Evolutionary dynamics of mutation rate in RNA-like replicator systems

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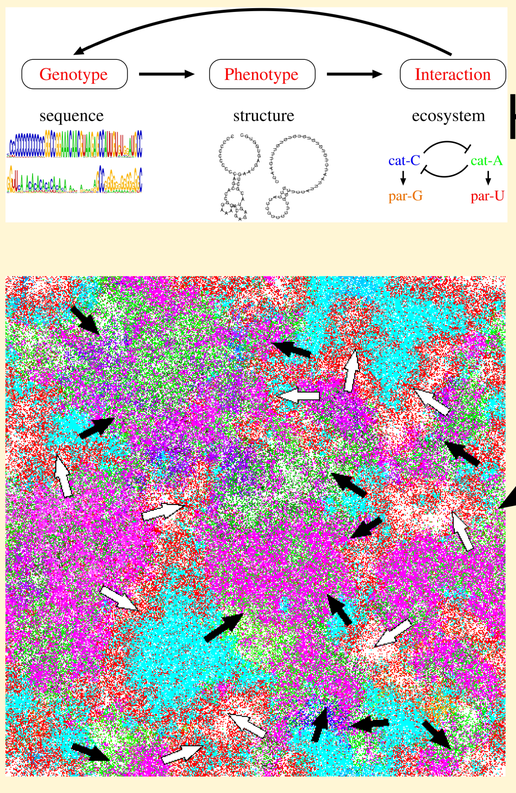
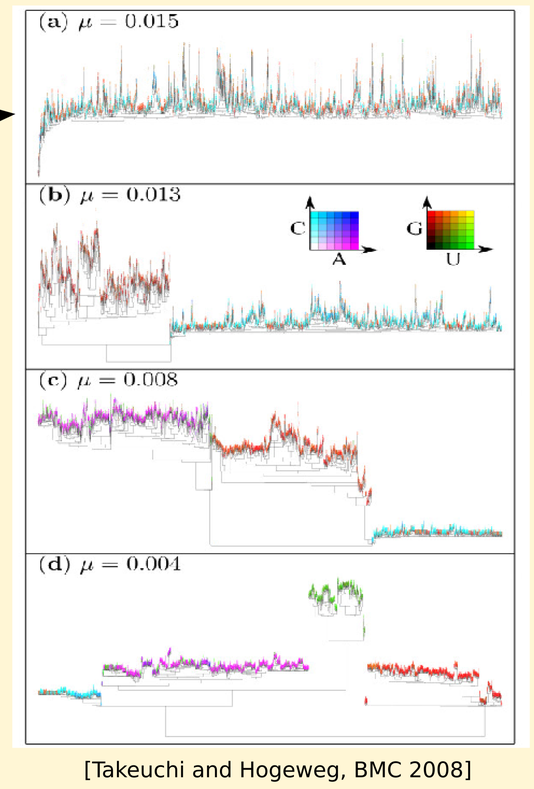
Introduction

In multilevel, eco-evolutionary models, ecological complexity evolves due to the feedback among information, function and (spatial) organization:
chain process of niche creation and speciation,
up to 4 quasispecies: 2 catalytic, 2 parasitic.



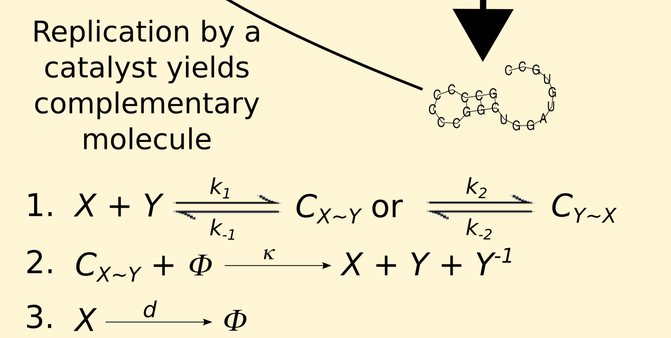


[Takeuchi and Hogeweg, BMC 2008]

