

Prebiotic evolution:
Circumventing Information threshold(?)
emergence of higher levels of selection

Last time

Minimal model of evolutionary dynamics:
Replicator equation – \rightarrow quasispecies

Error catastrophe

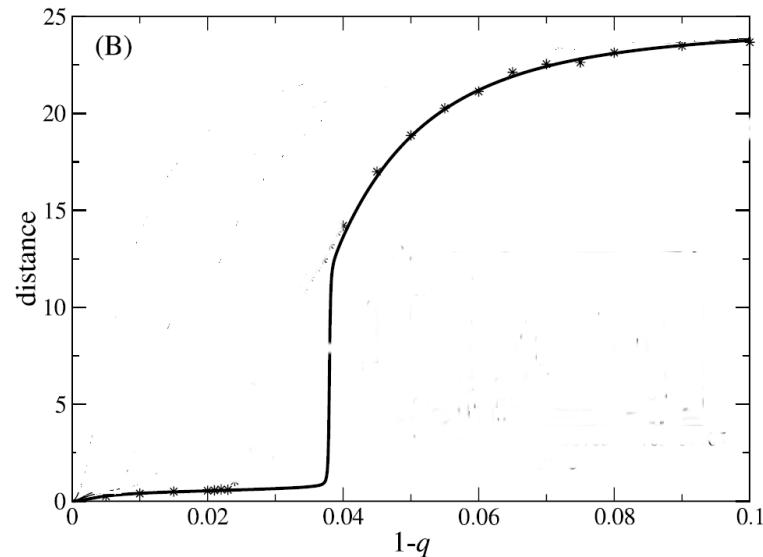
Replication should have high enough fidelity for Darwinian evolution to work
“survival of the fittest” not a tautology

Implies **Information threshold**: only limited information can be maintained / accumulated

Enough to get started?

How to overcome?

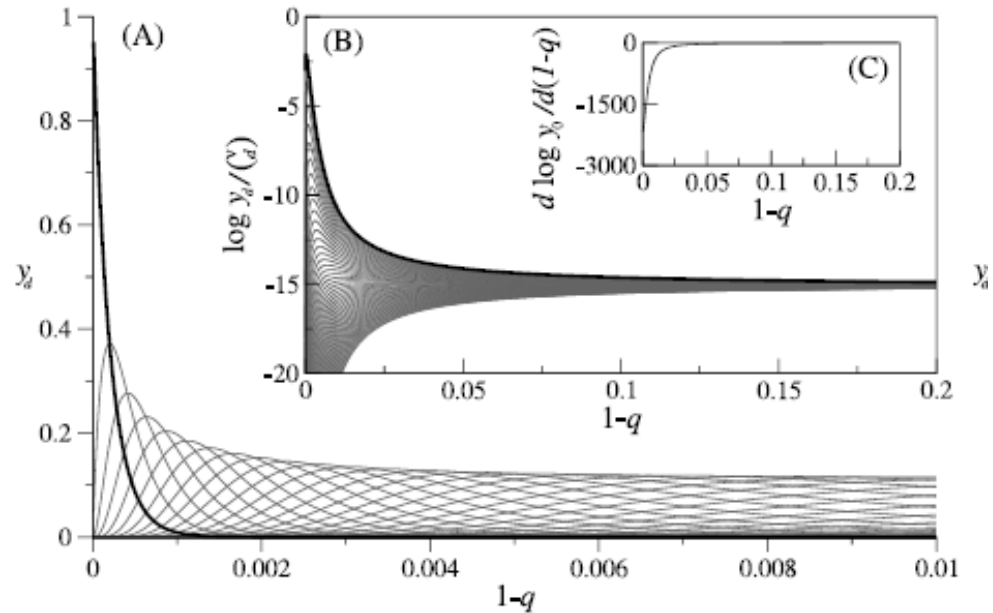
information threshold, further characterisation
Before the error threshold common ancestor is master
sequence
beyond the error threshold NOT



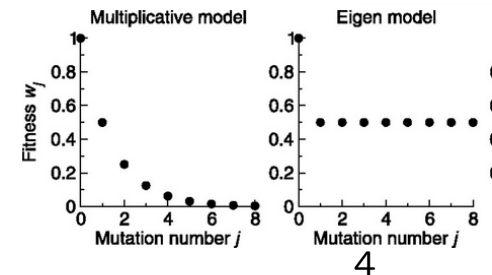
Common Ancestor: D to master seq.

cf Hermisson J, Redner O, Wagner H, Baake E. 2002

Delocalization but no threshold for exponential fitness landscape

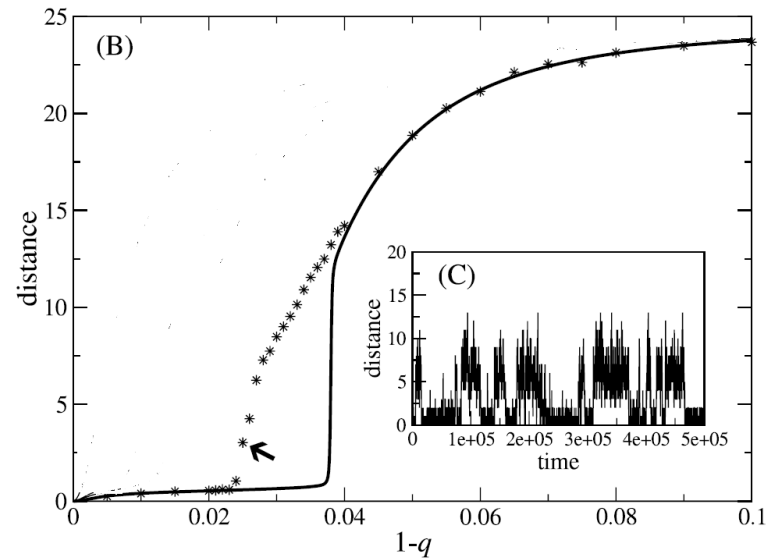
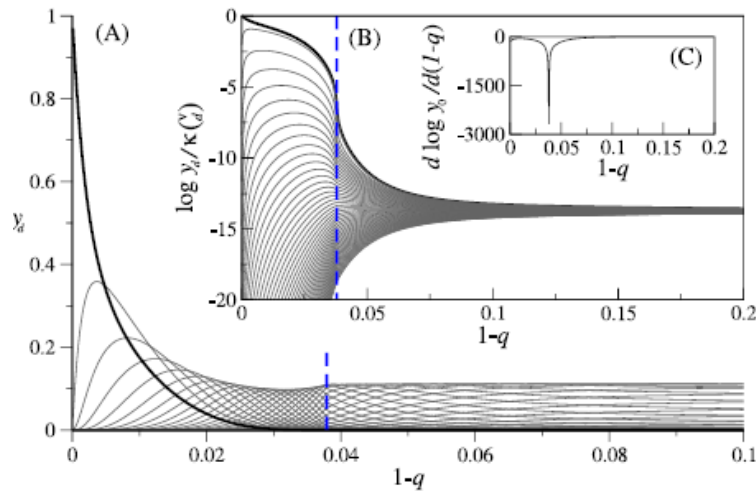


Takeuchi & Hogeweg (2007, BMC-evol)



However, if also lethal mutations - there is a sharp threshold

Common ancestor in finite population



Common Ancestor: D to master seq.

