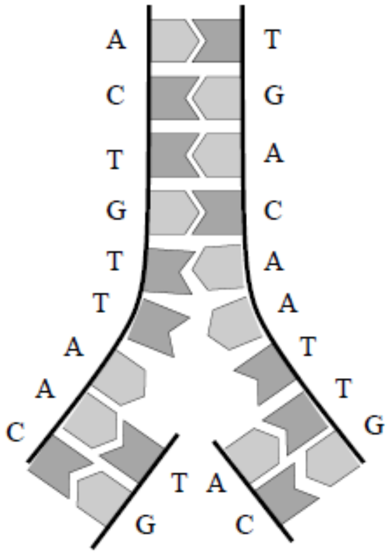
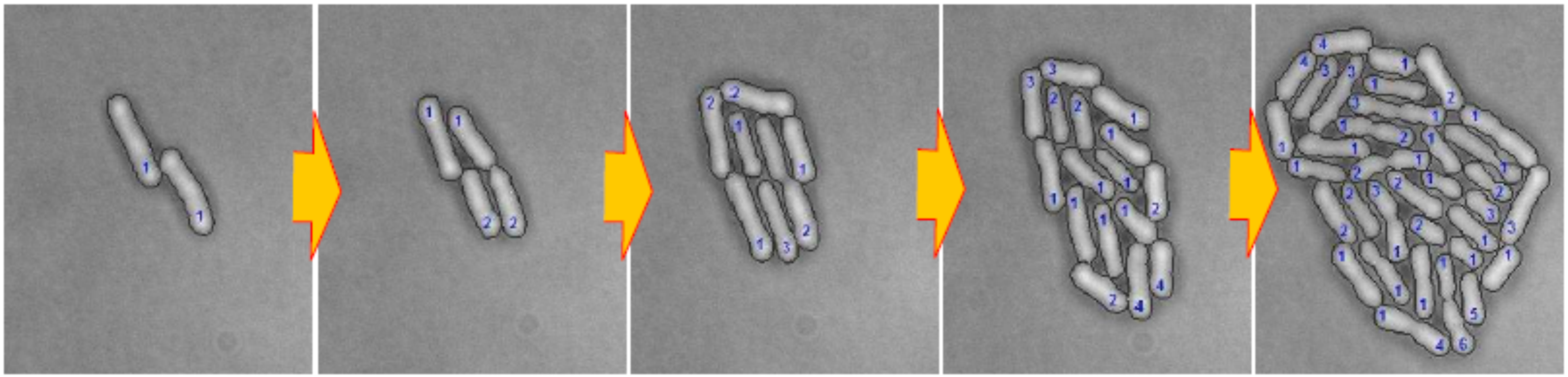

Competition and
Diversity
Kim Sneppen

Instability of Life:

Copying:





Unstable, yet Diverse:

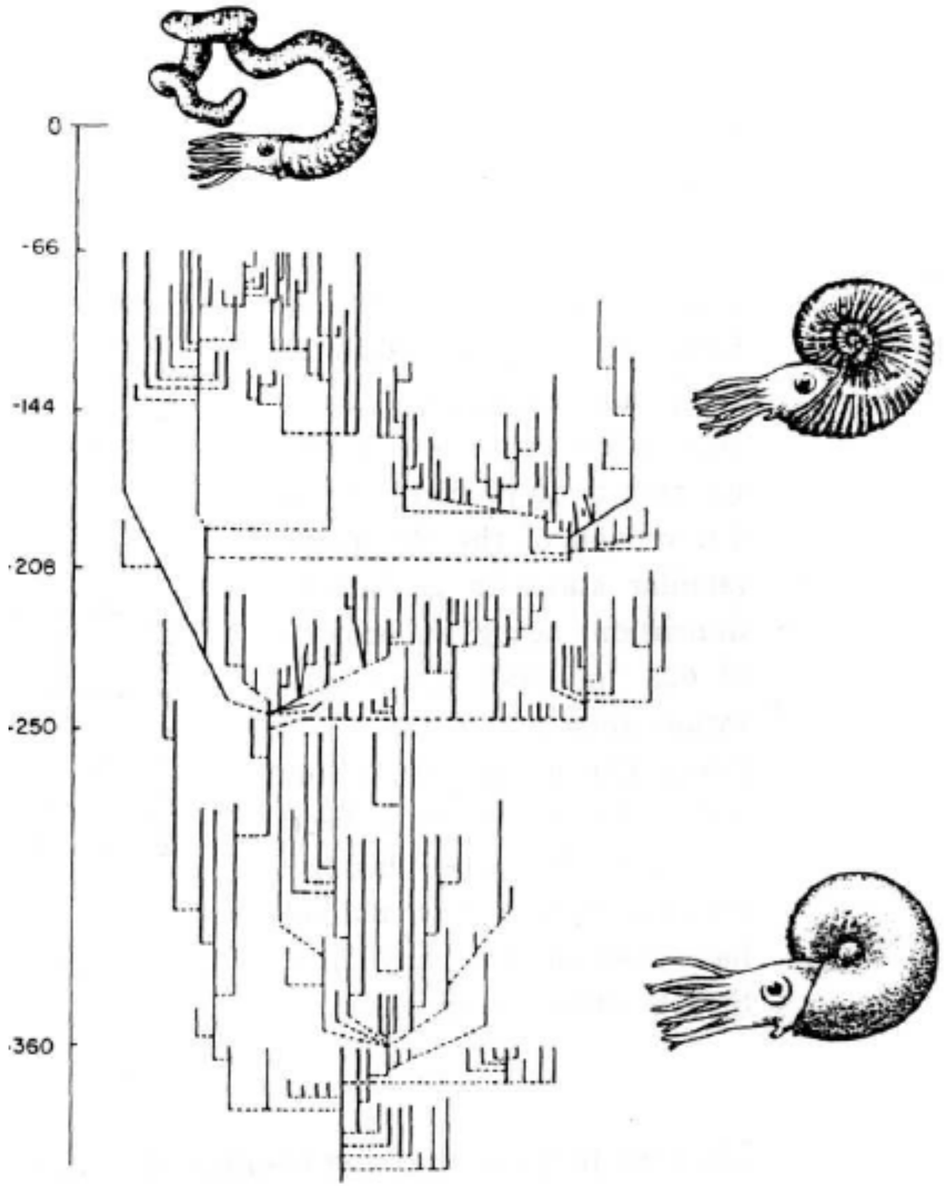
Very very long history:

Lots of Contingencies

→luck important

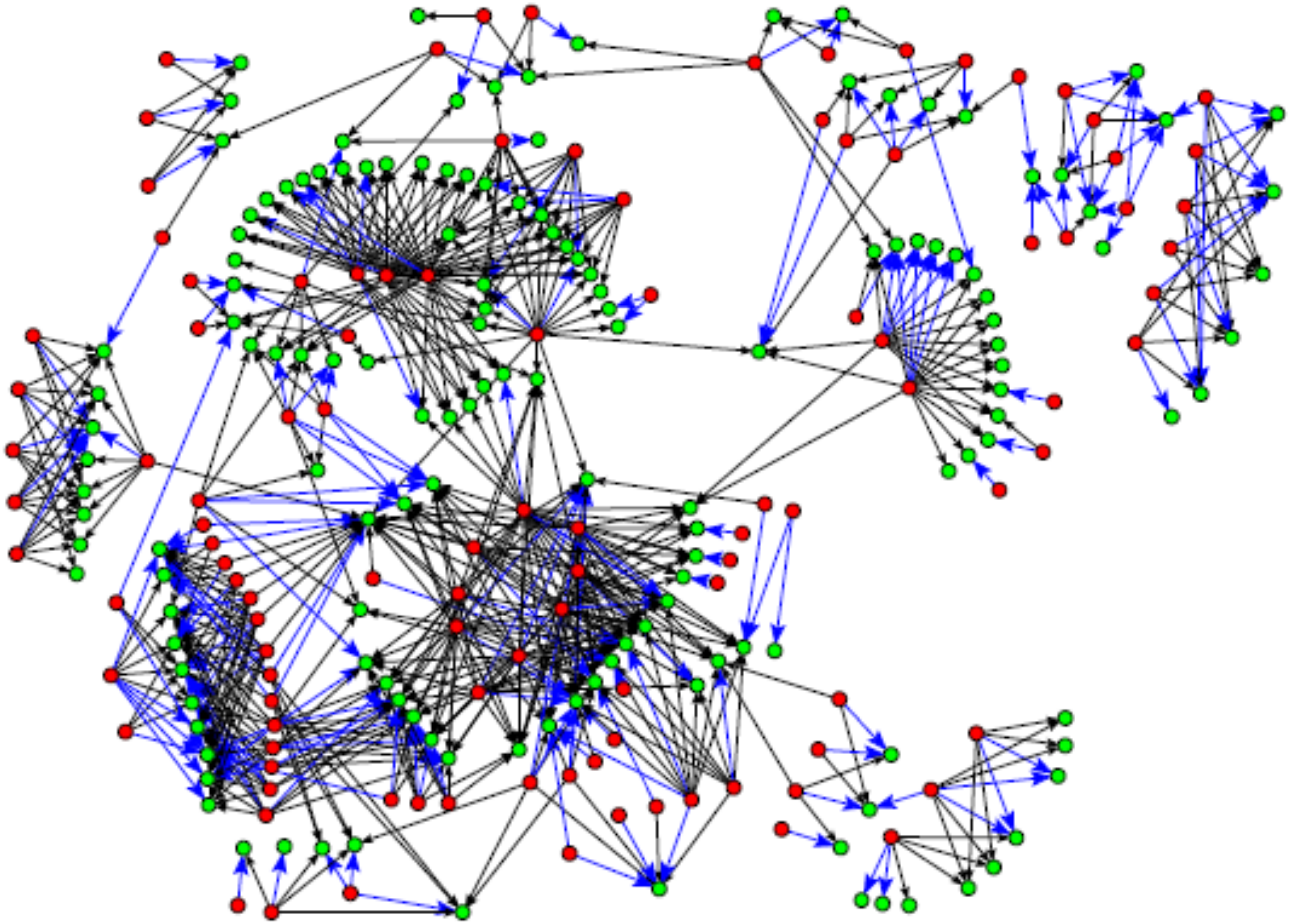
Separation of Timescales

→punctuations



Ecosystem diversity

What sustain diversity
when nodes compete

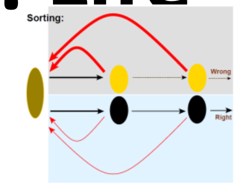


Its all about cycles:

1→2→1→2: Equilibrium

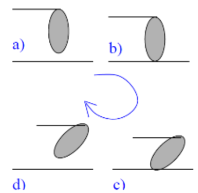
1→2→3→1→2→3→1...: Life

:error correction



:PCR

:molecular motors...



→here biological diversity

Competition and Diversity:

Cycles

(with *J.Mathiesen , N.Mitarai & A.Trusina*)

&

A Red-Queen race

(with Jan Haerter)

Lotka-Volterra quations

$$\dot{X}_i = \sum_j \Gamma_{ij} X_i X_j - \sum_j \Gamma_{ji} X_j X_i$$

Becomes unstable when number of species increase (R. May 1973).

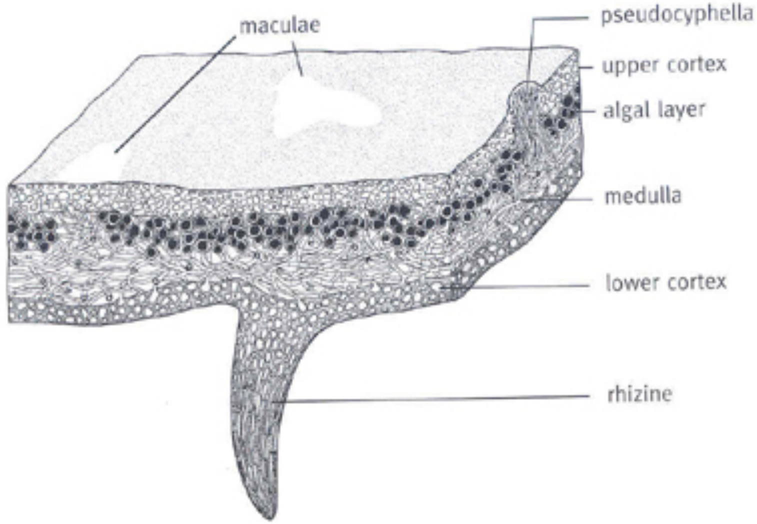
Evolving such network→

Collapse of Diversity →2 species

Sustainability of high diversity?