Attractor based solution to Eigen's Paradox.
Dependence on mutation rate

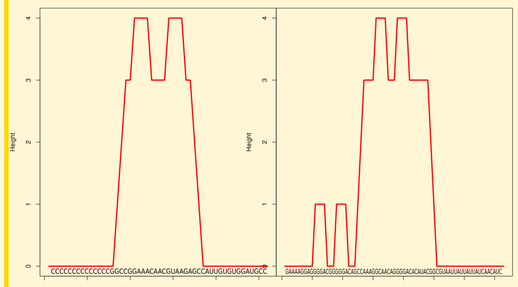
The model

RNA-like strings folded and located on a grid.
Dynamics: Reaction (1. complex formation, 2. replication, 3. decay)
Diffusion (random walk).



1. $X + Y \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} C_{X\sim Y}$ or $\underset{k_{-2}}{\overset{k_2}{\rightleftharpoons}} C_{Y\sim X}$
2. $C_{X\sim Y} + \Phi \xrightarrow{\kappa} X + Y + Y^{-1}$
3. $X \xrightarrow{d} \Phi$

One function explicitly modelled: to be a replicase, based on folding into a pre-defined structure, to which a default mutation rate is assigned, close to Error Threshold. Additional loops on the dangling ends contribute to lowering mutation rate. Mutations are substitutions and insertion/deletion



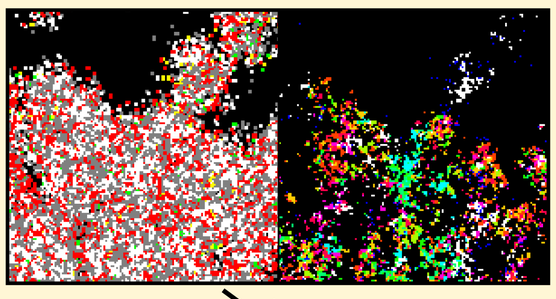
μ_0=0.013 p.b. μ_2~0.0033 p.b

QUESTIONS:

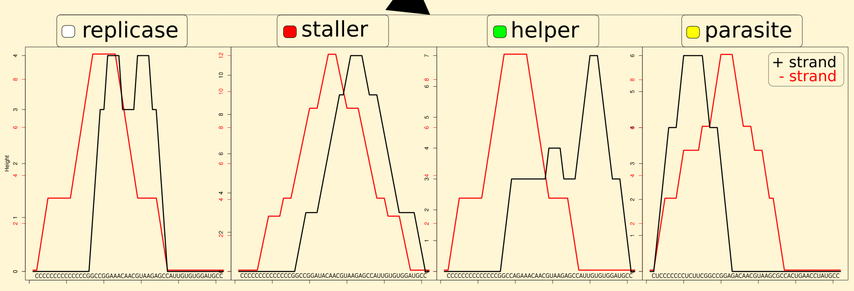
1) What are the conditions for which an eco-evolutionary system selects for lower mutation rates? What are the dynamics?
2) How is it possible to evolve/integrate new information, past the Information Threshold?

Quasi-species structuring

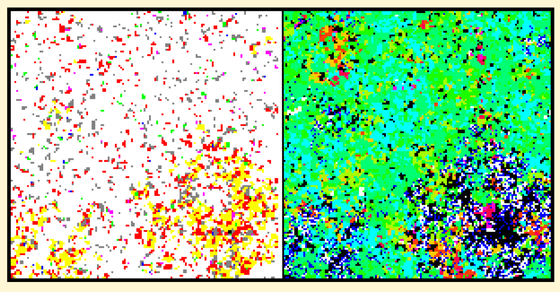
SET UP: FIXED LENGTH AND CONSTANT MUTATION RATE