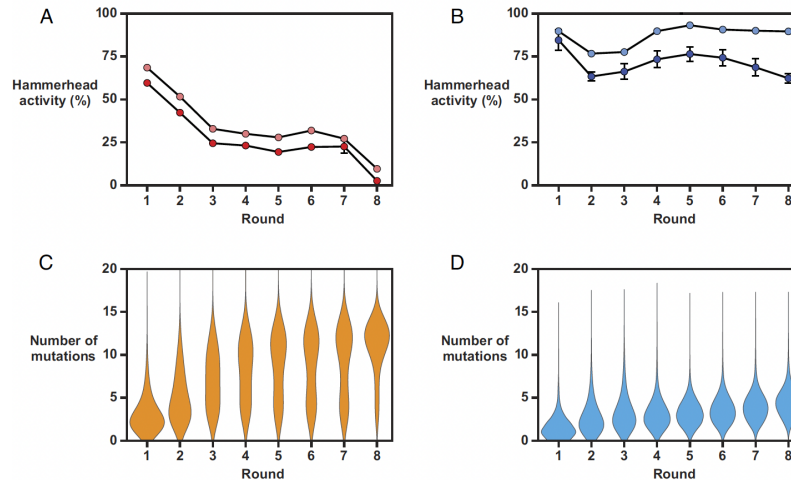
cf Takeuchi & Hogeweg (2007); Hermisson J, Redner O, Wagner H, Baake E. 2002

information threshold: any observational evidence RNA-catalyzed evolution of catalytic RNA (Papastavrou, Horning, Joyce 2024)

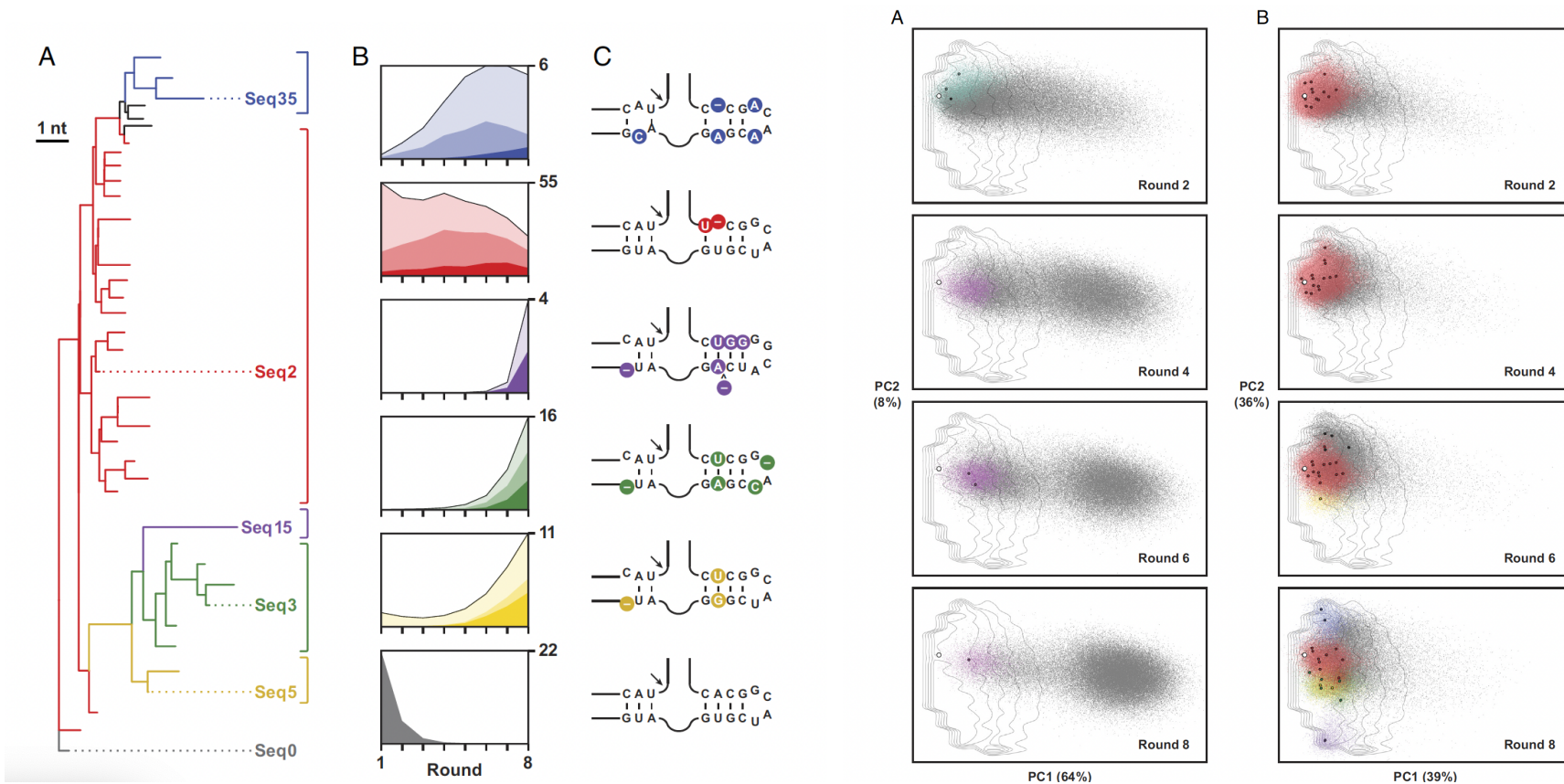
Last version of evolved RNA replicase was selected on yield and fidelity.

It can replicate the Hammerhead ribozyme + and - strand in continued experimental evolution, where it increases fitness (replicatability, but slightly decreased functionality)

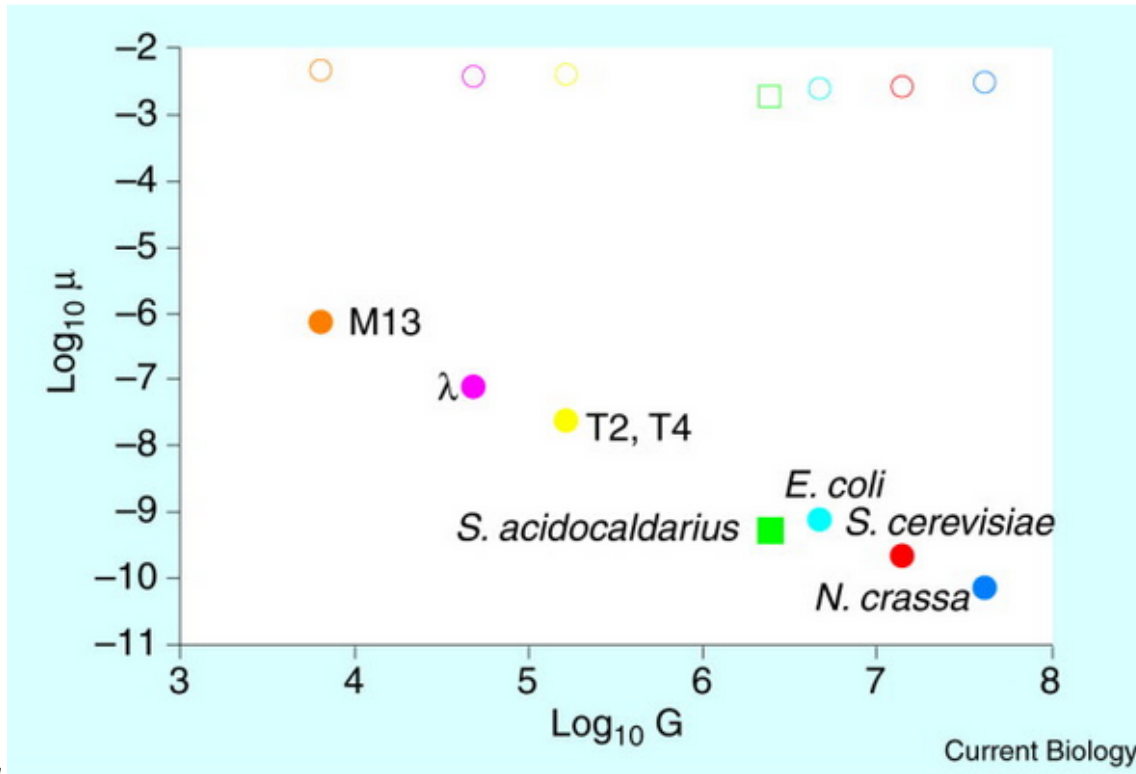
Previous version, above error threshold and sequences diverse to random sequence.



Evolution of the quasispecies of the hammerhead ribozyme



Information threshold - any observational evidence?

