Evolution of complexity in RNA-like replicator systems

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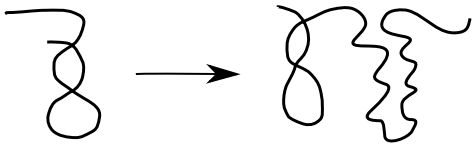
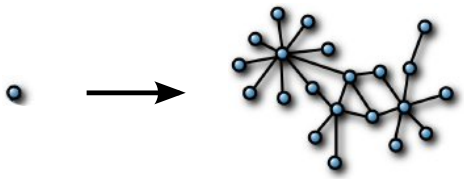
Evolution of Complexity in replicators

$$X_j + \emptyset \xrightarrow{X_k} 2X_j$$

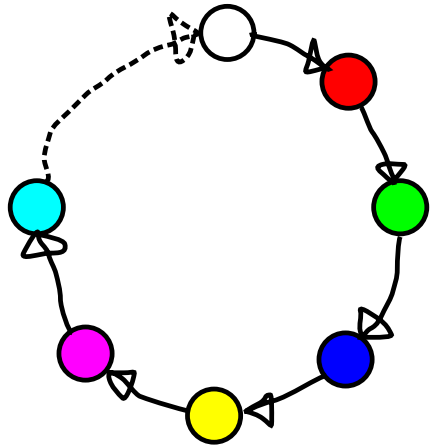
- Individual-based complexity



- Population-based complexity



Hypercycle



$$X_{i+1} \xrightarrow{X_i} 2X_{i+1}$$

[Eigen & Schuster '79]

Evolution of Replicator Systems

- Replicator network + Random perturbation
- Evolution of invidual replicators

  Genotype $\longrightarrow$ Phenotype $\longrightarrow$ Interactions

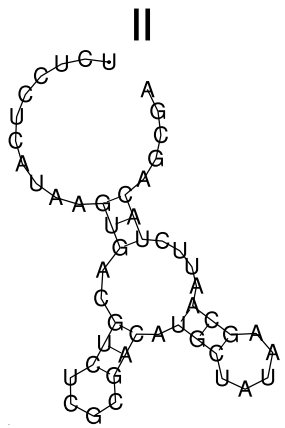
RNA folding Genotype-Phenotype Mapping

Sequence → Structure (i.e. genotype → phenotype)

UCUCCUCAUAAGUGACGUCUCGCGACAUGCUAUAAGCAAUUCUACAGCGA

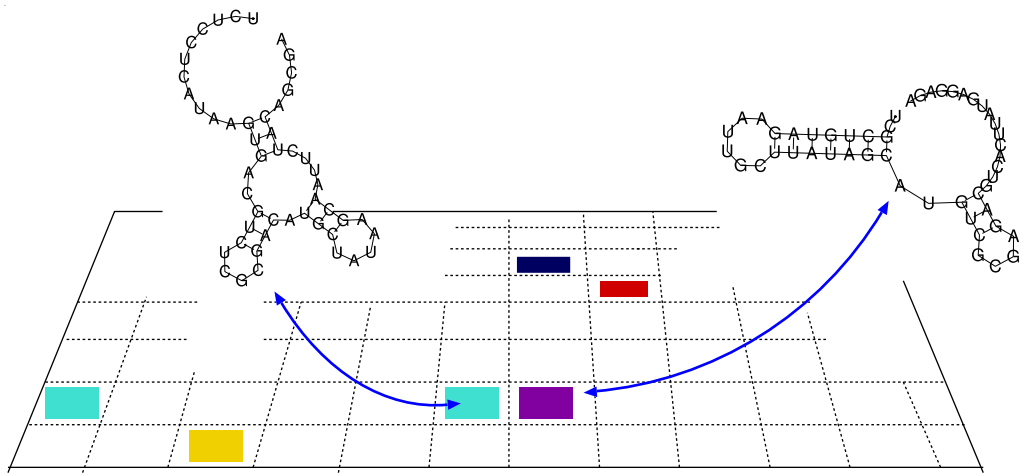
↓

. . . . . (((. . (((. . . .))) . (((. . . . .))) . . . .))) . . . .



