Multi-level evolution in models of RNA world

Nobuto Takeuchi & Paulien Hogeweg
Theoretical Biology/Bioinformatics Group
Utrecht University, the Netherlands

Introduction.

The stability of replicator systems is confronted by two problems:
(i) a large mutation rate—**error-threshold**;
(ii) junc templates parasitizing the catalysts—**parasites**.

We previously studied (i) the error-threshold from two levels:
(1) **below** replicator (structure of molecules)—genotype-phenotype map;
(2) **above** replicator (population structures)—group selection.

We now combine two approaches to examine (ii) the problem of parasites in catalytic networks, and investigate the evolutionary interplay between the process above and below replicators.

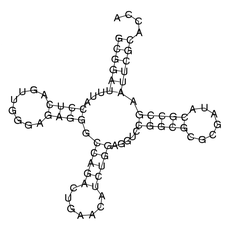
(1) Below replicators.

Q: *Does the error-threshold disappear by mutational neutrality?*

Basic equations:

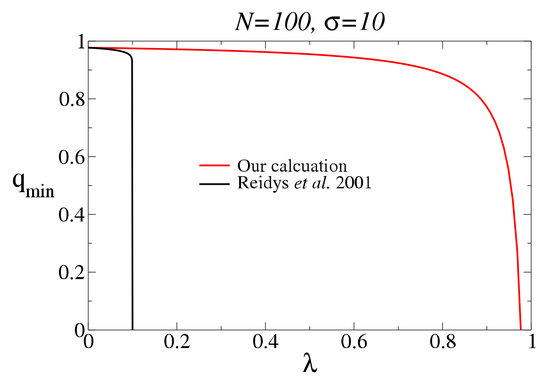
$$\text{Master phenotype: } dx/dt = \sigma Q x + \sigma\Lambda(1-Q)x - Dx - \Phi x,$$
$$\text{Mutant phenotype: } dy/dt = y + \sigma(1-\Lambda)(1-Q)x - Dy - \Phi y$$

Additive assumption ➡ $Q_e = \sum_{d=0}^{N} \binom{N}{d} q^{N-d}(1-q)^d \lambda^d = \{q + (1-q)\lambda\}^N$

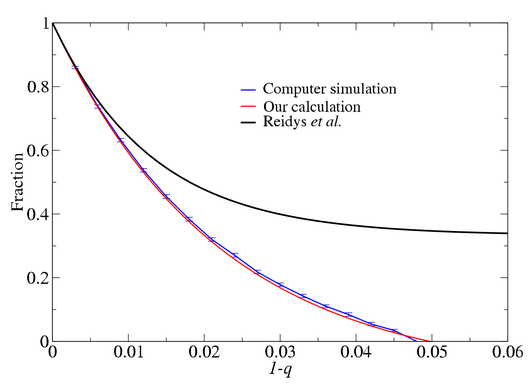


Results: $q_{\min} = (\sigma^{-1/N} - \lambda)/(1-\lambda)$

Phenotypic error-threshold



Comparison with simulations

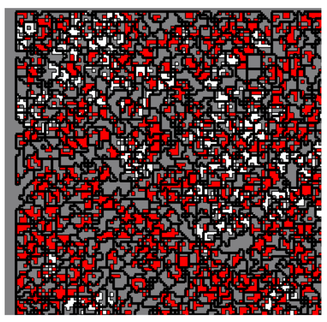


A: *An increase of the error threshold by mutational neutrality is limited.*
(Ref. Takeuchi N. et al., *BMC evol biol*, 2005 **5**:9)

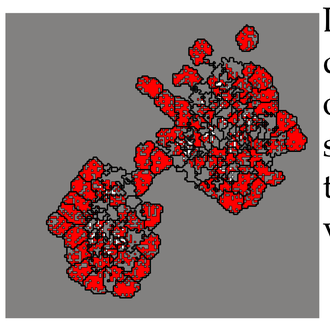
(2) Above replicators.

Q: *Does group selection circumvent the error-threshold despite stochasticity?*

Models: Replicator: Cellular Automata, Vesicles: Cellular Pots Model.



Neutral model: the master seq. and mutants contribute equally to the growth of vesicles.