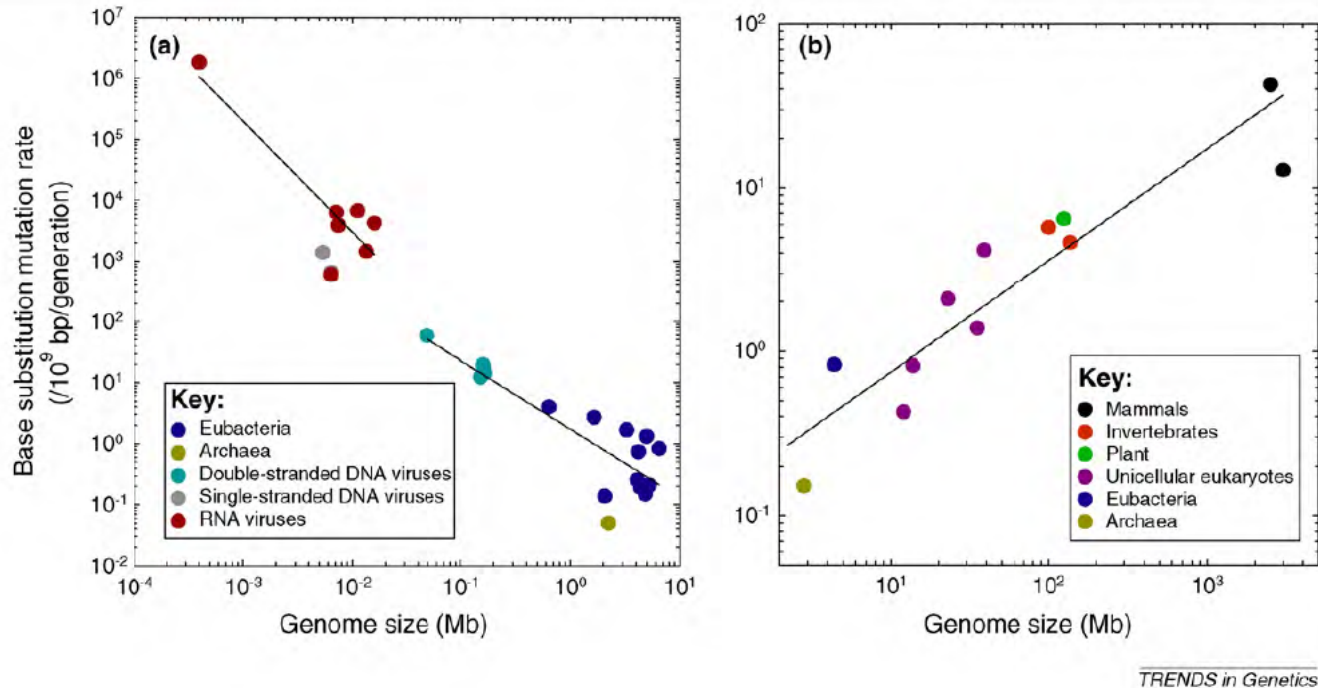


Drake's rule:
constant (BUT LOW!) per genome mutation rate

mutation rate "evolved" property
(cf Sulfolobus in very harsh environment)

Sniegowski " Evolution: constantly avoiding mutation" current biology 2001

Information threshold - any observational evidence?



retaining low mutation rates impossible in eukaryotes because of small population sizes? (“above” error threshold?)

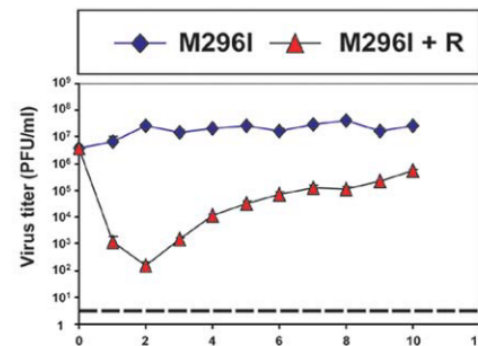
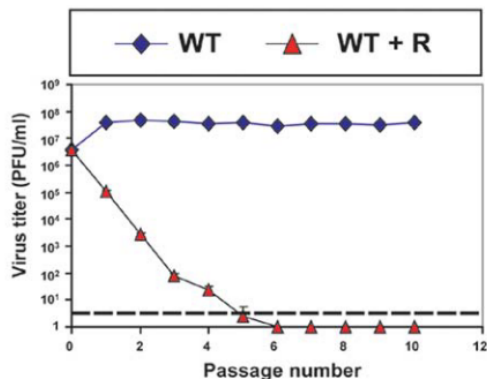
Lynch 2010 TIG

cf “constructive neutral evolution”
9

Error threshold and antiviral strategies

error threshold and/vs extinction threshold and/or new mutants

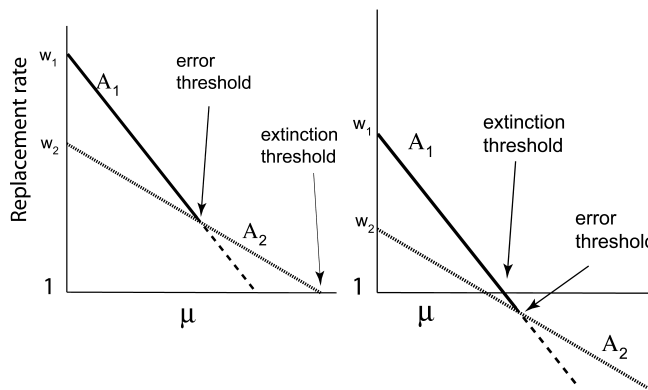
Perales C, Agudo R, Domingo E. PLOS-one 2009



WT extinction by mutagenesis

mutant resistant to mutagen

(mutation in RNAdep RNA pol.)



Bull et al 2005 Plos comp biol

How e to 'solve' or 'circumvent' information threshold?

Did we ask the wrong question?

Did we use the wrong model?

Only little information needed for higher quality replication?

2(3) main directions to try to circumvent problem

“more replicators”

“more RNA in replicators”

BOTH

FIRST

more replicators: ecosystem based solution

Hypercycles (Eigen's original solution)

Emergence of higher levels of selection

First attempt to circumvent information threshold: Hypercycles, Eigen and Schuster

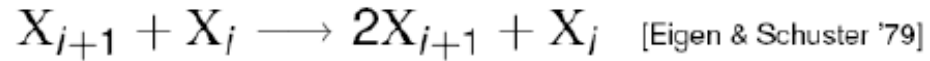
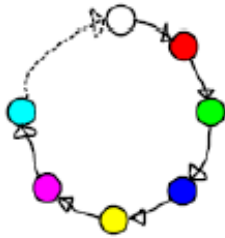
If one replicator has too little information - use many
However beyond the many of the quasispecies: evolved and
coordinately optimized.

Specific catalysis of reactions

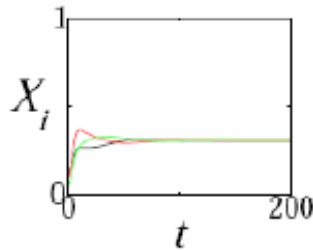
$$dX_i/dt = a_i X_i + b_i X_i X_j - \Omega_i$$

- (no mutations): look at 'ecosystem'
- ONLY stable topology: cycle

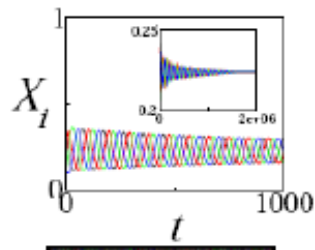
Hypercycle properties



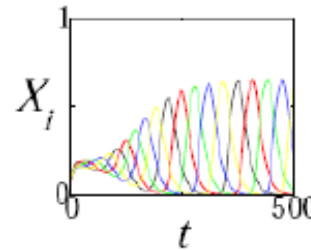
■ 3-member



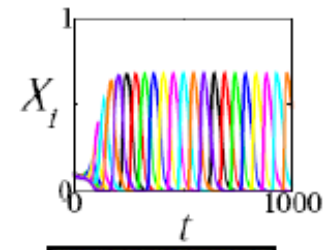
■ 4-member



■ 5-member



■ 9-member



- Selection LOCAL on amount of catalysis received
- growth and contraction of cycles

HOWEVER

- Once only selection/survival of the first
- NO selection for GIVING catalysis: Parasites

Nothing in biology makes sense except

.....in the light of Evolution (*Dobzhansky 1973*)

BUT SO FAR

evolved biological complexity does not seem to make sense
in the light of evolution.

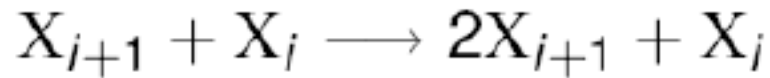
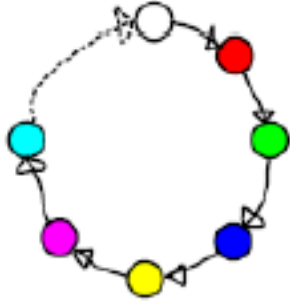
HOW TO DEBUG?