Fig. 1. *Photograph of a crustose lichen community on a rock in an alpine environment (at 1300m altitude, Jotunheimen, Norway).*

(Crustose) Lichen anatomy



• composite organisms of fungi and green algae

• fungal keep the overall organism coherent

• glows slowly (~0.1mm/year)

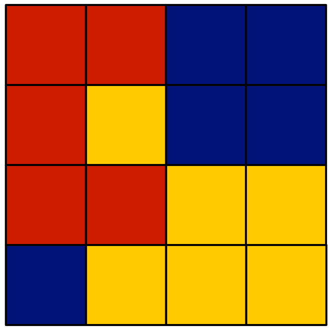
•Spores disperse on a global scale with winds

Fossils records suggest that fungi developed symbiotic partnerships with photoautotrophs before the evolution of vascular plants. As old as ~ 600 mil years

- **Compete for space**
- **Stand-offs**
- **Rare invasion ("Predation")**

Model:

Space (2-dimentional lattice) and interaction matrix.



$$\Gamma = \begin{pmatrix} 0 & 0 & 1 \\ 1 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}$$

Each site can carry at most one species

$\Gamma(s,s')$ is set to

1 with **probability** γ

0 otherwise

cf. Jackson and Buss (1975)
Similar model for coral reef

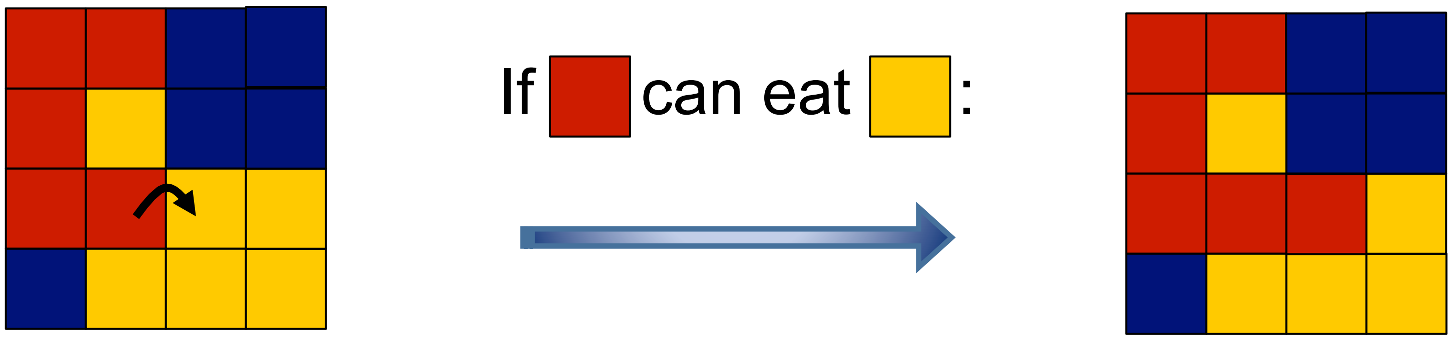
- A simple lattice model with
  - Competitions
  - Extinction and Rare immigration / speciation

- Phase transition to stable high diversity state
  - Self-organization of spatial distribution

(EFFECTIVELY) ONE PARAMETER MODEL!

2-dimensional latice model

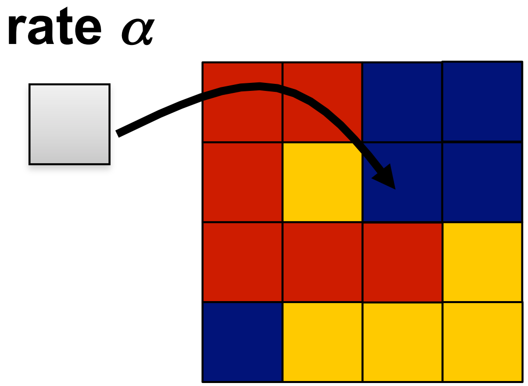
- **At each invasion attempt, choose a site (try to attack) and its neighbor (to be attacked) randomly**



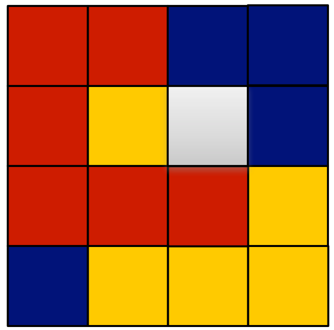
Each site can carry at most one species

cf. Karlson and Buss (1984) Similar model for coral reef

Model: speciation



New species introduced at rate $\alpha \rightarrow 0$



Model: Randomly assigned interaction network with prob. γ

- “predation” interaction between species pre-assigned **fixed throughout the simulation**

Matrix representation

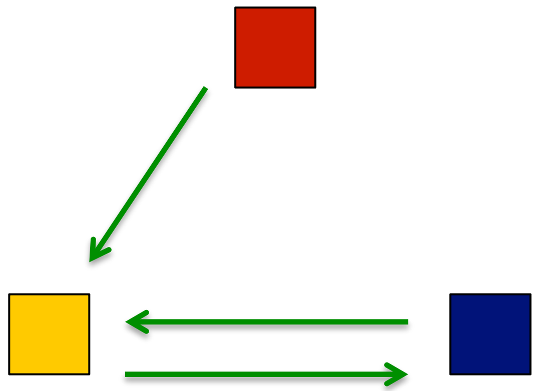
$$\Gamma = \begin{pmatrix} 0 & 0 & 1 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}$$

$\Gamma(s,s')$ is set to

1 (s can eat s’) with **probability γ**

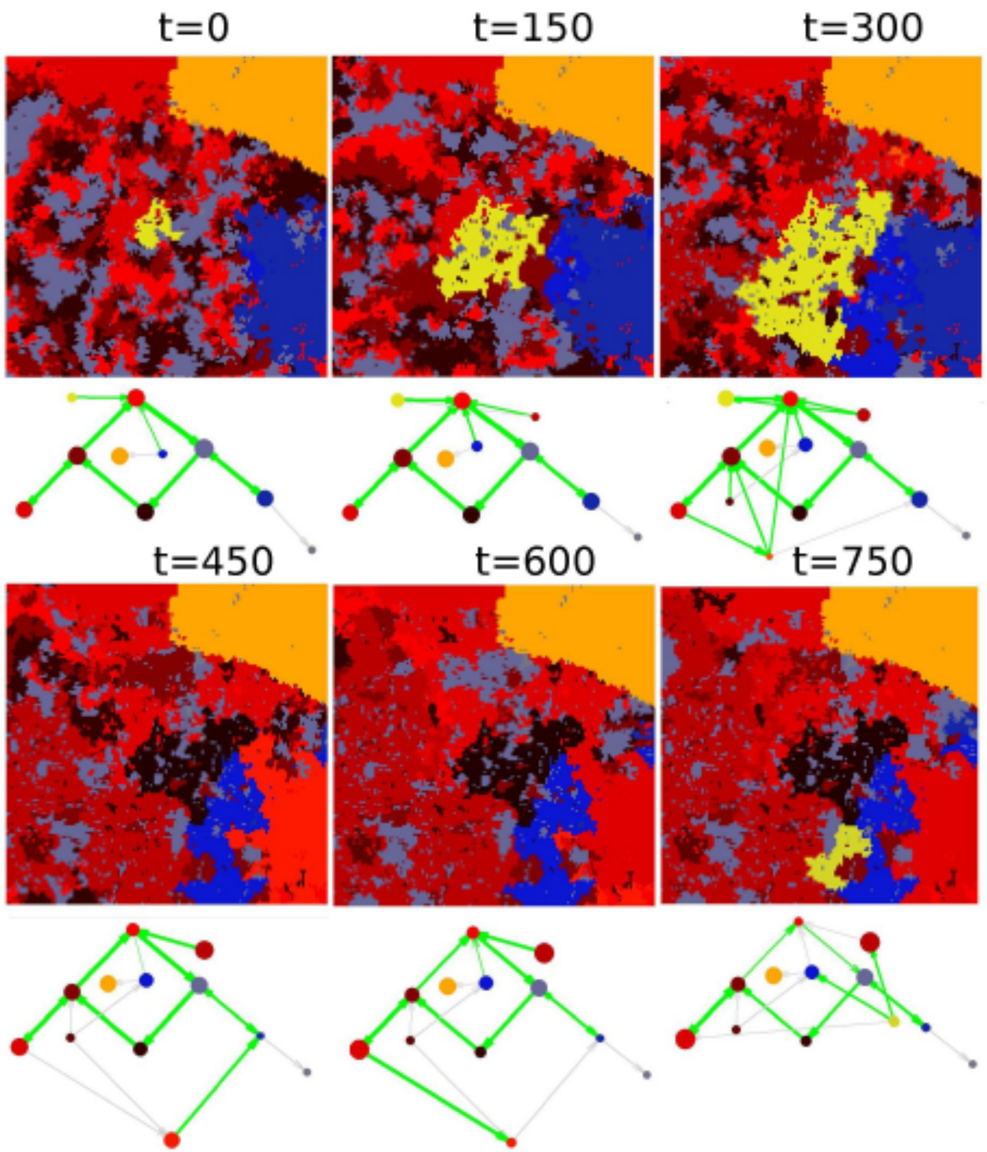
0 with probability 1- γ

Network representation



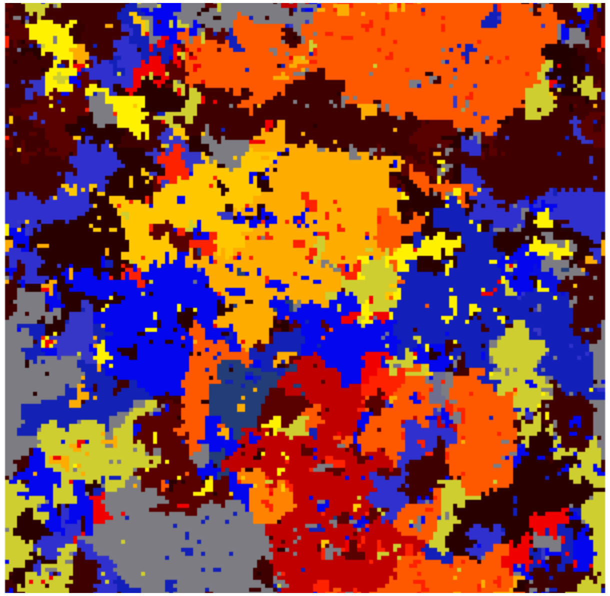
Arrows:
From “predator” to “pray”

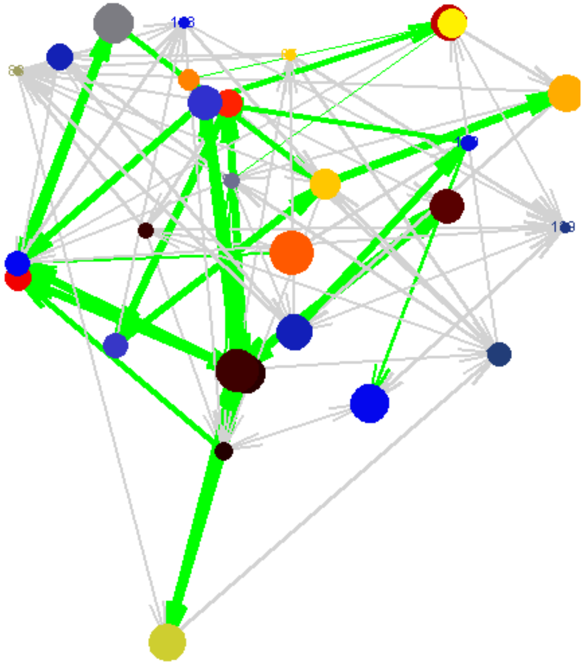
→



$\alpha = 0.1, \gamma = 0.1$

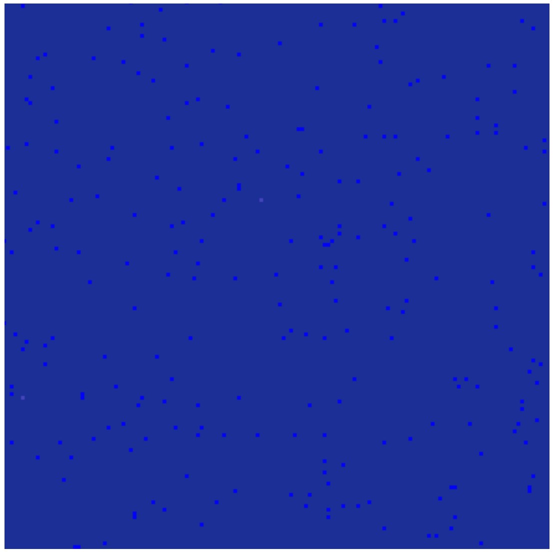
- Only part of interaction network is active.
- Small patches are always created.