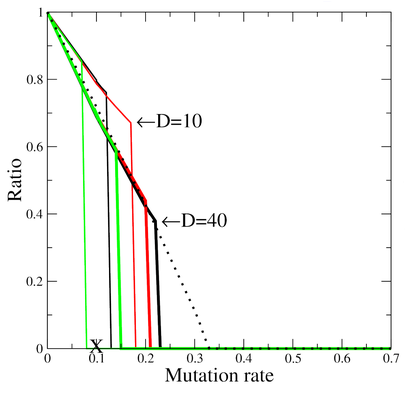


Differential-division model: only the master seq. contribute to the growth of vesicles.

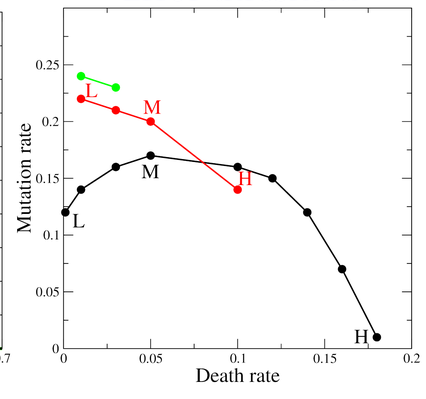
Colors: white=master seq.; red=mutants; **black**=vesicle wall.

Results of neutral model:

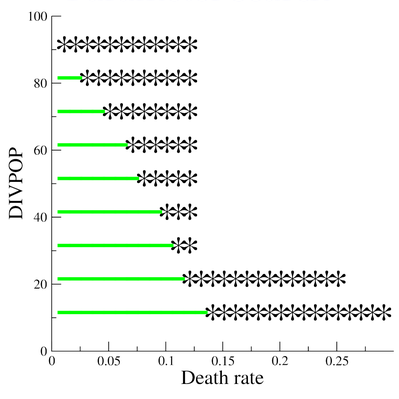
Ratio of master seq.



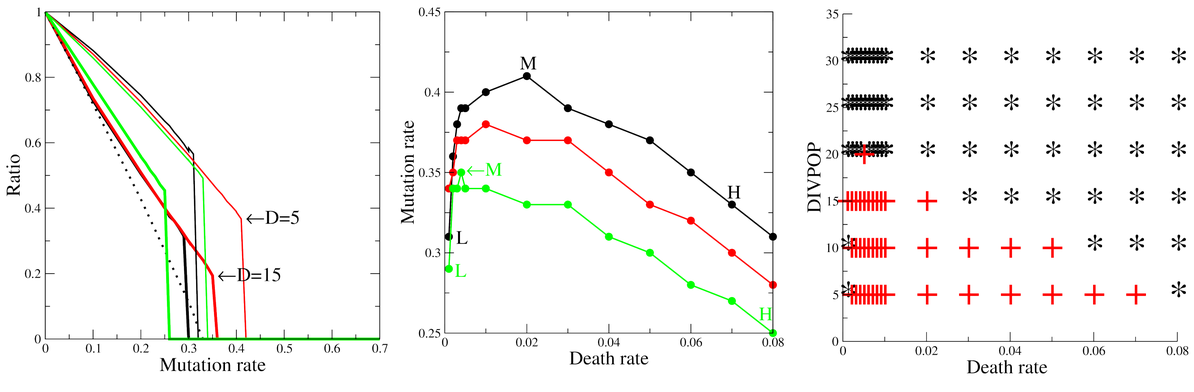
Error-threshold



Parameter search



Results of differential-division model:

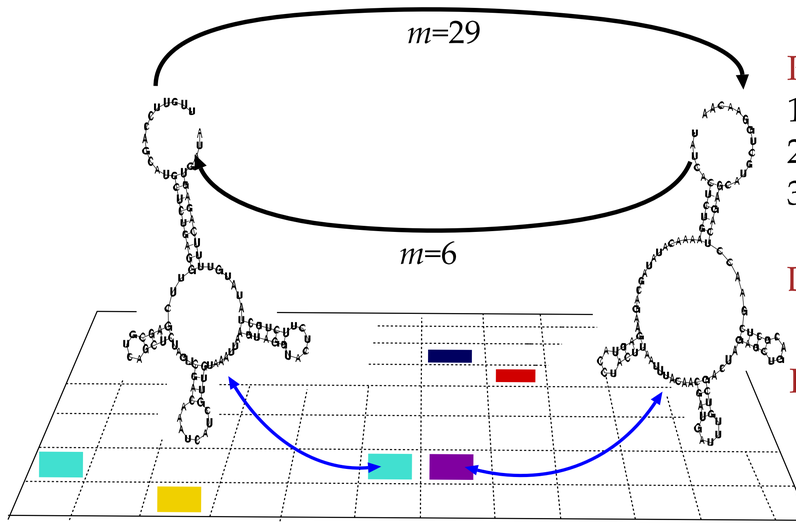


A: *Error-threshold becomes even more severe in neutral model.*
Group selection does not work for free: Stochastic effect is strong.
(Ref: Hogeweg P. & Takeuchi N., *Orig Life Evol Biosph* 2003)

(1+2=3) Below & Above replicators.