Nothing in biology makes sense except

-in the light of Evolution (*Dobzhansky 1973*)
-in the light of CA (s.l.)
 -local interactions
 -micro-macro transitions
 -non-linear dynamics etc.
 -"simple rules – > complex behavior"

nothing in biology makes sense except in the light of Both

Hypercycle model (Eigen and Schuster '79): cycle only possible topology

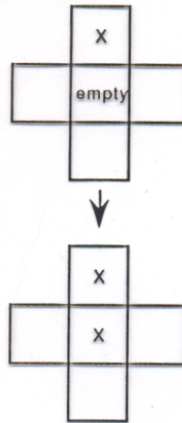


$$dX_i/dt = a_i X_i + b_i X_i X_j - \Omega_i$$

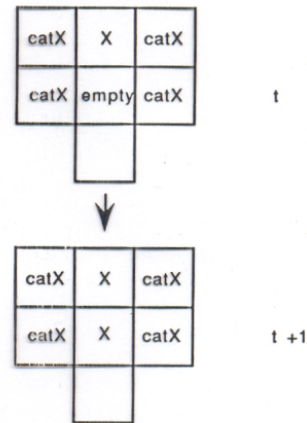
A. decay



B. replication



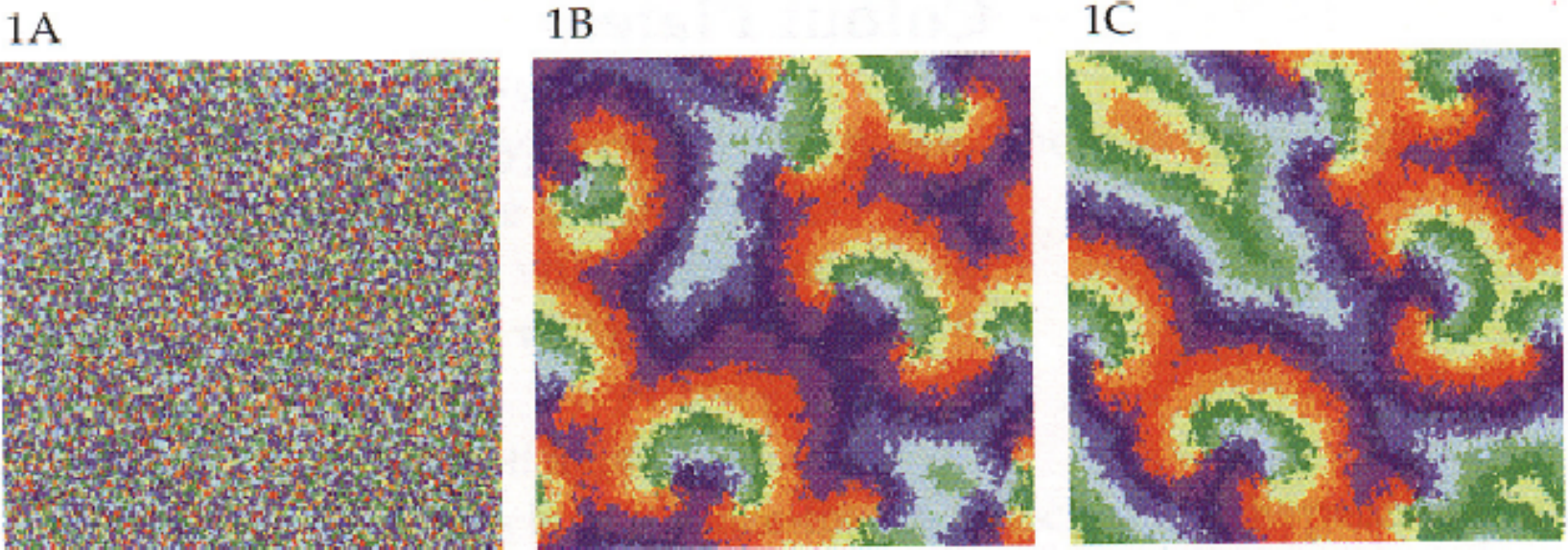
C. catalysed replication



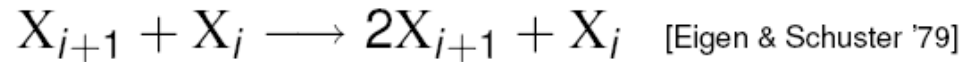
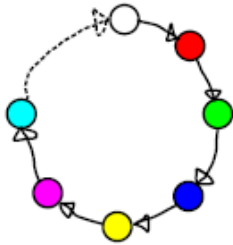
CA model:
1992

Boerlijst and Hogeweg

Spiral waves: generic patterns in oscillating systems



Hypercycle model prototype of multilevel selection

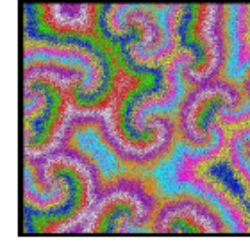
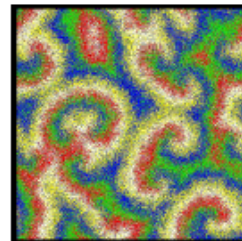
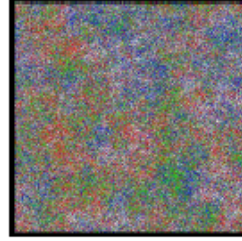
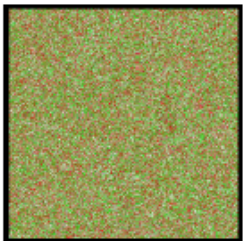
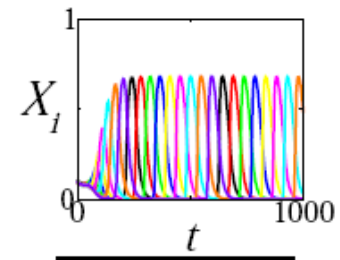
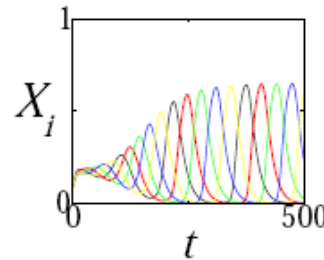
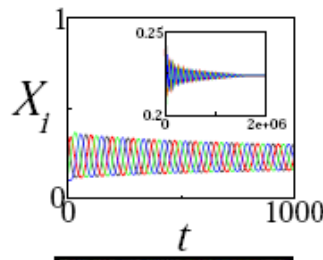
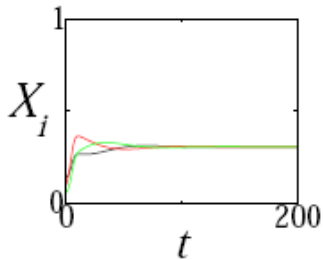