Hamm. dist. from master sequence



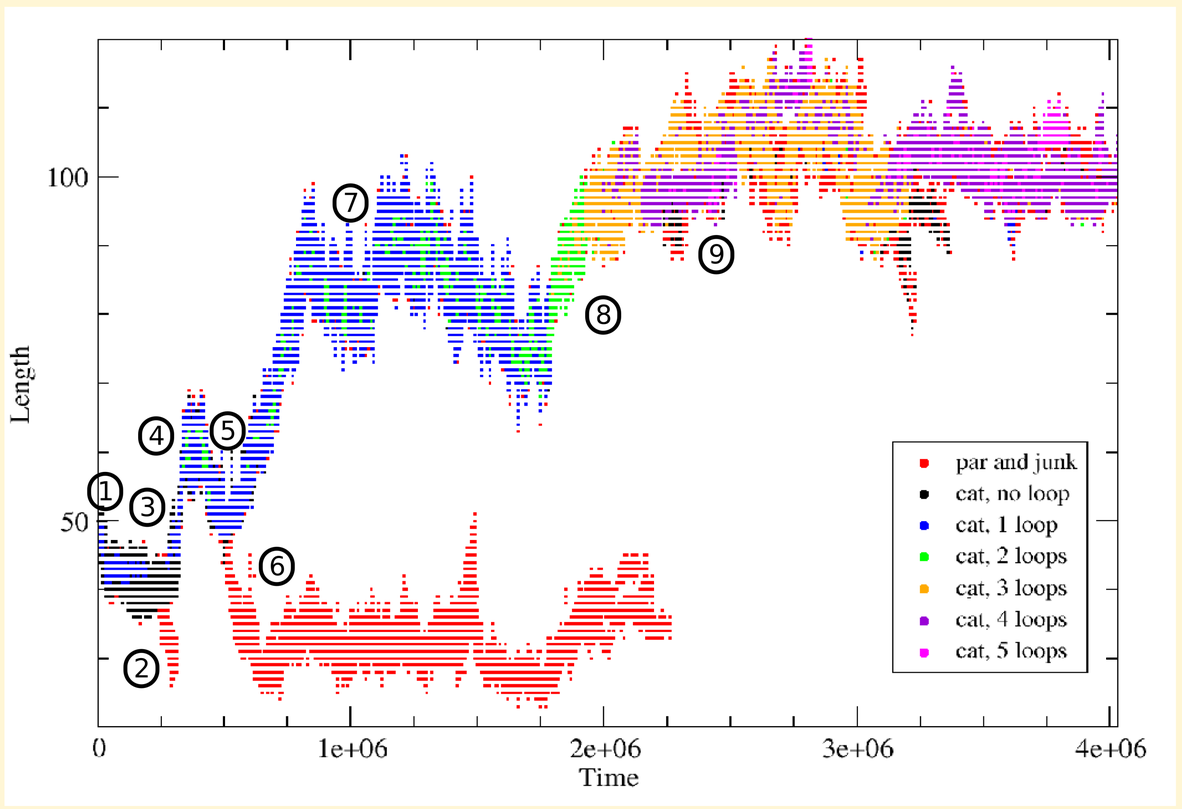
At high mutation rates a "mutational" division of labour emerges in the quasi-species. Non-replicable sequences distribute in space close to parasites and prevent their further evolution.



Hamm. dist. from master sequence

At lower mutation rates fewer mutants make the overall growth faster, but the system becomes susceptible to parasites, which later on speciate into a separate lineage.

Evolving the proof-reader



1)Shrinkage of original (pre-evolved) catalyst
2)Speciation of parasite
3)Speciation of longer, neutral catalyst (which outcompetes former catalyst and parasite)
4)Evolution of extra loop
5)Decrease of average length
6)Speciation of new parasite
7)Neutral inflations and shrinkages do not *necessarily* result in the evolution of new loops
8) - 9) the process repeats (indefinitely?)

THE INCREASE IN LENGTH AND INFORMATION HAPPENS ONLY IF THE GAIN IN REPLICATION ACCURACY COMPENSATE FOR THE LOSS IN REPLICATION RATE

The process for the evolution of the “proof reader” consists of a cycle of:
- Niche creation due to *steep* quasi-species exploitation by parasites
- Speciation of a neutral, longer sequence
- Loop discovery (lower μ)
- Steepening of the quasi-species

CONCLUSIONS

A storage-based (single molecule) solution to Eigen's Paradox can evolve from ecological complexity.

The mechanism for the decrease of the mutation rate depends on the feedback between the evolved ecological interactions and the structure of the quasi-species.

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