Q: *By taking both processes below and above replicators into consideration, can a system be stable against parasites?*

Model: Above replicators: **catalytic reaction networks**.
Below replicators: **RNA folding genotype-phenotype map**.



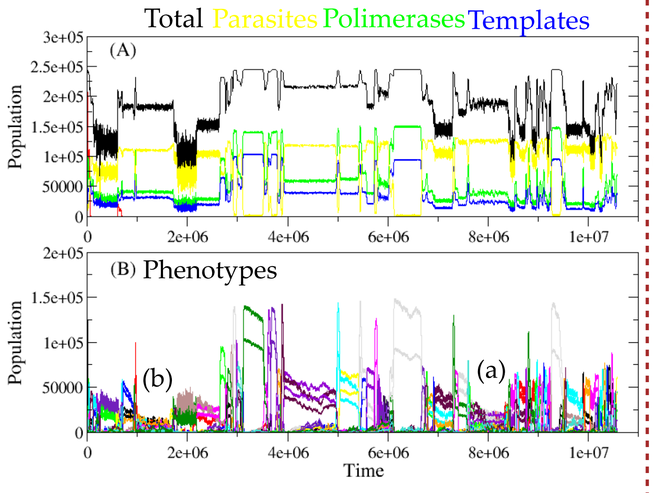
Above replicators
Reactions of molecules:
1. template based polymerization;
2. degradation;
3./4. binding/unbinding btw. 3'-end & 5'-end. ($1\text{-}e^{-0.02m}$ / $e^{-0.02m}$)
Diffusion of molecules.

Below replicators
Polymeraze: 3 stems connected by m-loop.
Parasites: other 2ndary structures.

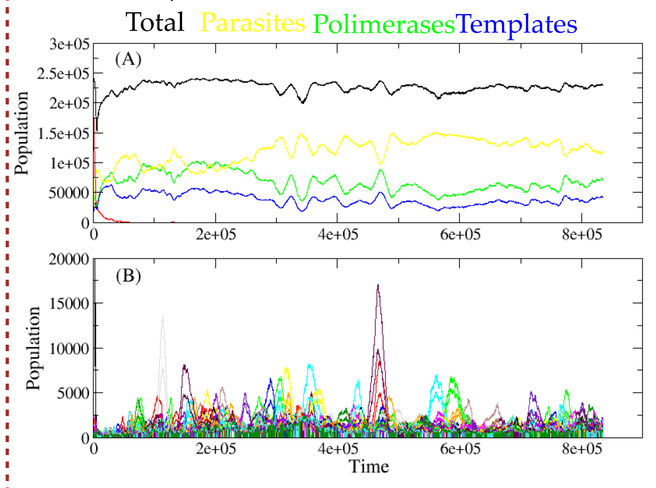
Results:

Low mutation intensity

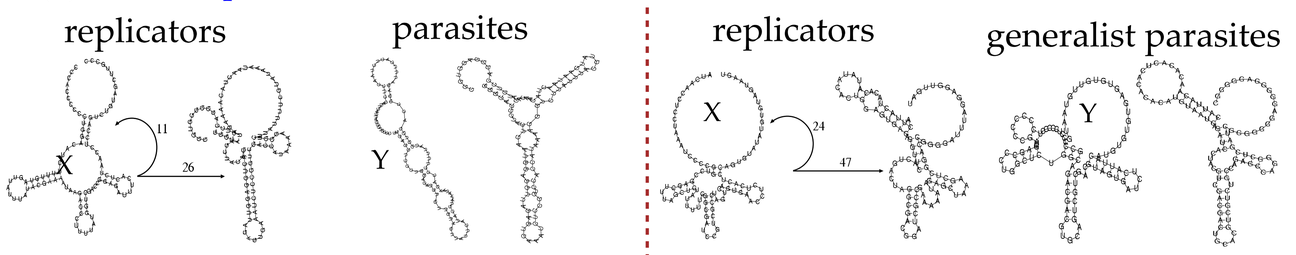
(1) Population dynamics.