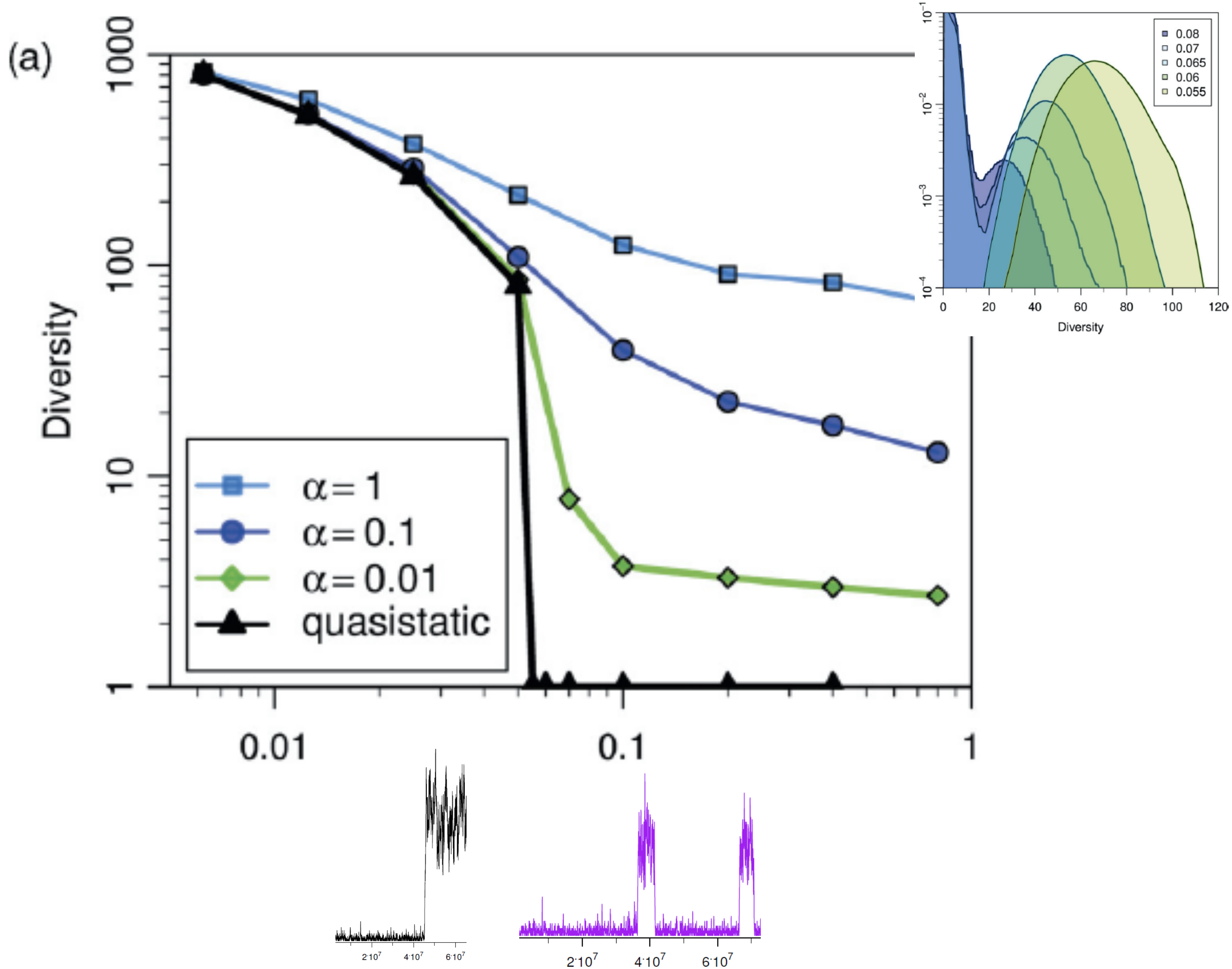




γ=0.1, α=0.1

Random neighbor





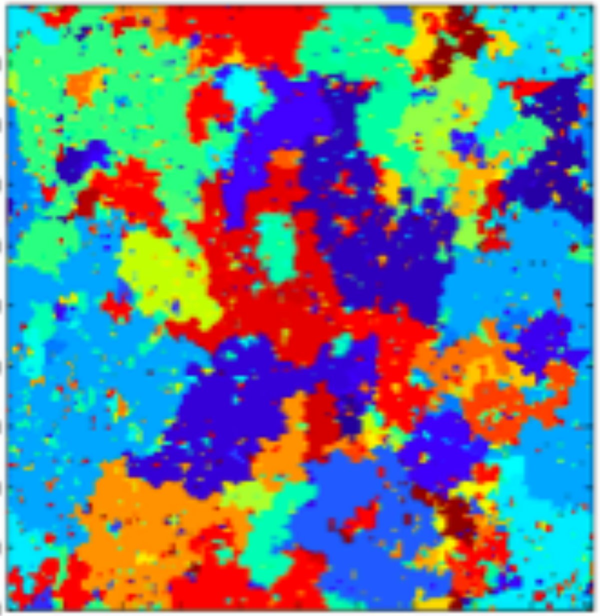
(a)
Diversity
1000
100
10
1
0.01
0.1
1
α = 1
α = 0.1
α = 0.01
quasistatic
0.08
0.07
0.065
0.06
0.055
Diversity

Snap shots at high diversity state:

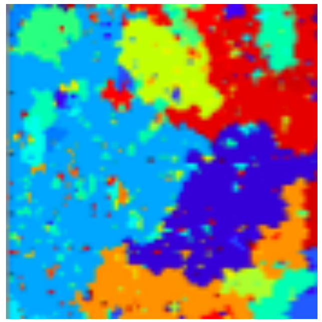
many patches are formed; create niches for each other

L=1200

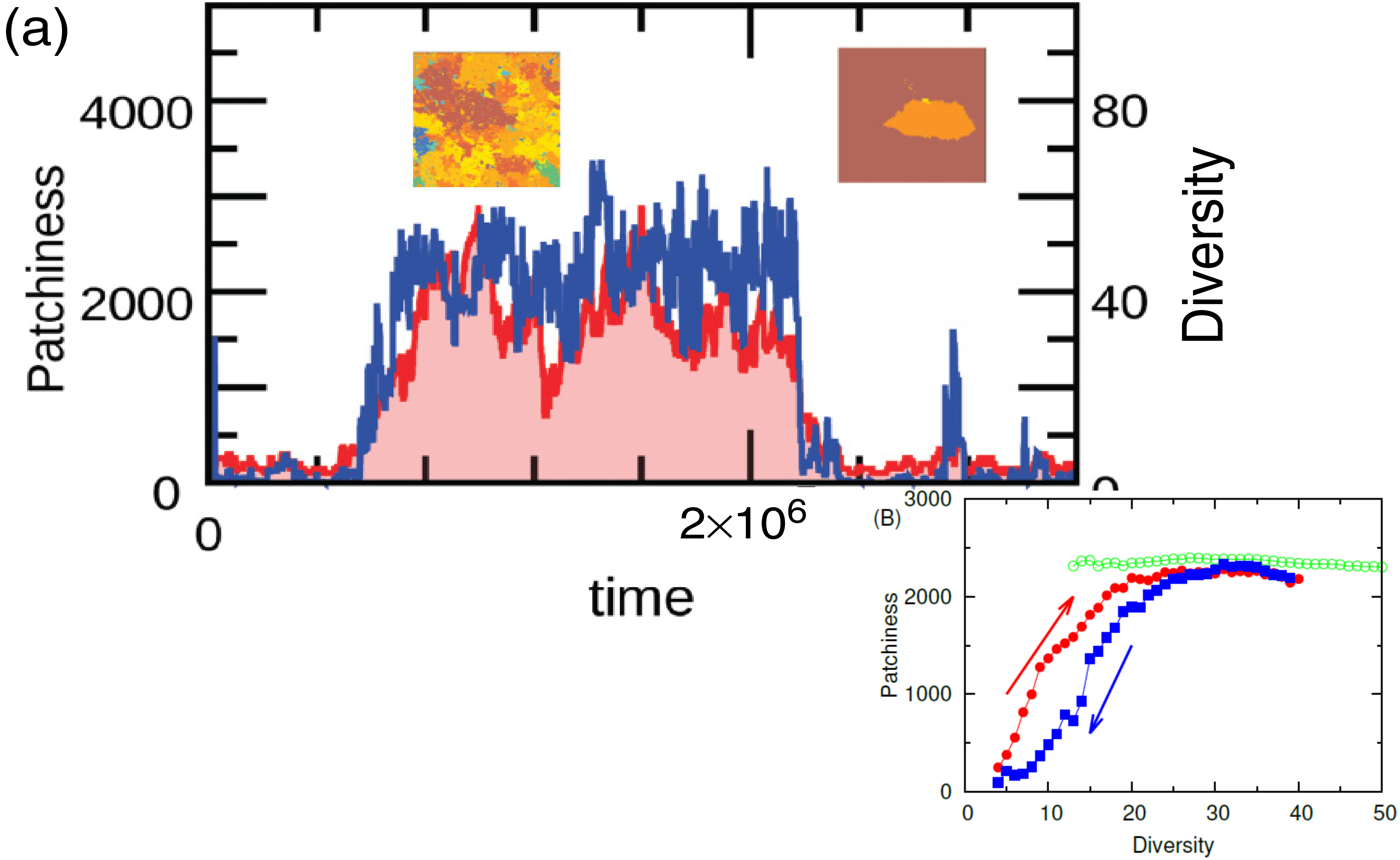
L=200



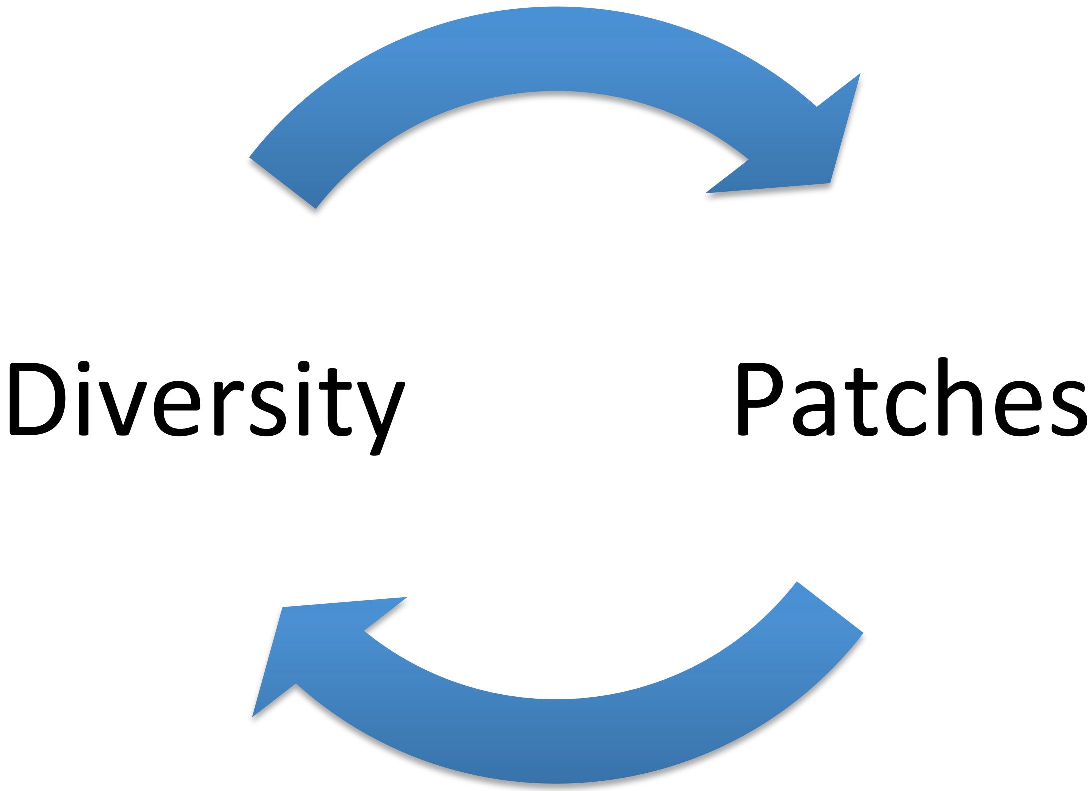
NB: L=100 does not work: Patches percolate