■ 3-member

■ 4-member

■ 5-member

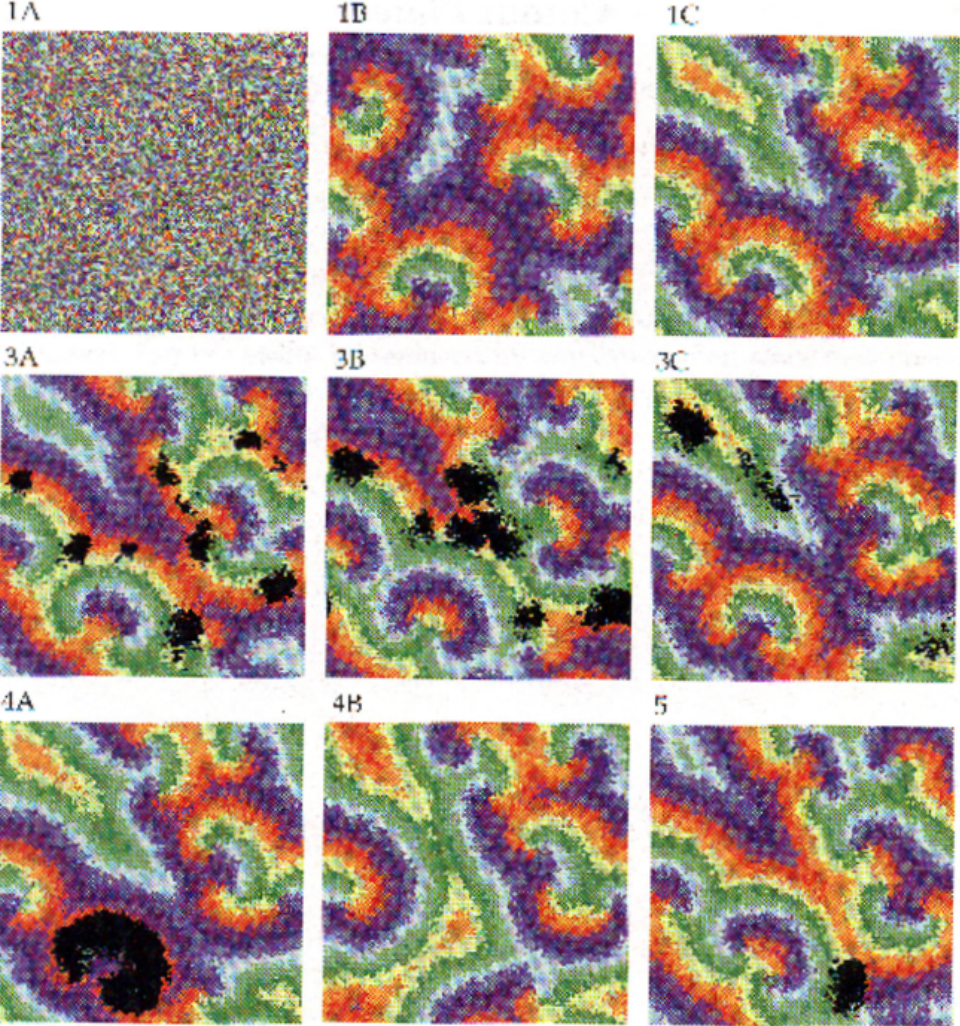
■ 9-member



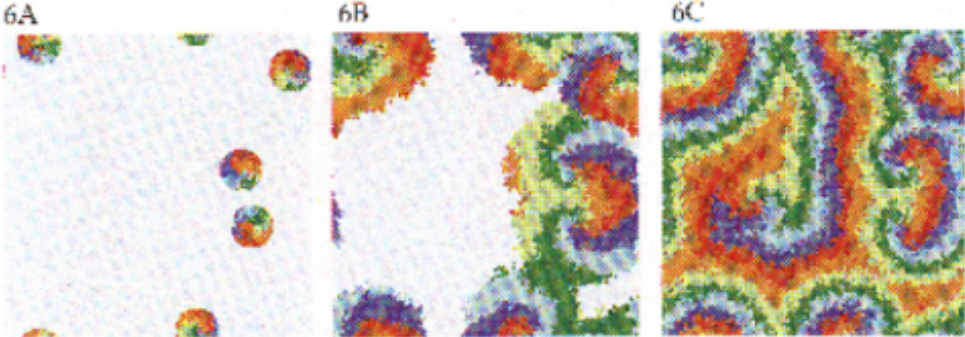
chaotic waves (N=4)

stable spiral waves (N > 5 (9))

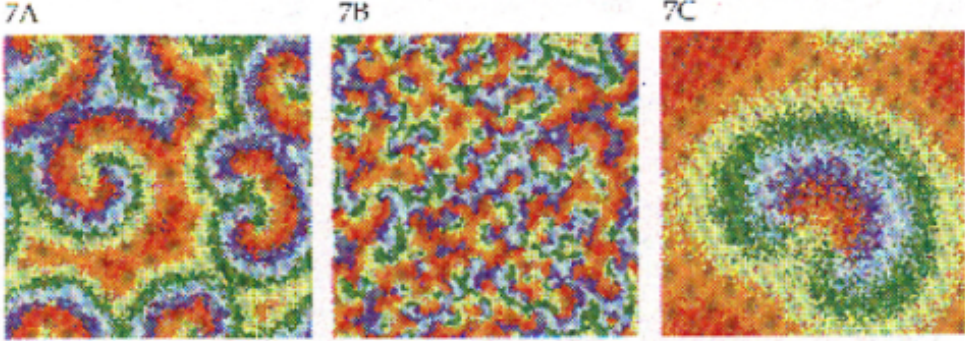
PARASITE INVASIONS AND EXTINCTION



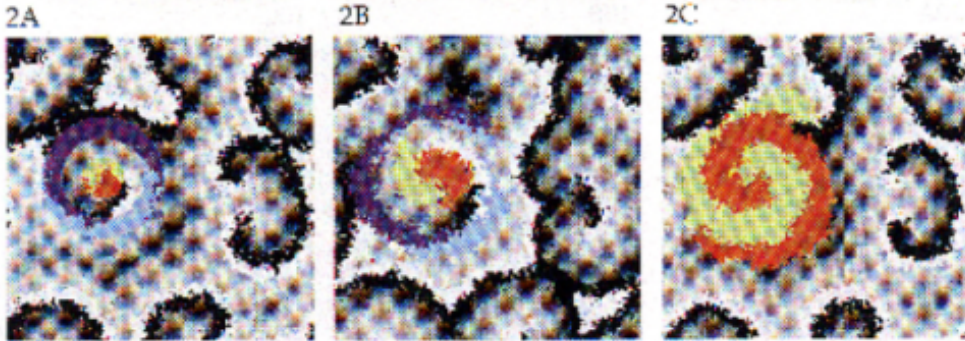
spiral dynamics



regrowth from core

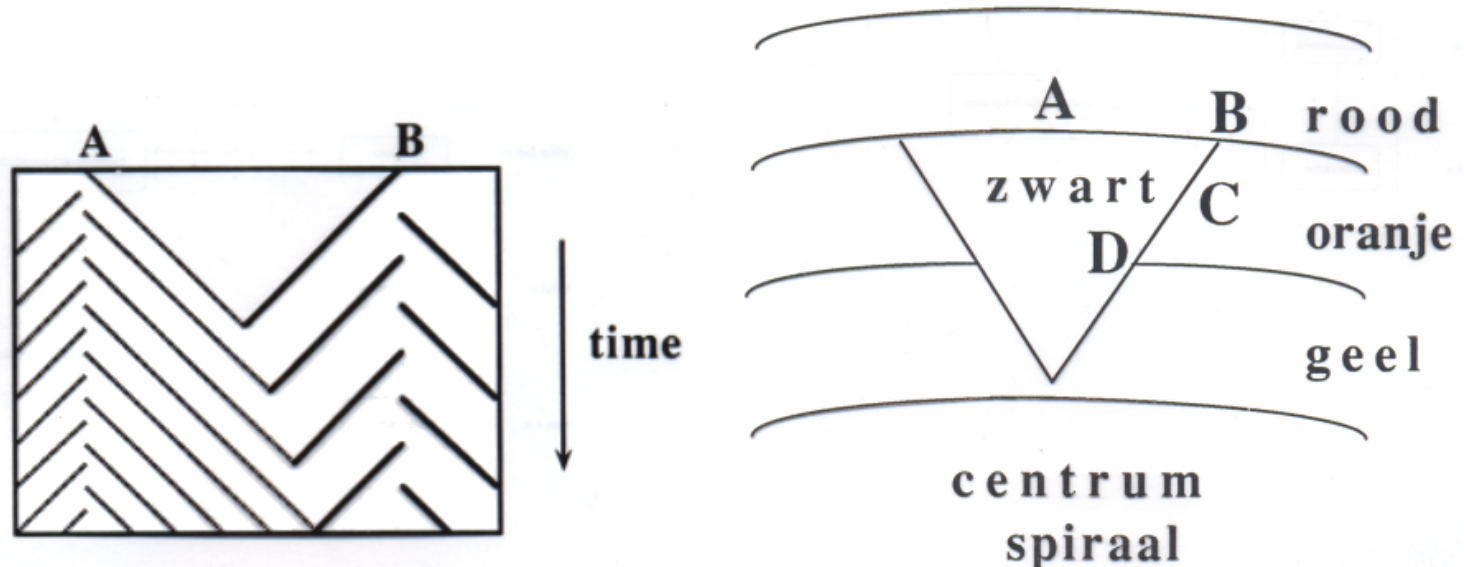


diffusion(low,none,high)