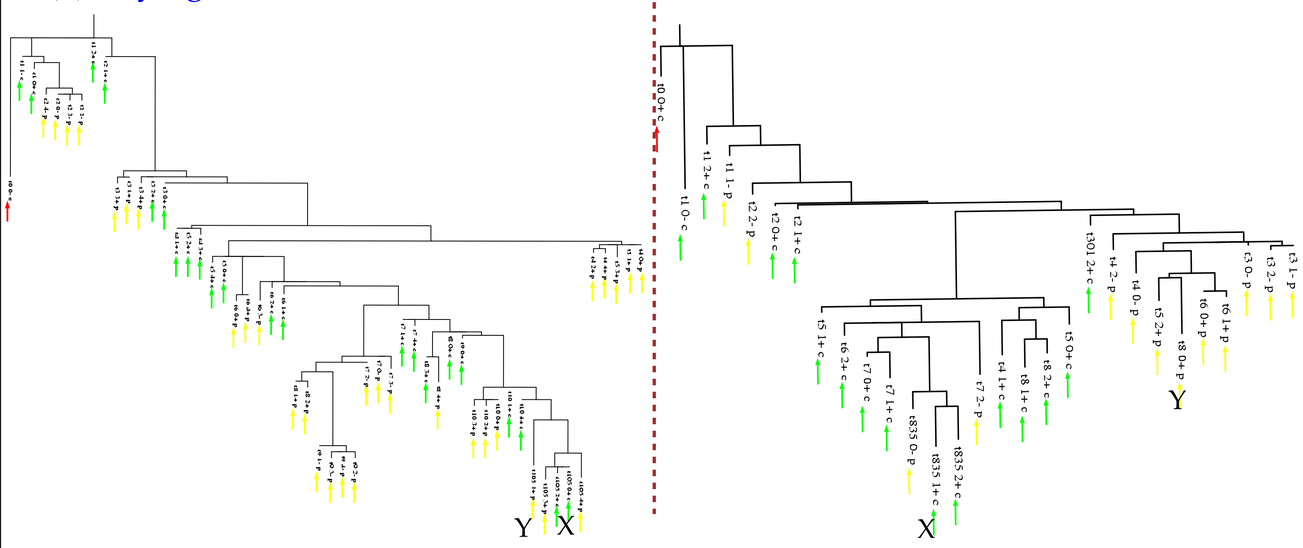
High mutation rate



(2) Below replicators: the structures of RNA.



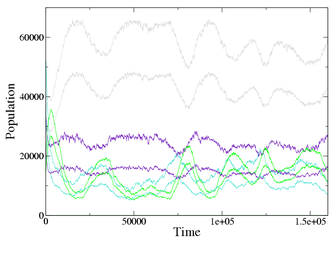
(3) Phylogenies.



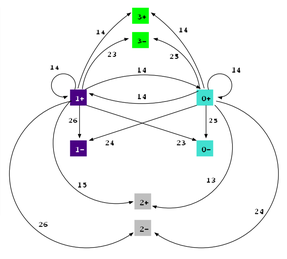
(4) Above replicators: reaction networks.

(a)Parasites increase diversity

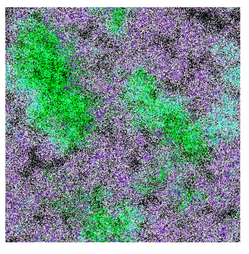
population dynamics



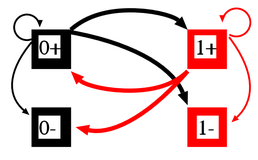
network topology



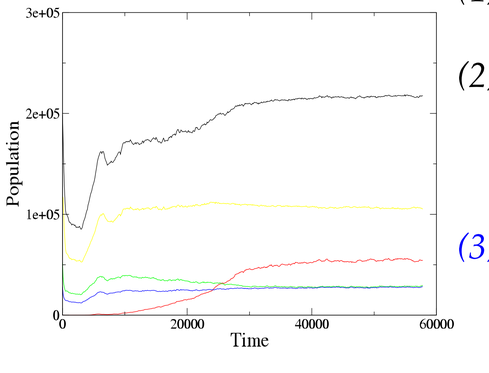
spatial patterns



(b) Hypercycle (Altruism)



(5) Very large mutation rate.



Conclusions:

(1) *The system actually becomes more stable with a larger mutation rate.*
(2) *The system chooses different molecular structures and network topologies depending on the mutation rate: generalist vs specialist; symmetric vs asymmetric catalyst.*
(3) *The processes below and above the molecules influence each other, and self-organize into a viable system.*