Patchiness → diversity

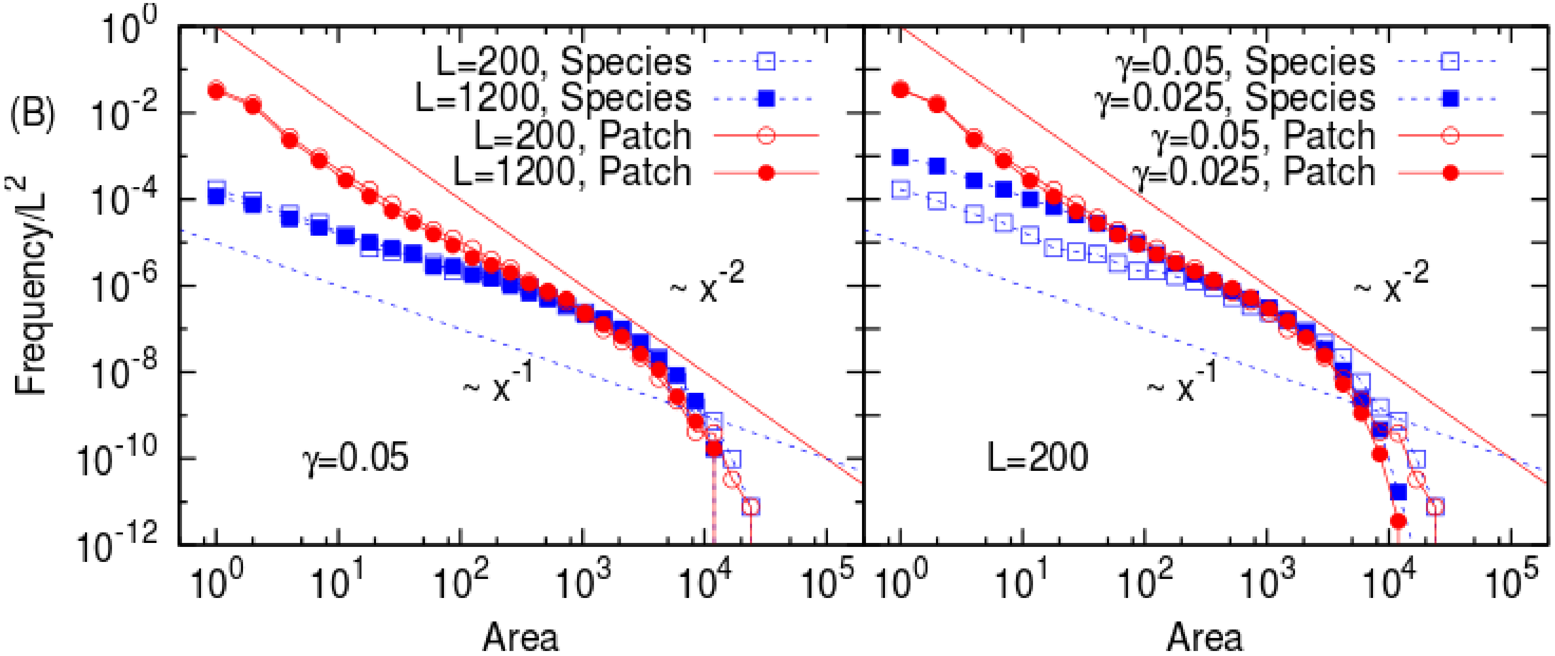


Patches are important!



Patchiness =heterogenety, can be self organized

Patch size distribution: Patches replaced with new species -> High diversity



Note that the maximum patch size is much smaller than system size.

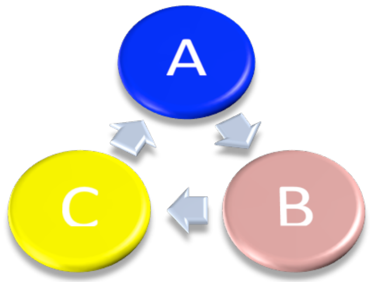
How to make patches: Cyclic relationship?

<u>Cyclic relationship</u>
Cycles dynamically create many patches

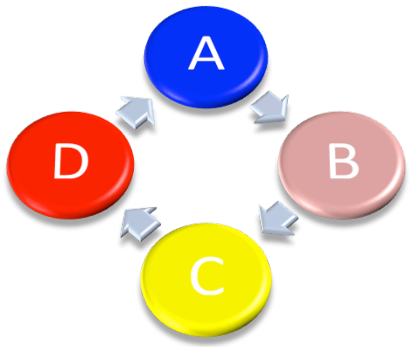
One of the species dies out due to noise