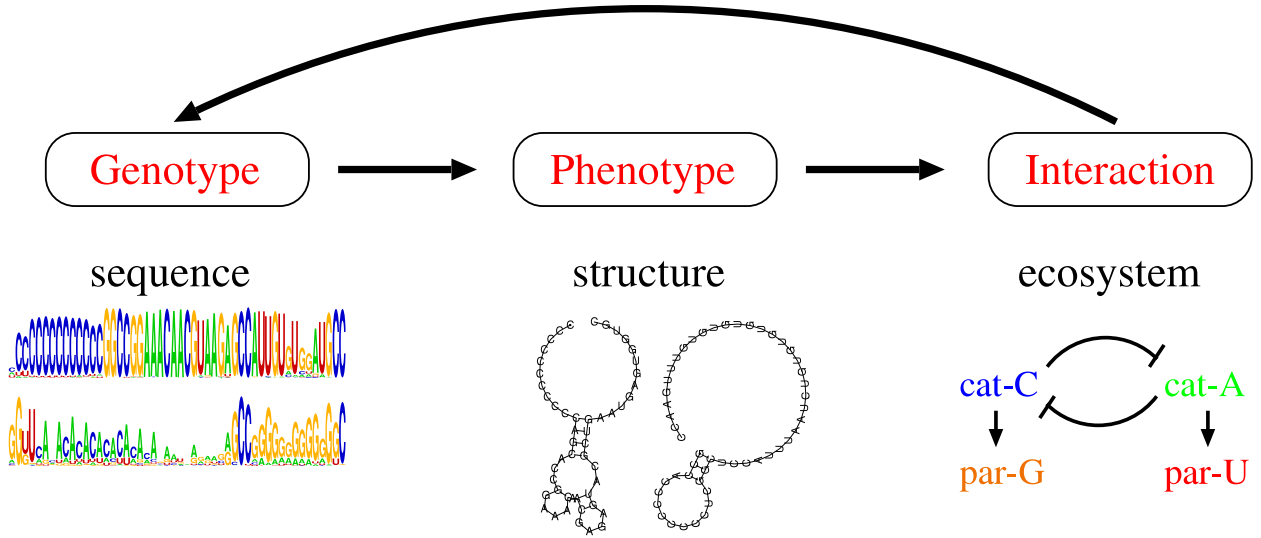
Evolution of RNA-like Replicator Systems (Takeuchi & Hogeweg '08)

Phenotype → Interactions



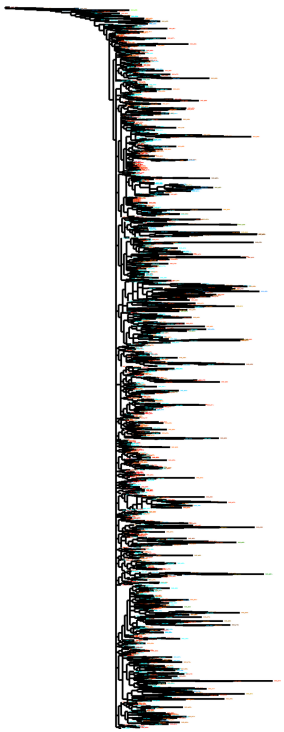
- Complex: 5'-end → 3'-end
- Replication: if phenotype correct

Evolution as a Cycle of Multi-level Processes

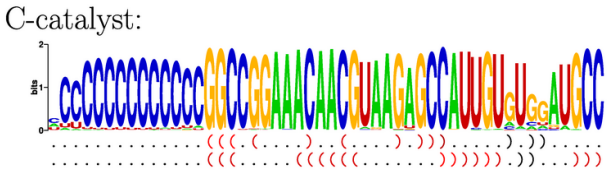


Evolution of Patterns in ($\mu = 0.015$)