'inclusive fitness'
20

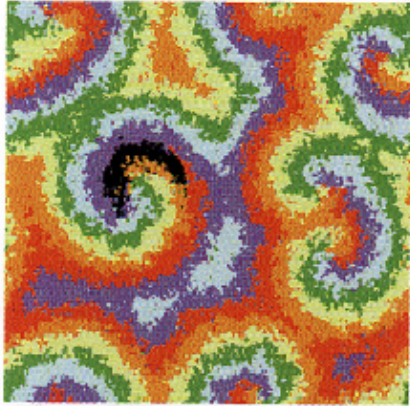
Properties of Spirals



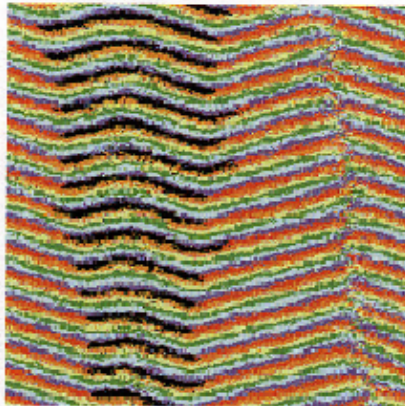
- **Faster Rotating Spirals:** Take over the domain of slower rotating ones
- **Core of Spiral:** produces all offsprings in long run

positive selection for early death

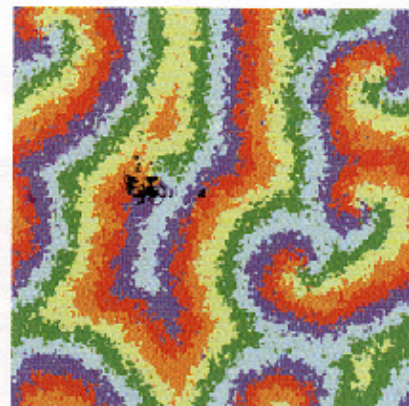
12A



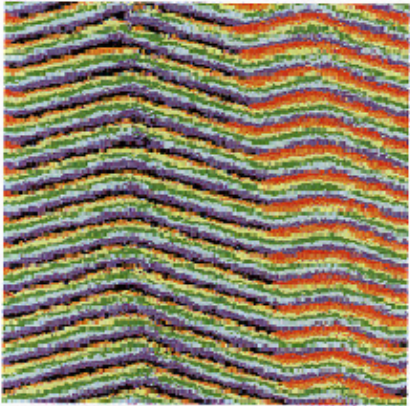
12B



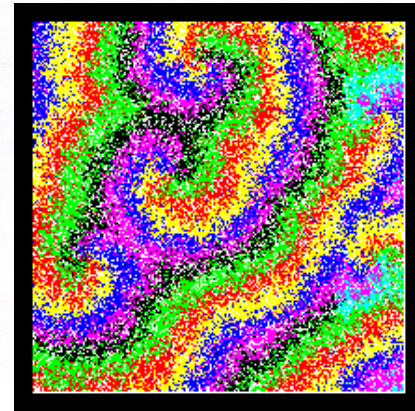
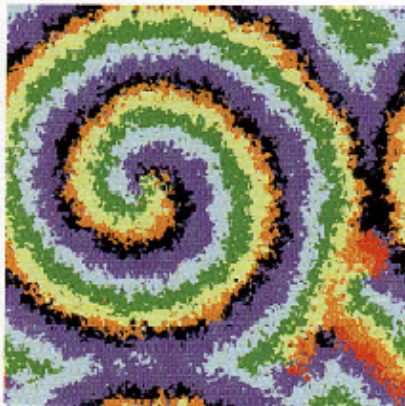
12C



12D



12E



Selection for higher decay

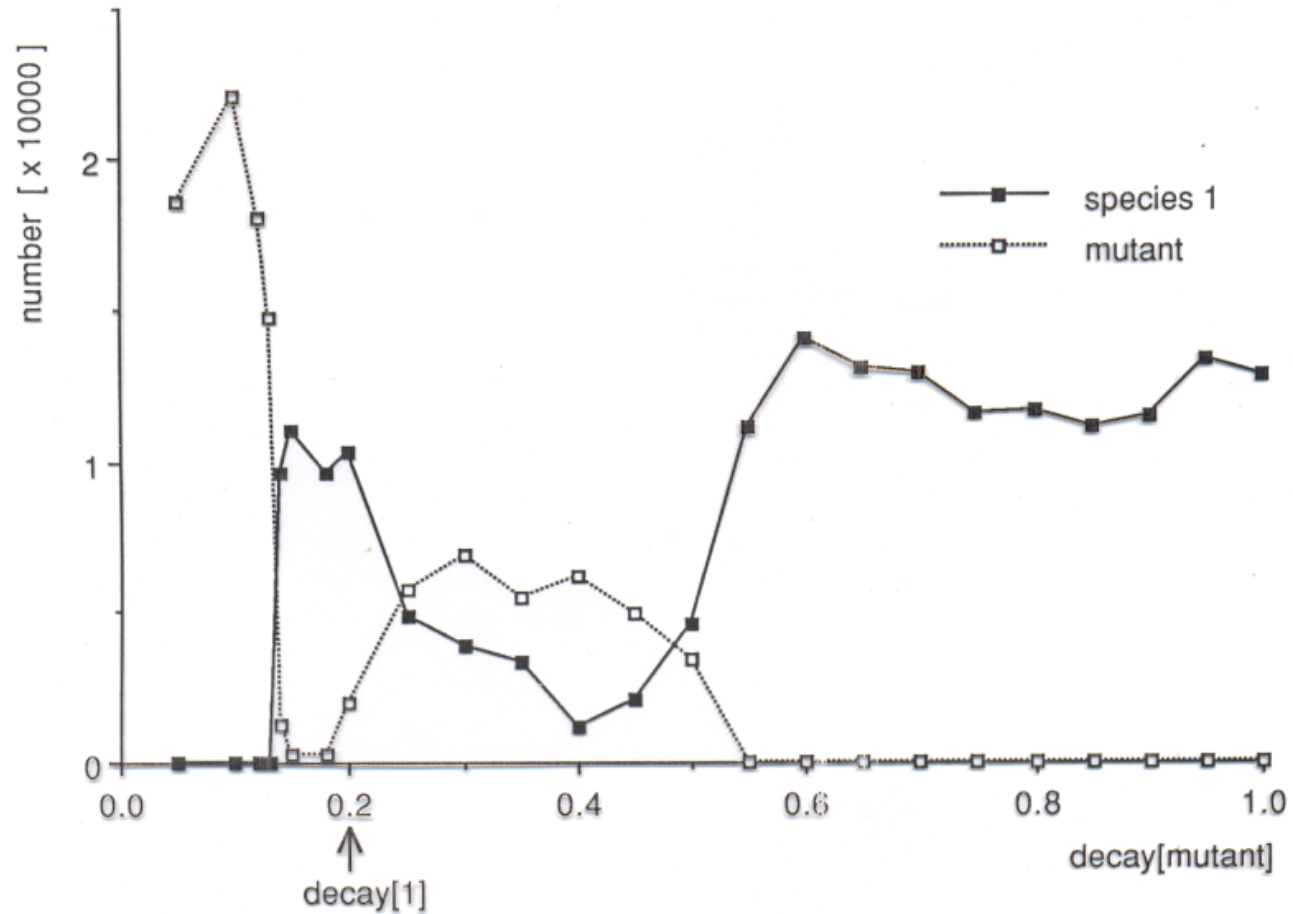
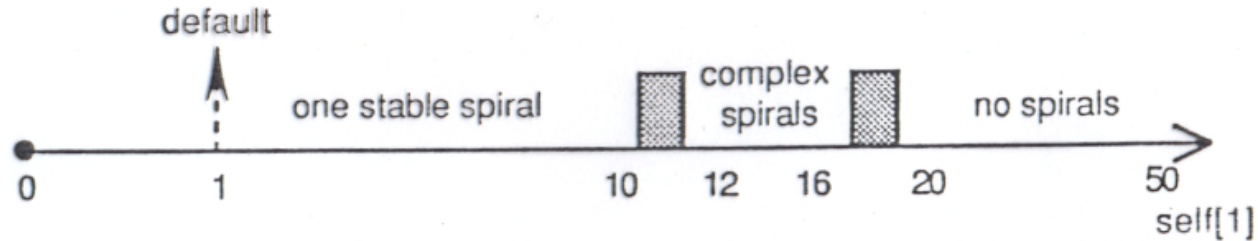