Patches left if the cycle is large enough

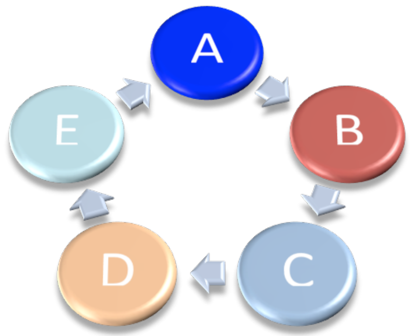
Cycle length 3: Rock-Scissor-Paper



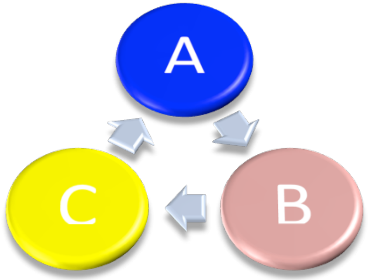
Cycle length 4

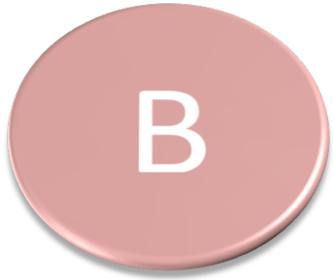


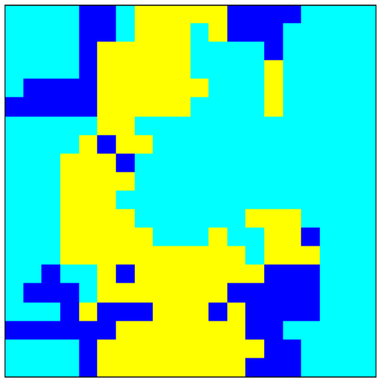
Cycle length 5

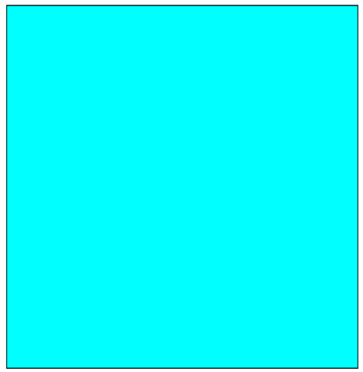


Cycle 3 give long lasting oscillation but leaves no patche





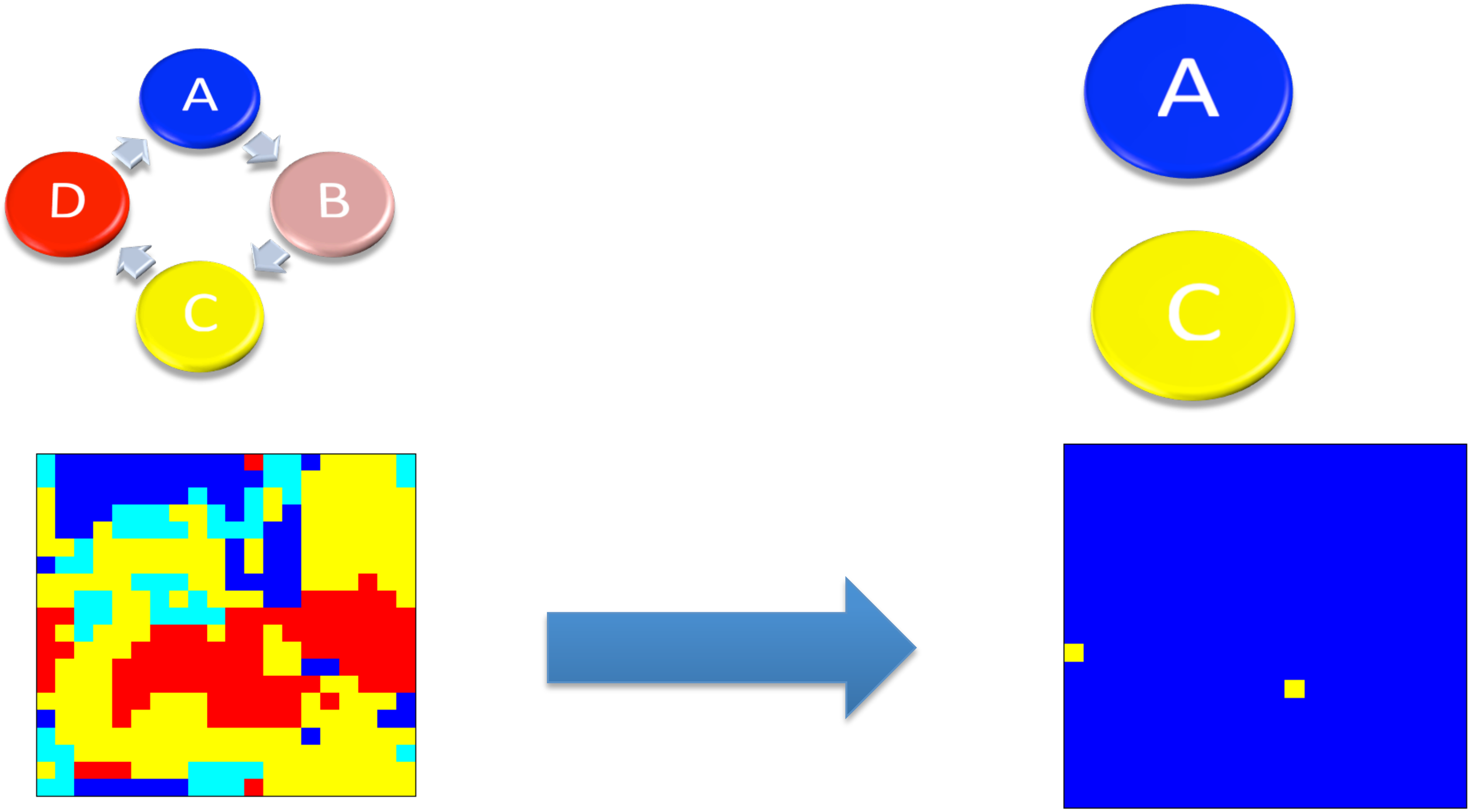




Dynamics gives complex pattern,
and population oscillate for a long time, but…

Noise results in extinction,
and it can leave only one patch

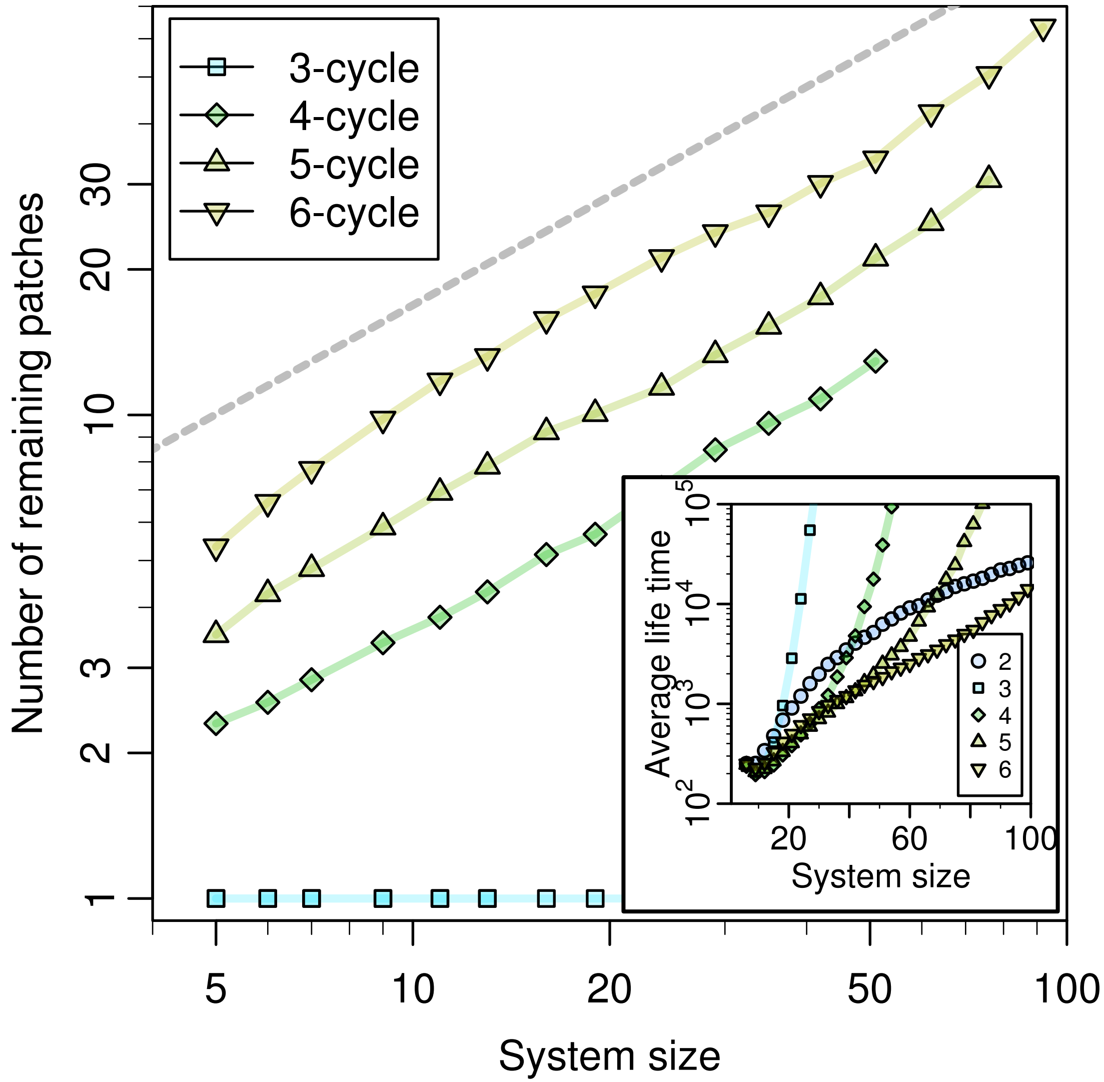
Cycle 4 and larger can leave patches

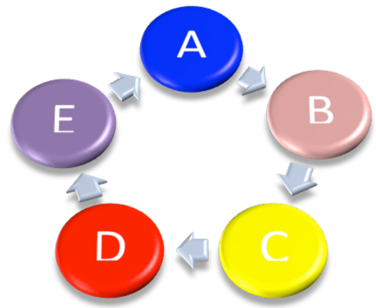


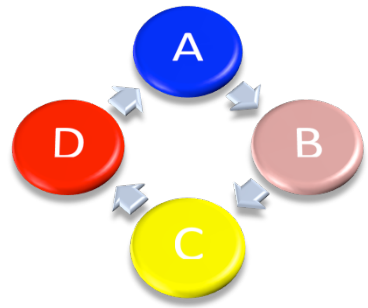
Dynamics gives complex pattern

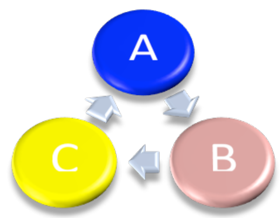
Noise results in extinction,
But multiple species and
patches can be left

How to make patches: Cyclic relationship?

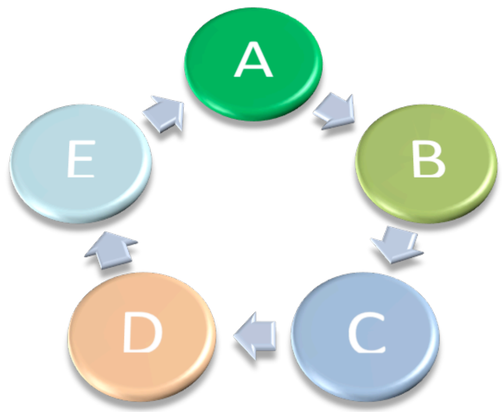


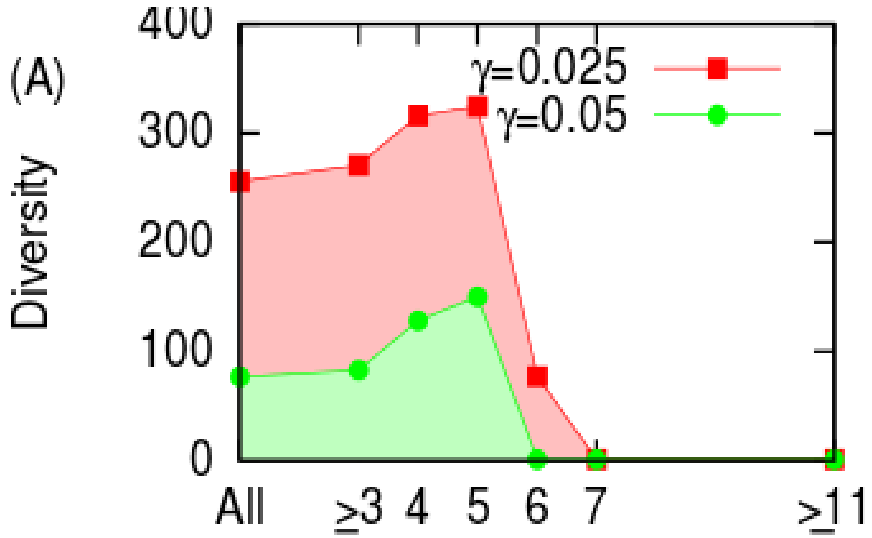


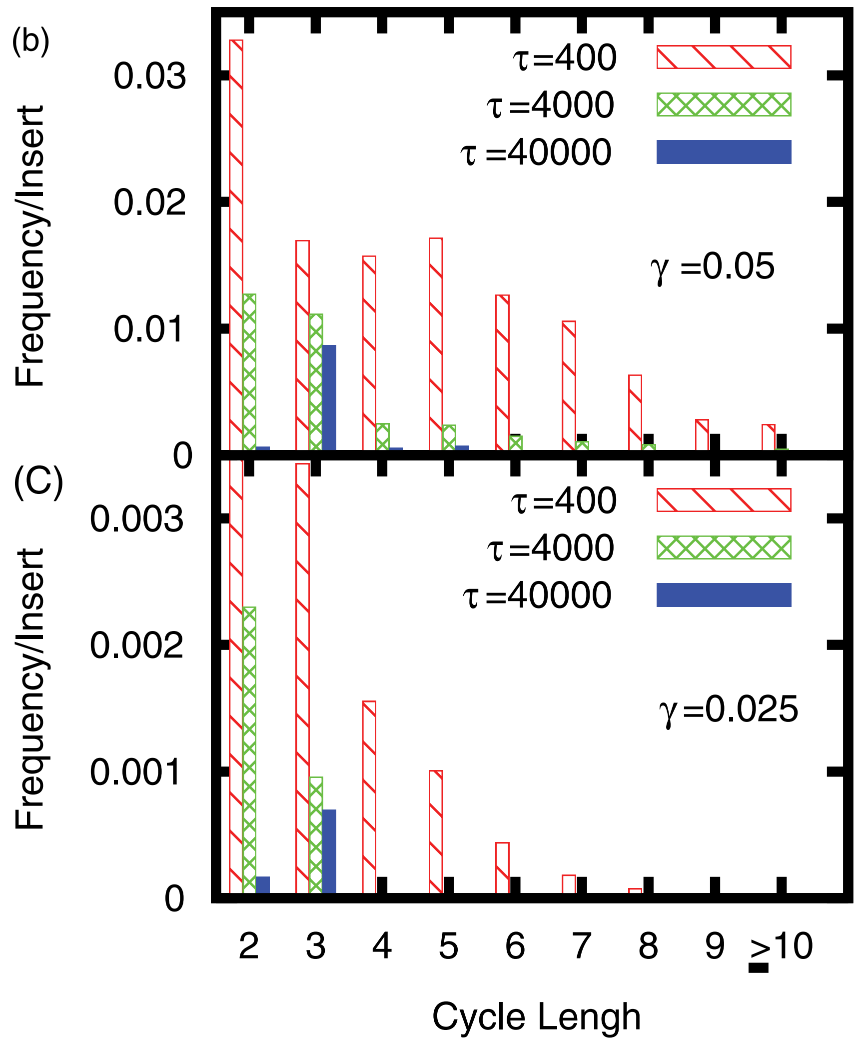




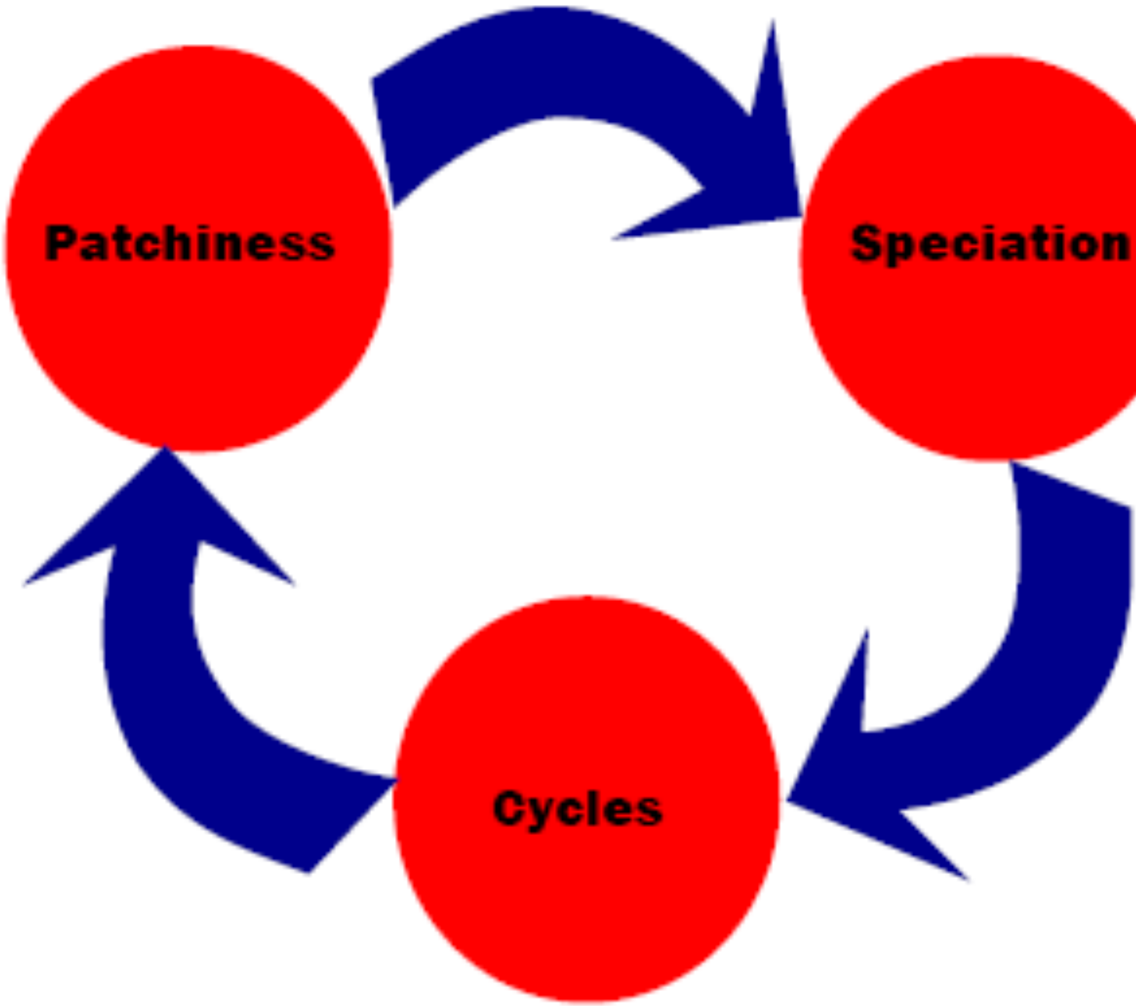
Cycles →Patchiness→Diversity:







→Cycle
(of cycles)



Model lessons

→Merge allopatric and sympatic speciation, by self organized heterogenety: *cycles→patchiness→speciation*

→Species ``fitness" given solely by local environment, use in large scale evolution model→

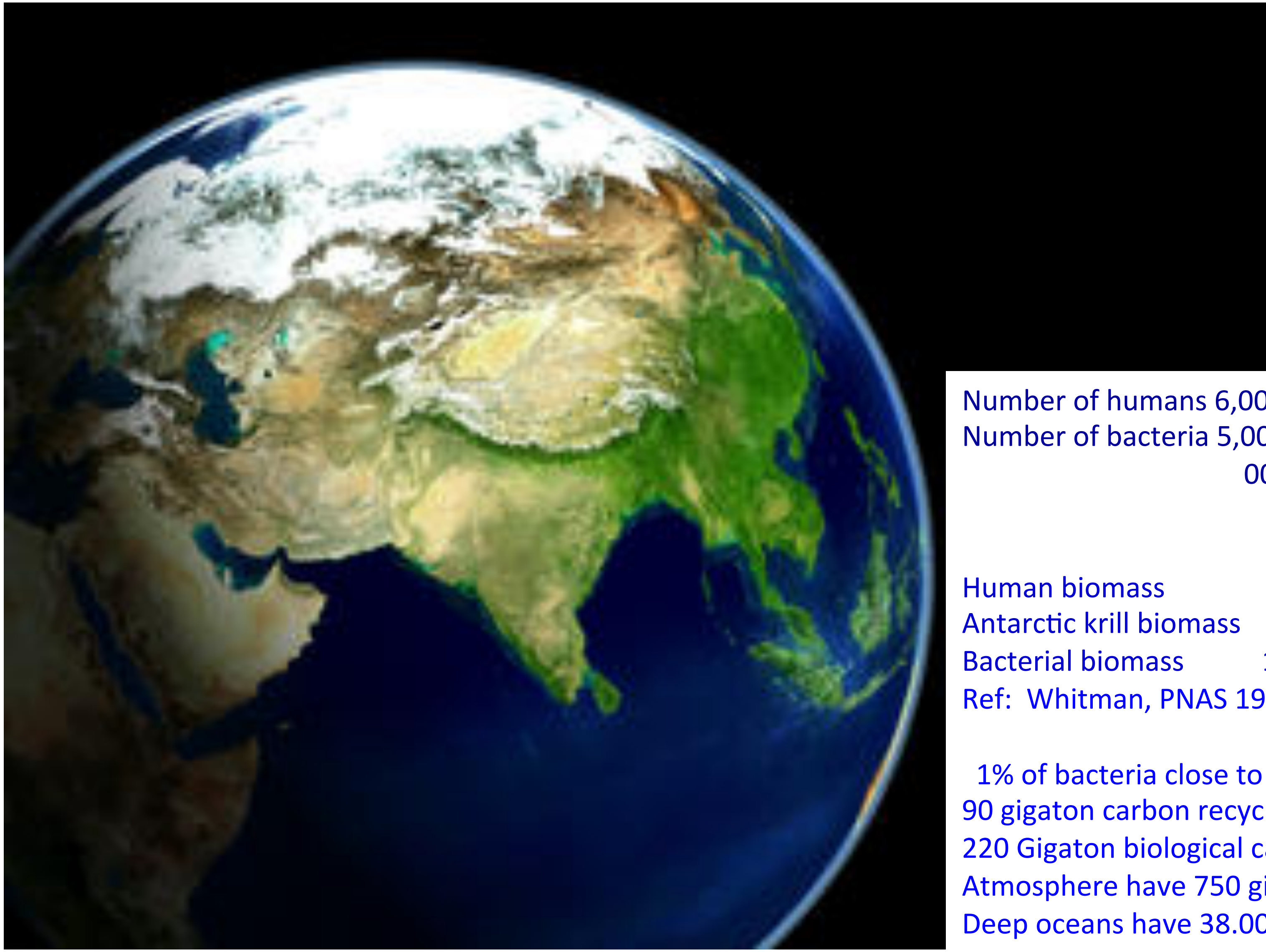
Together with:

Joachim Matthiesen

Namiko Mitarai

Ala Trusina

Phage/Bacteria rules the world:

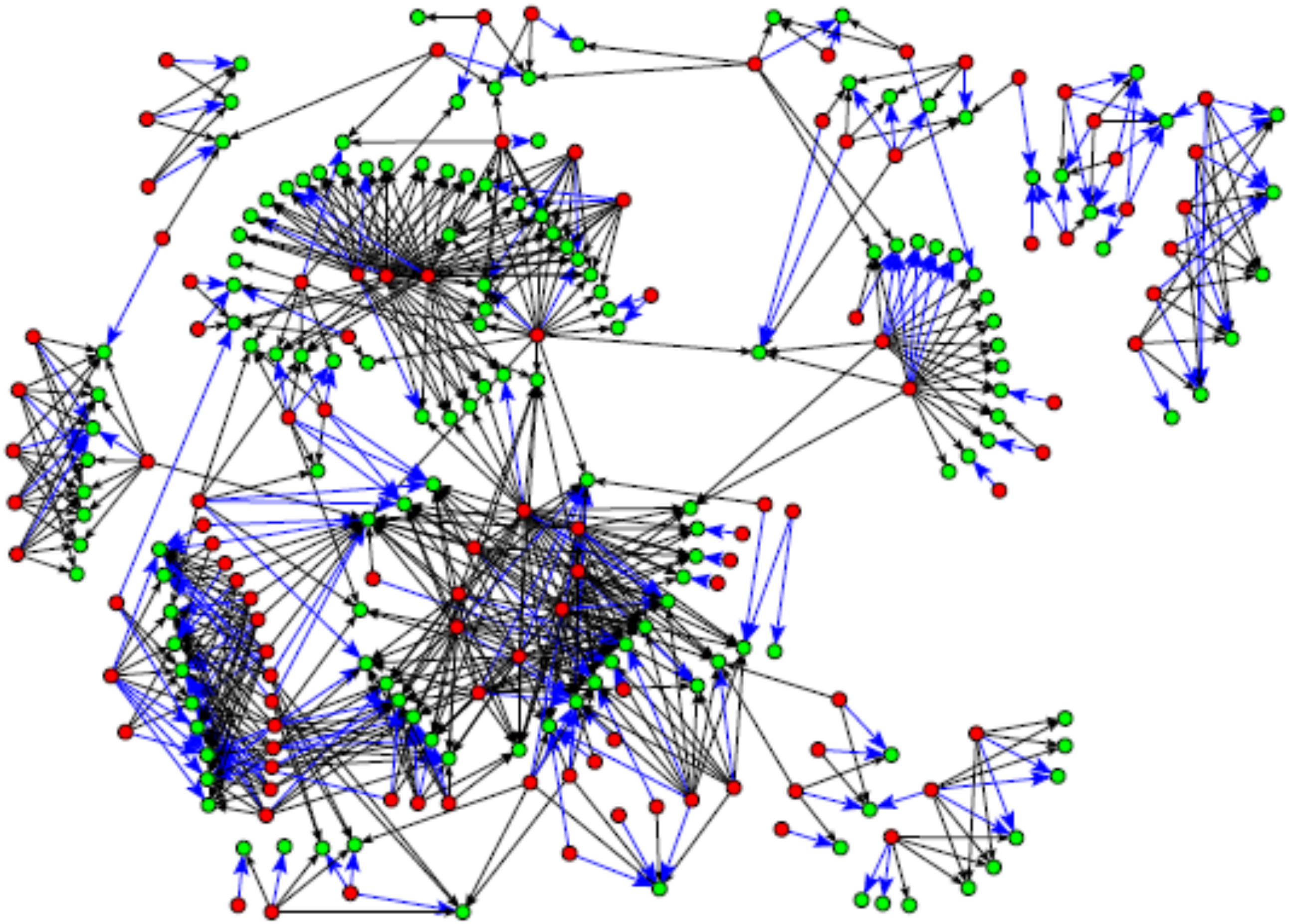


Number of humans 6,000,000,000
Number of bacteria 5,000,000,000,000,000,
000,000,000,000,000

Human biomass 0.250 Giga tons
Antarctic krill biomass 0.500 Giga tons
Bacterial biomass 1000 Giga tons
Ref: Whitman, PNAS 1998.

1% of bacteria close to sea surface→dynamics
90 gigaton carbon recycled per year from sea surf.
220 Gigaton biological carbon recycling per year
Atmosphere have 750 gigaton carbon
Deep oceans have 38.000 gigaton carbon

Phage-Bacteria systems:

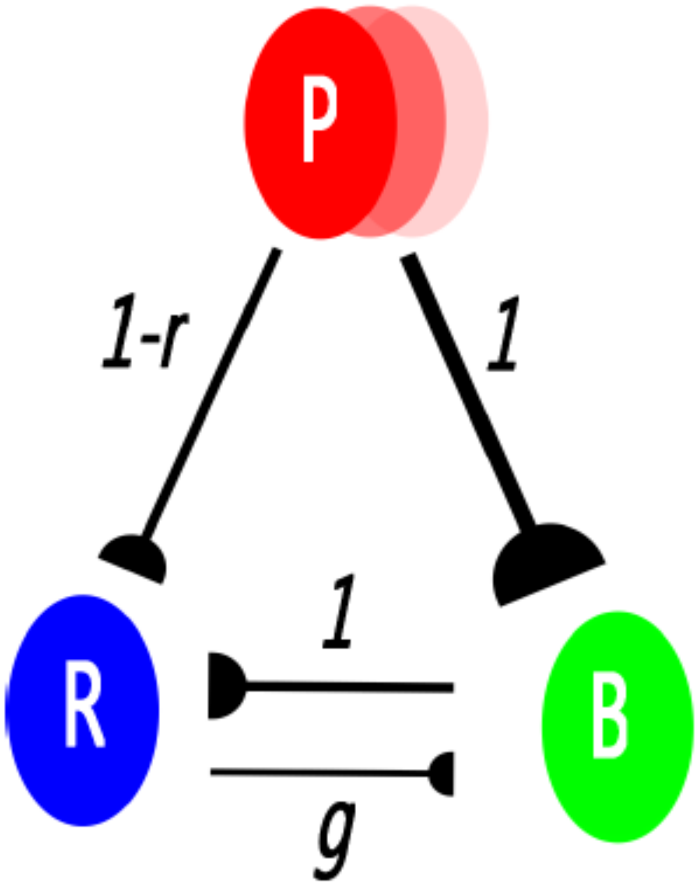


Network from Flores et al (2012), data from Moebus (1980)