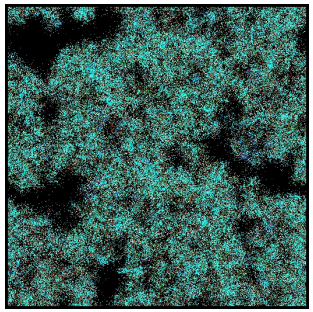
- Population of Sequences



- Genotype & Phenotype



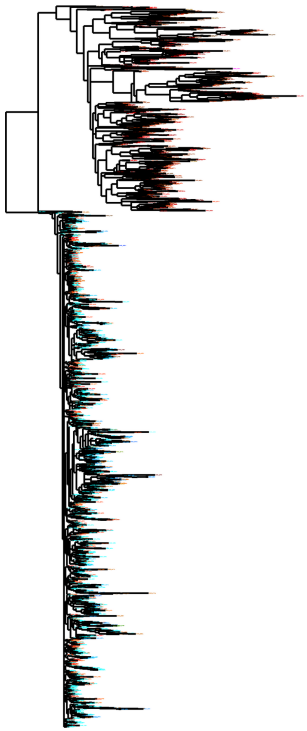
- Space & Time



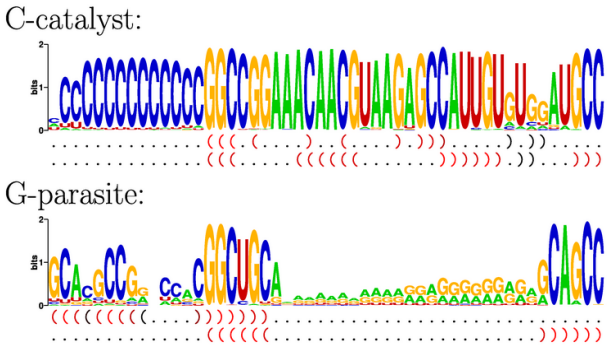
C-cat

Evolution of Patterns in ($\mu = 0.013$)

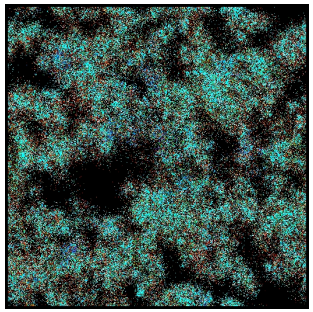
- Population of Sequences



- Genotype & Phenotype



- Space & Time



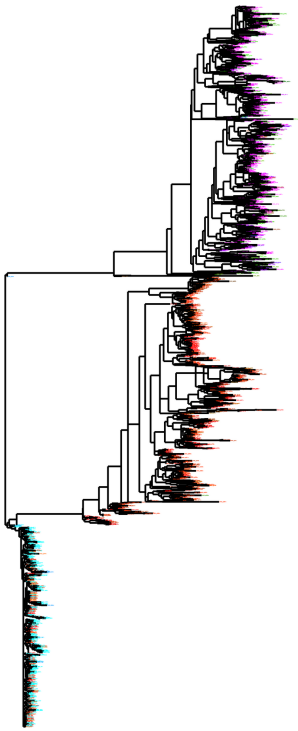
C-cat

↓

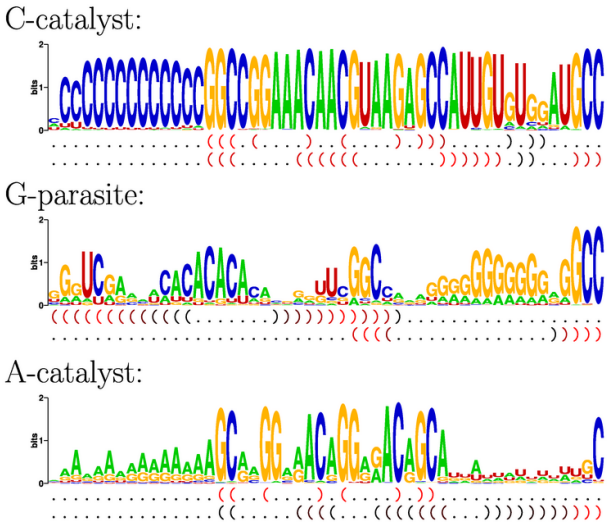
G-par

Evolution of Patterns in ($\mu = 0.008$)