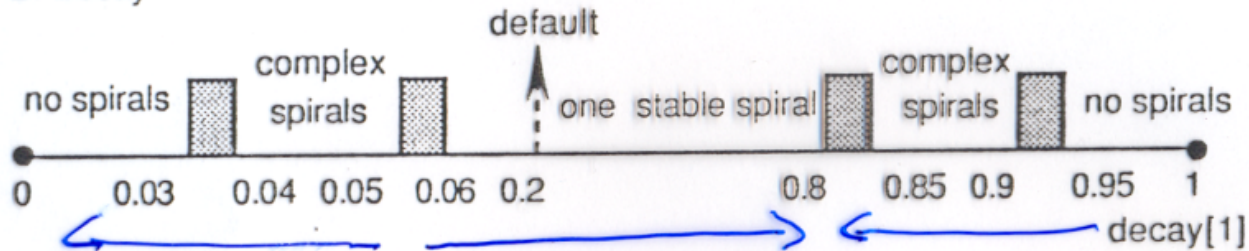
FIGURE 6 Number of molecules 4000 timesteps after infection with a decay mutant (Boerlijst & Hogeweg)

Spirals and the Edge of Chaos

A. Selfreplication



B. Decay



C. Catalytic support

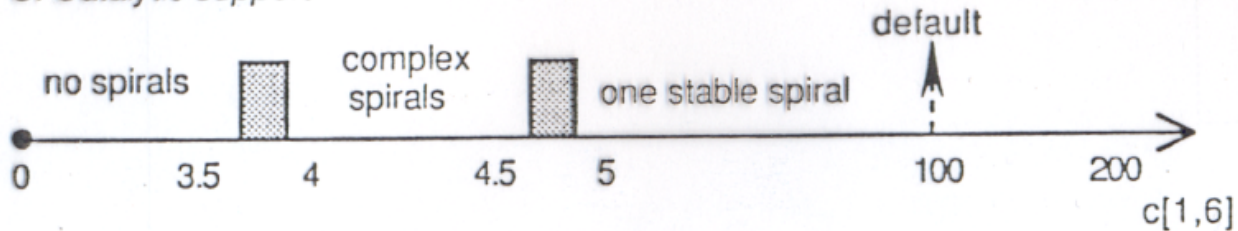


FIGURE 3 Stability results for various parameters of species 1, after 1000 timesteps.

Conclusion

**Hypercycle properties: in spatial model
everything differs from well mixed system**

- Limitcycle \rightarrow spiral wave patterns ($\gg 5$ stable)
- CAN be resistant to strong parasites
- Local interactions \rightarrow Selection non Local
- Not “once only selection”
- Spiral waves enslave molecules
- Positive selection for: early death, giving catalysis
- evolution towards 'edge of chaos' ('border of order')

Multilevel evolution

Did we solve the Information threshold problem?

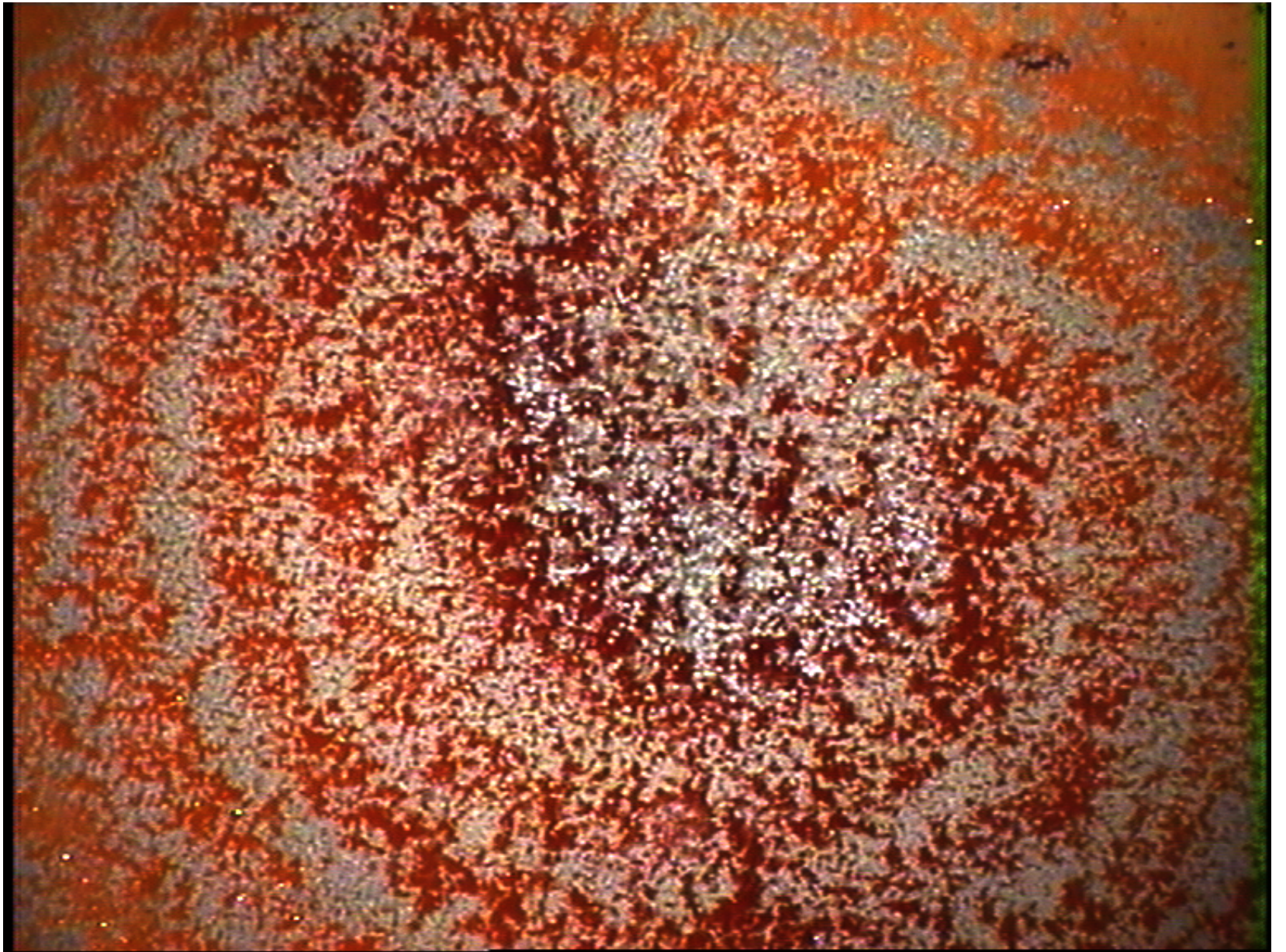
NO.....