B=succeptible

R=partially resistant

P=phage

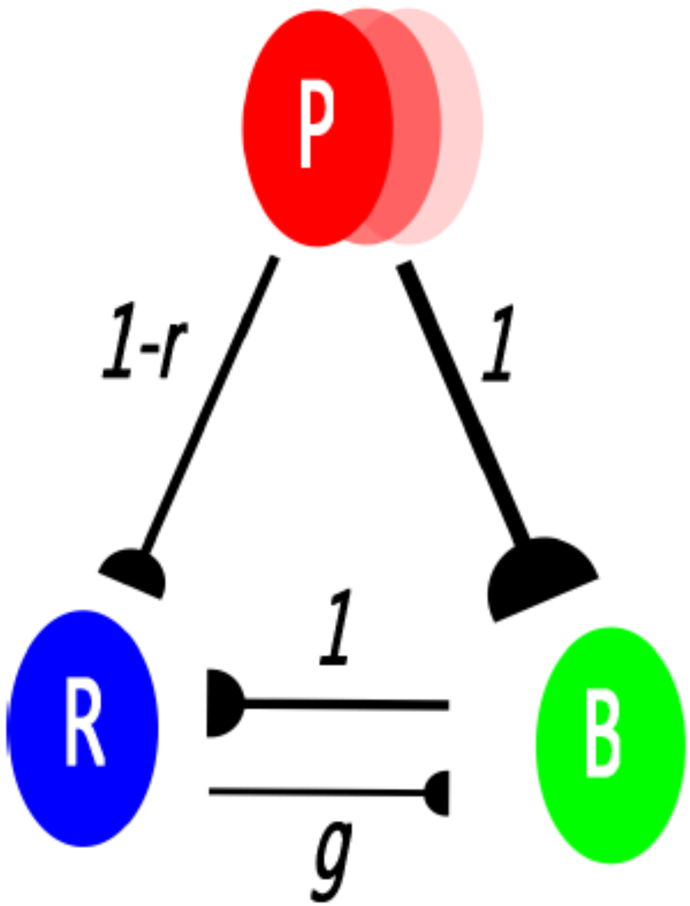


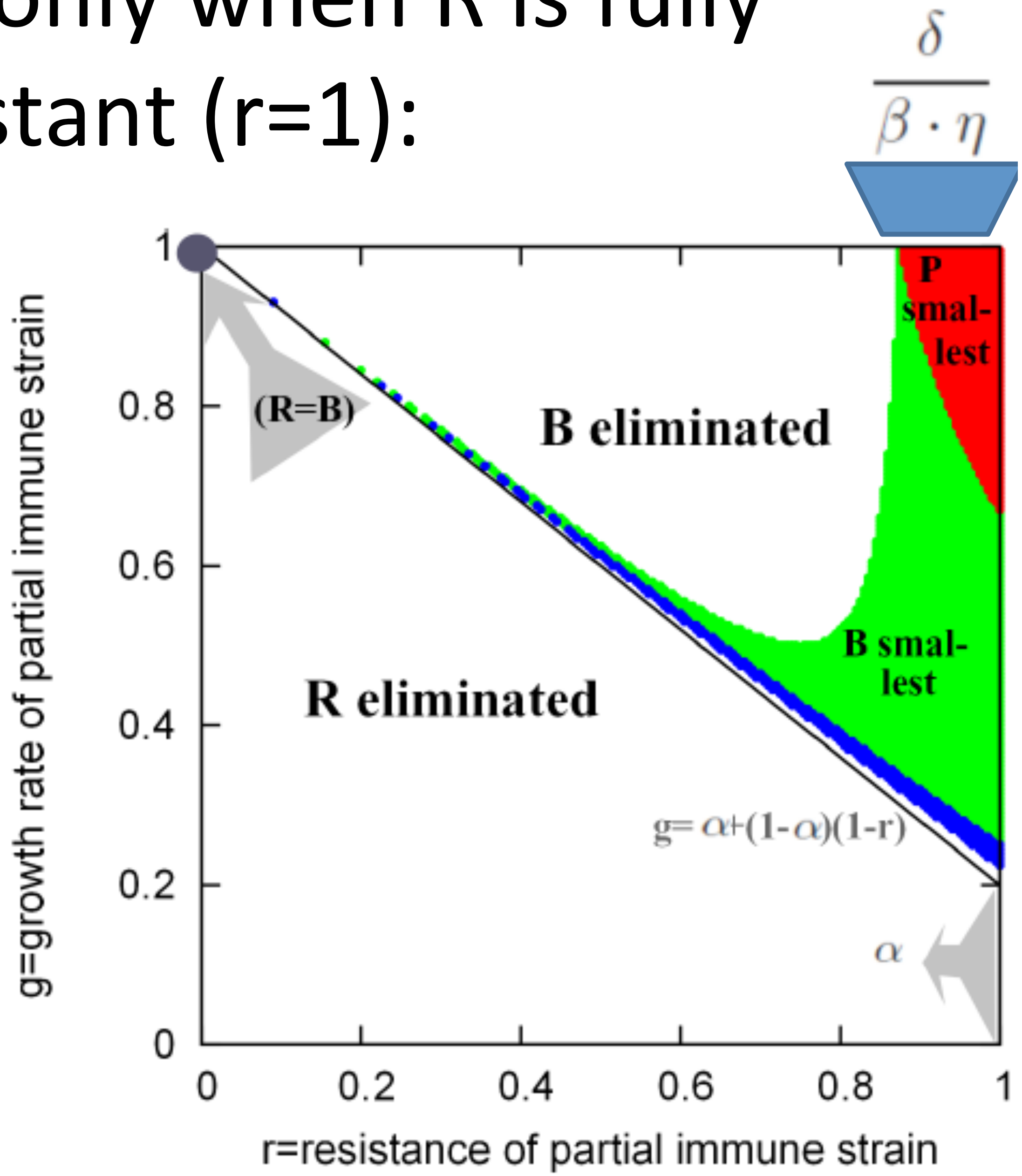
$$\frac{dB}{dt} = B \cdot (1-(B+R)) - \alpha \cdot B - B \cdot \eta P$$

$$\frac{dR}{dt} = g \cdot R \cdot (1-(B+R)) - \alpha \cdot R - (1-r) \cdot R \cdot \eta P$$

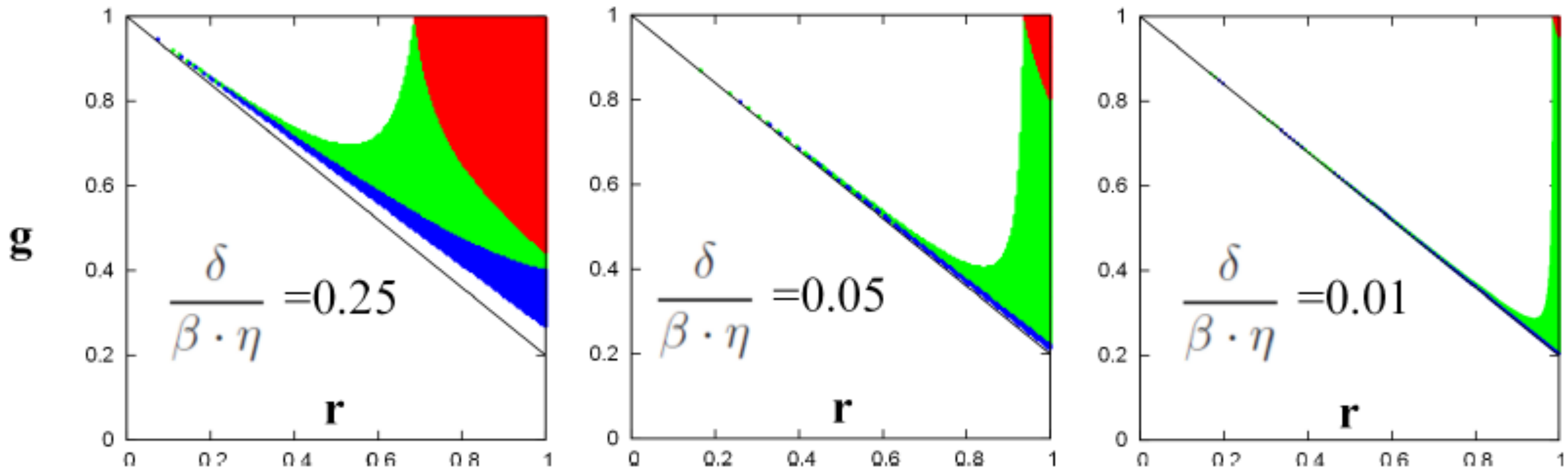
$$\frac{dP}{dt} = \beta \cdot B \cdot \eta P + \beta \cdot (1-r) \cdot R \cdot \eta P - \delta \cdot P$$

Coexistence only when R is fully resistant (r=1):





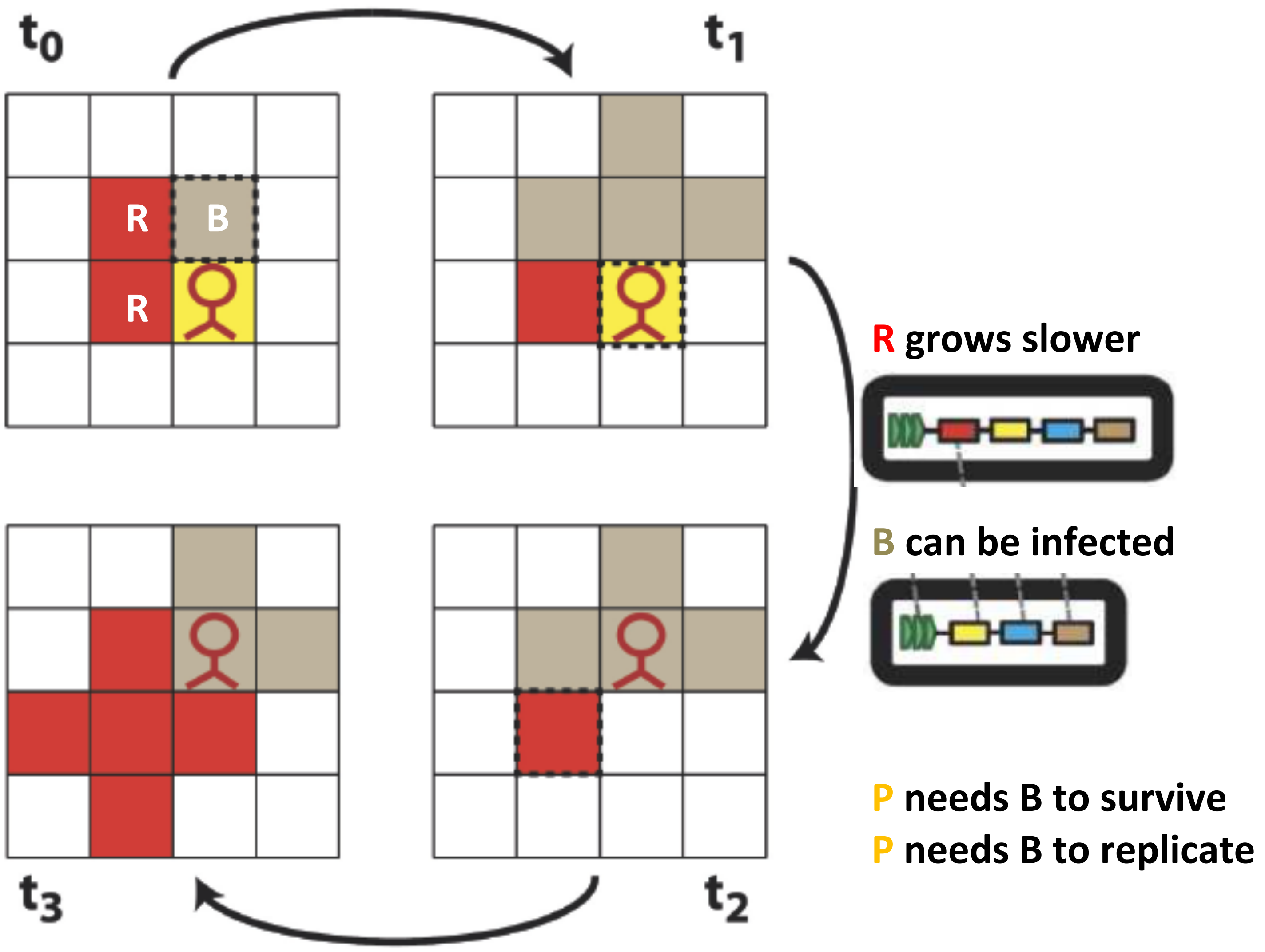
Cannot be fully resistant to all in the whole world
→
Local resistance