because in PDE hypercycles not resistant to parasites?...NO

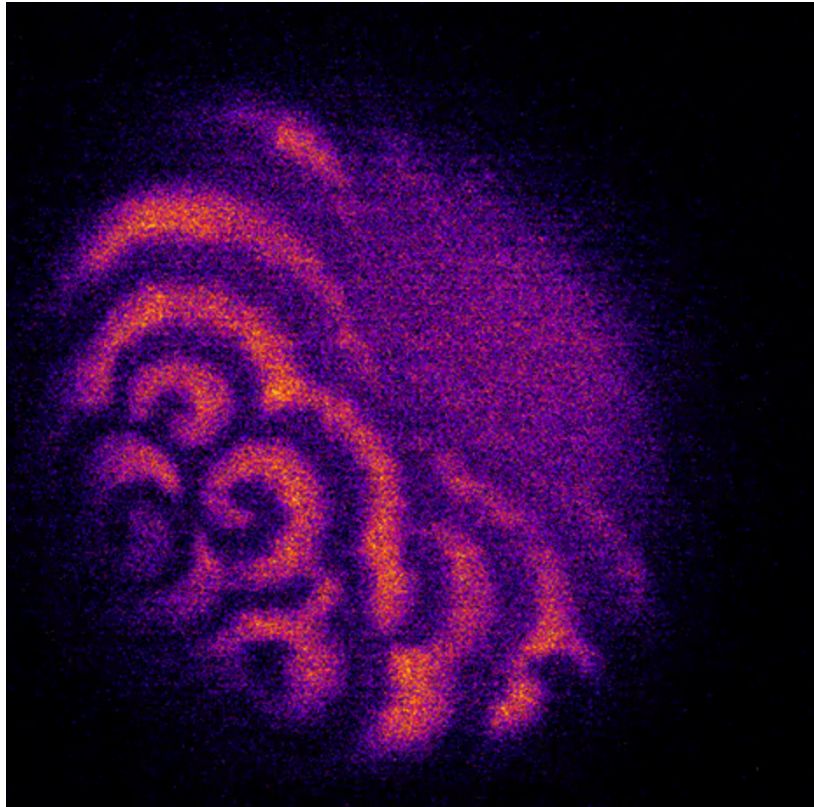
because spirals do not exist?.... NO





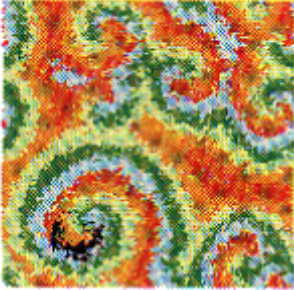


spiral waves in many intra and inter cellular rocesses
e.g. fertilized eggcells

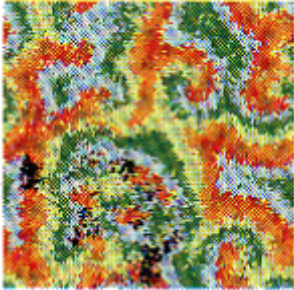


Shortcut mutants

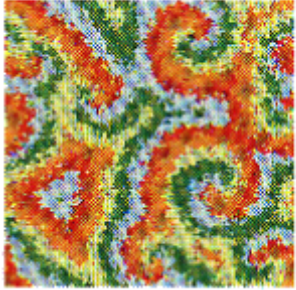
13A



13B

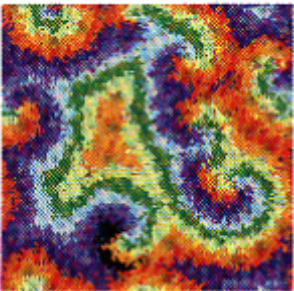


13C

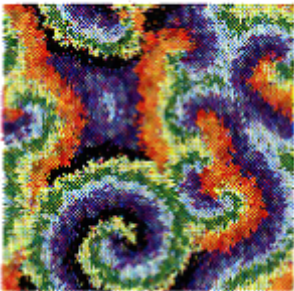


$$5 - > 4 \Rightarrow 5$$

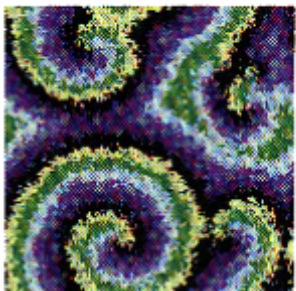
14A



14B

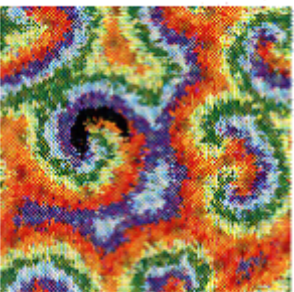


14C

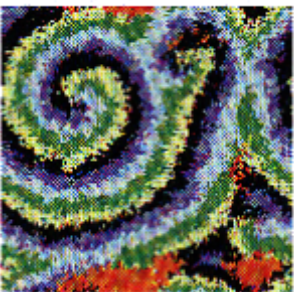


$$7 - > 6 \Rightarrow 6$$

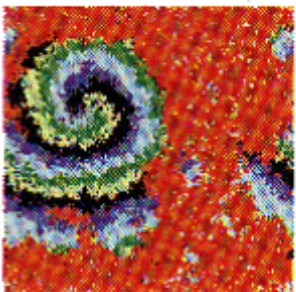
15A



15B

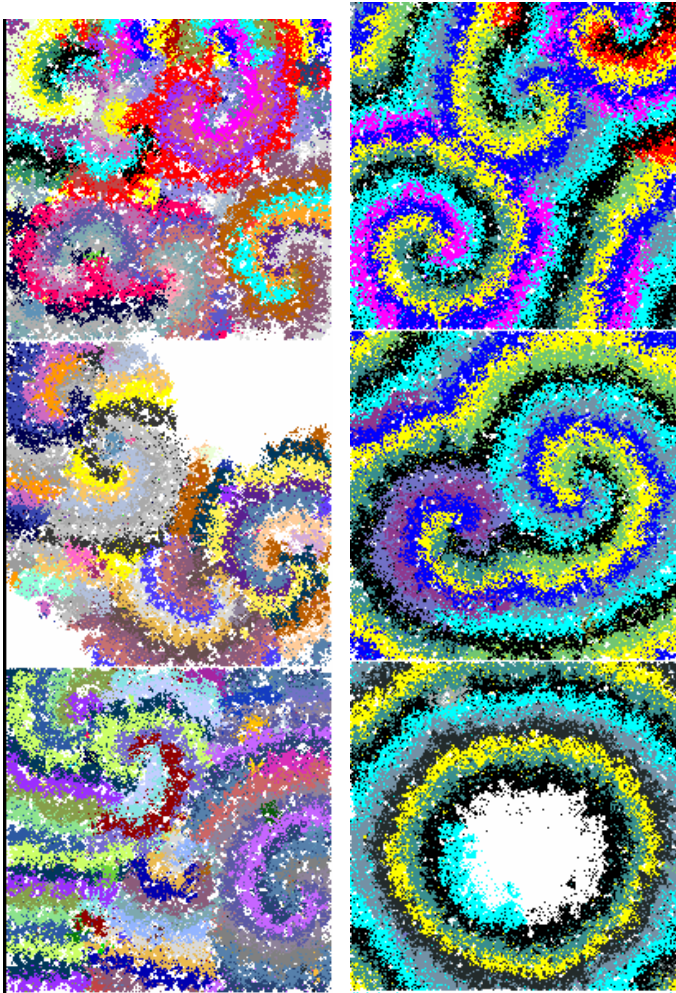


15C



$$6 - > 5 \Rightarrow \parallel$$

. *!!STUDIED SO FAR ONLY AS ECOSYSTEM WITH INVASIONS!!*



. **Limited stability of Spatial Hypercycle with mutations!**

conclusions

- Hypercycles NOT a solution to the information threshold also in spatial eco-evolutionary setting.
- Emergent spiral patterns comprise a higher level of selection.
- Changes all selection pressures of the lower level
 - prevents parasite invasion, selects early death

multilevel selection (type 1)

HOWEVER

the spirals are not themselves replicating entities
Once destroyed the system dies

Multilevel evolution

- CA Universe: (cf. Crutchfield, Wolfram)
Micro – > Macro (.... – > – > etc)
STATIC (simple) 'rockbottom' **?one more soul?**
- BUT: In evolving systems also Macro – > Micro:

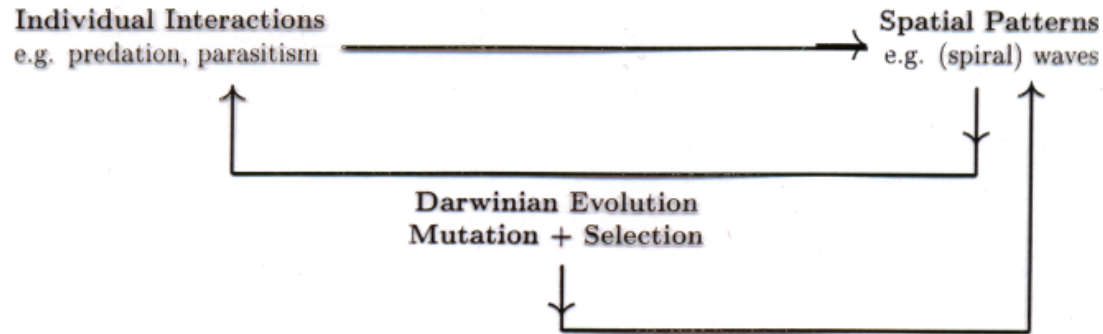


Figure 1: Relation between local interactions and spatial pattern formation in eco evolutionary models

lowest level

does not make sense except in the light of

higher level processes