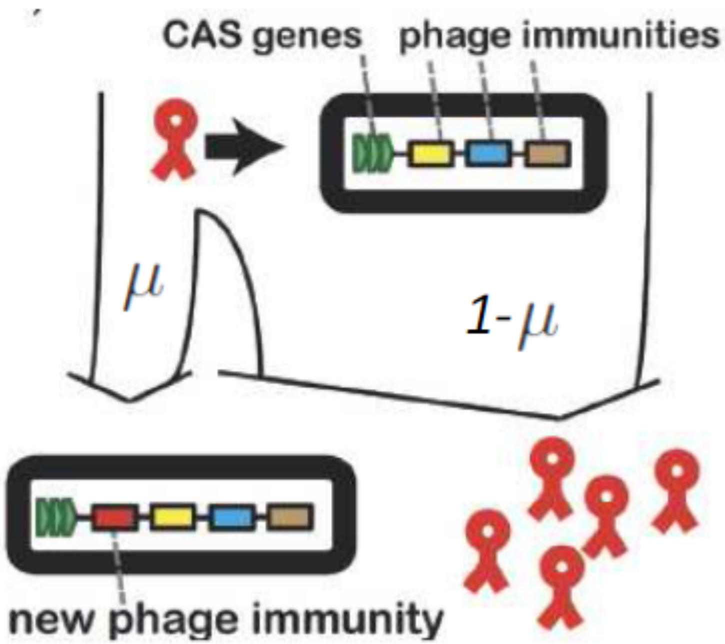
Larger efficiency of phages →

Agent based updating on lattice

many phages, many immunities:



+Gain and loss of immunities (CRISPR-model):



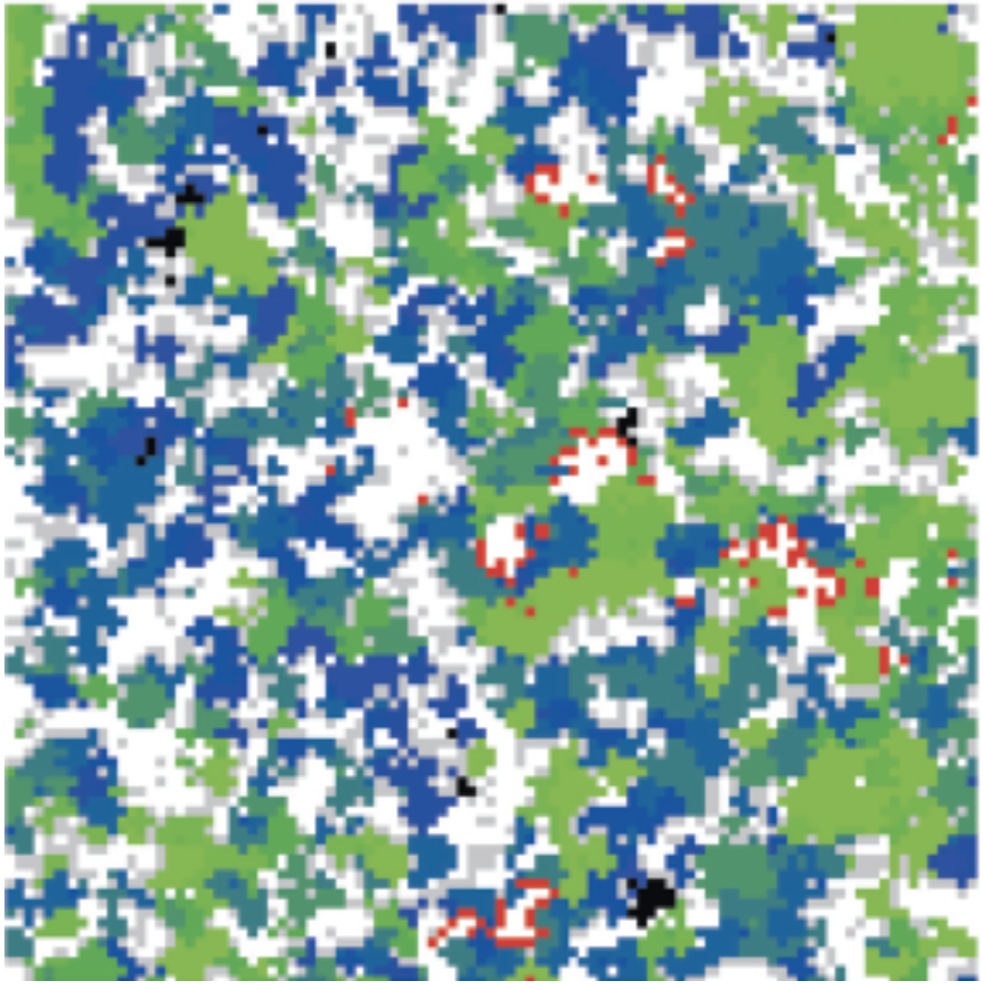
+

Removal of one phage immunity with probability μ' at bacterium duplication.

(this loss-rate is self organized)

This gain-rate is set to 0.1
As our unit is 100.000 bacteria in
One colony.

→Diversity (in a Red-Queen race):

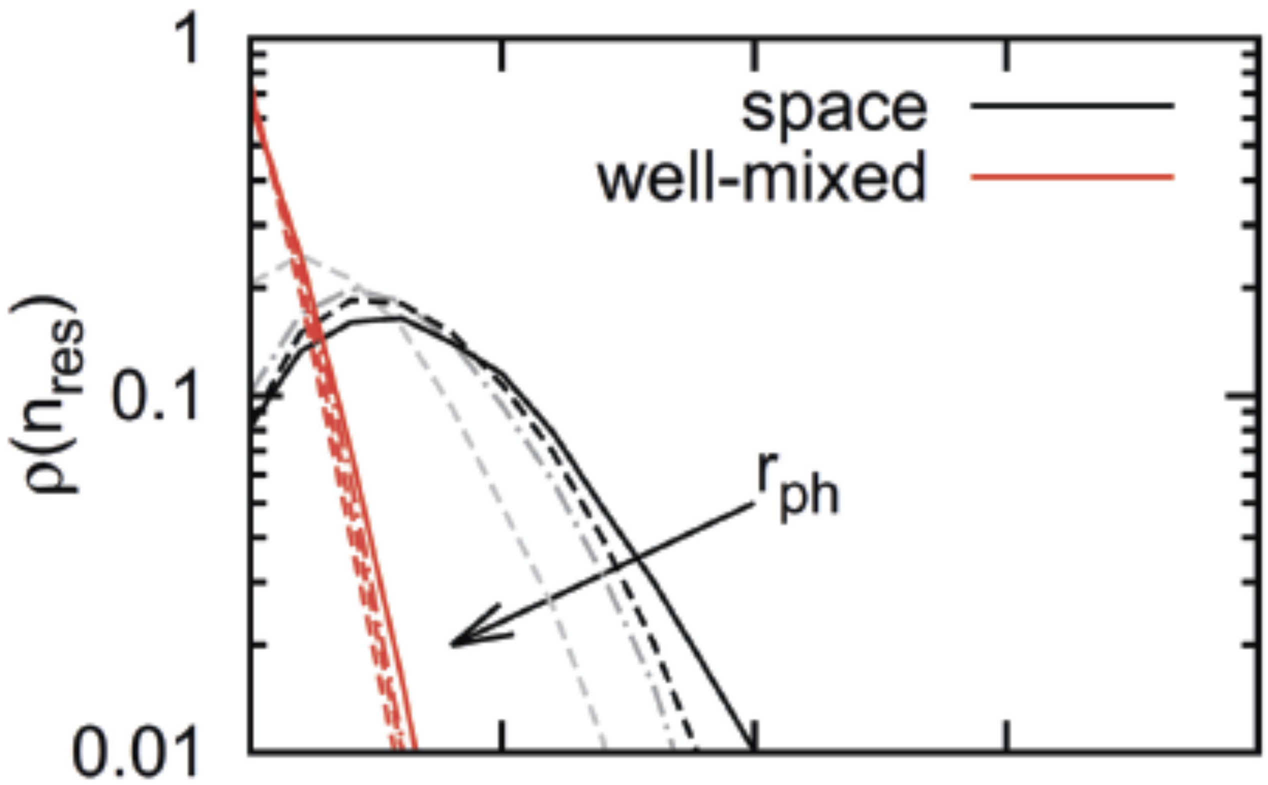


Red:
One phage type
Grey:
All other
Phage types

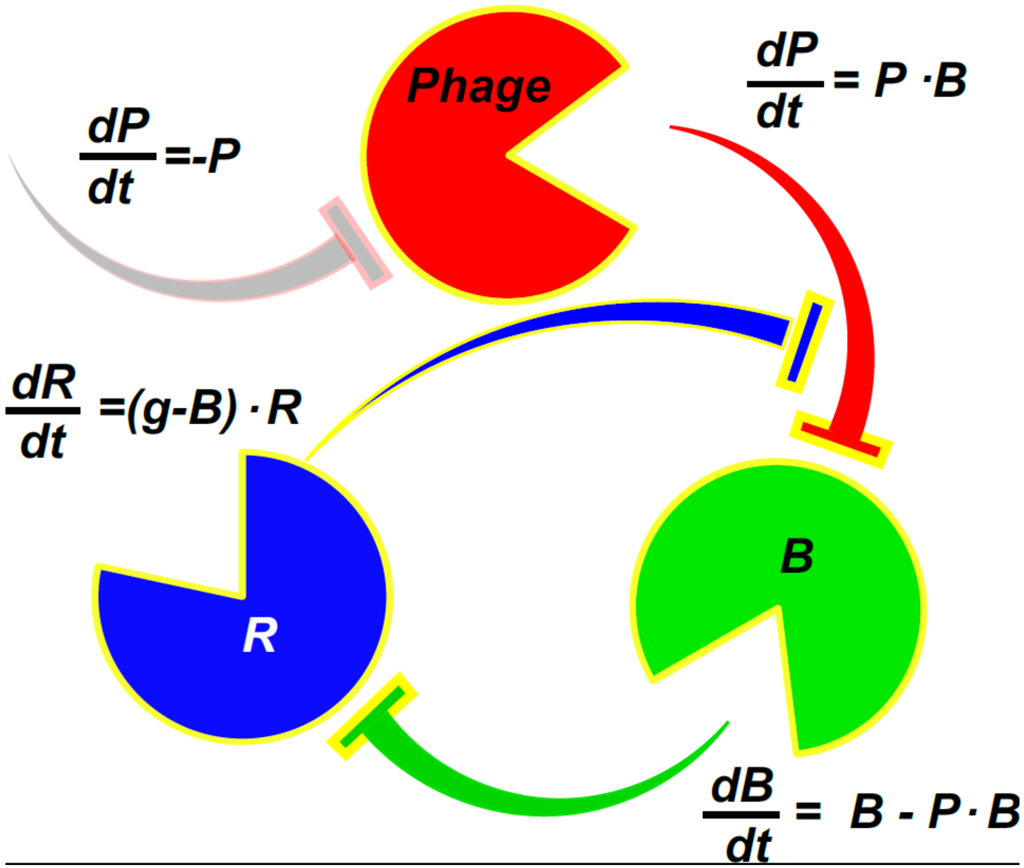
Black (0) to Blue to Green: Bacteria with increasing number of immunities

Without space→ immunities meaningless

(little chance to meet same phage again)



Cycles & Red-queen:



Bacteria= B→R→P

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