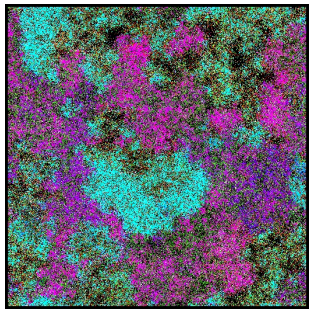
- Population of Sequences

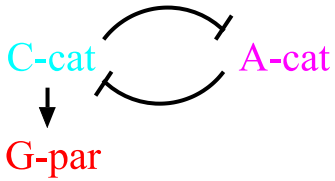


- Genotype & Phenotype



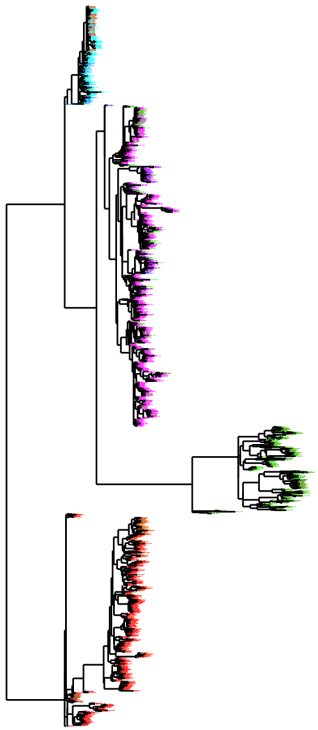
- Space & Time



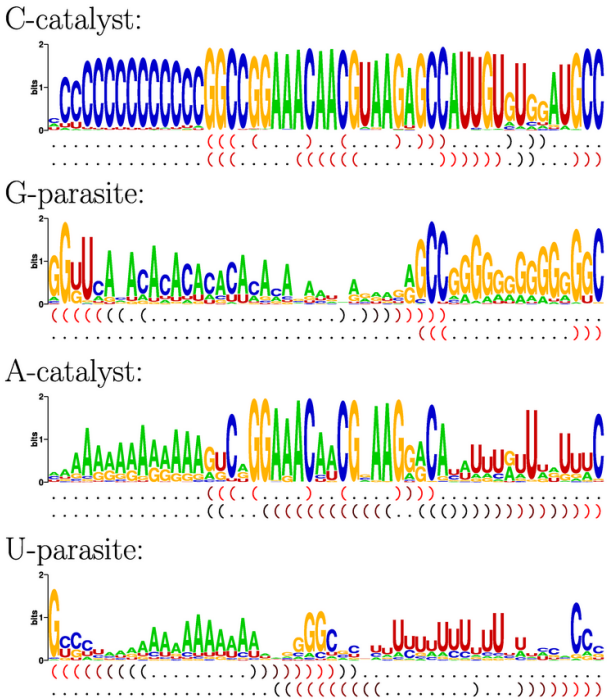


Evolution of Patterns in ($\mu = 0.004$)

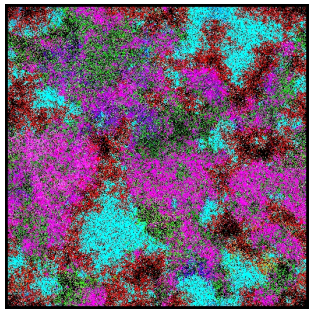
- Population of Sequences

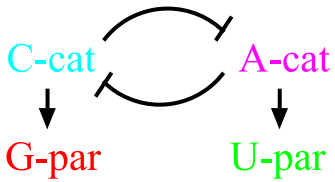


- Genotype & Phenotype

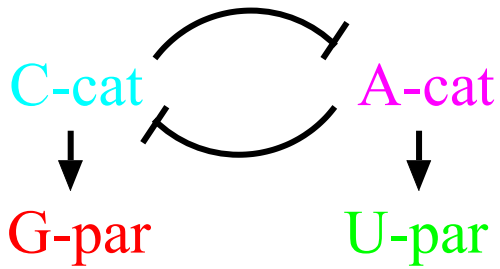


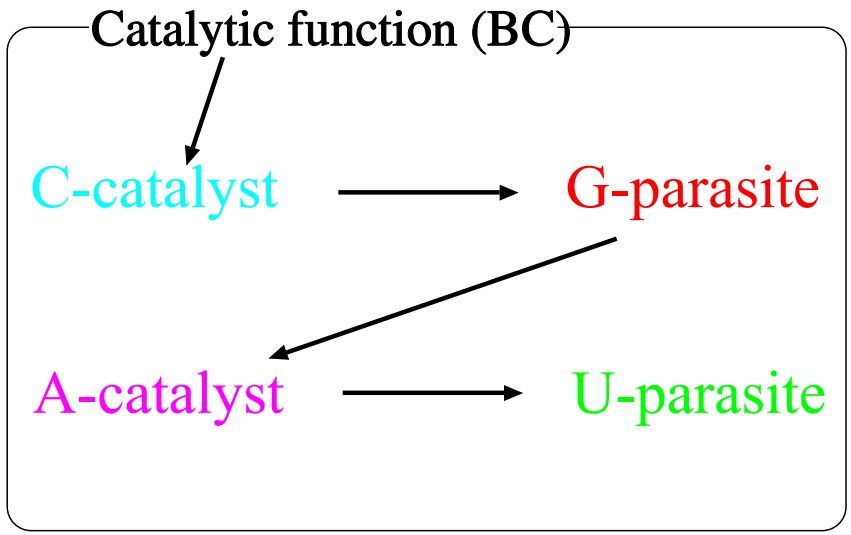
- Space & Time





Chain reaction of niche generation & speciation





Mutation rate & Diversity

- Greater mutation rates weaken parasites

  (Kaneko & Ikegami '92; Hogeweg & Takeuchi '03 & '07)

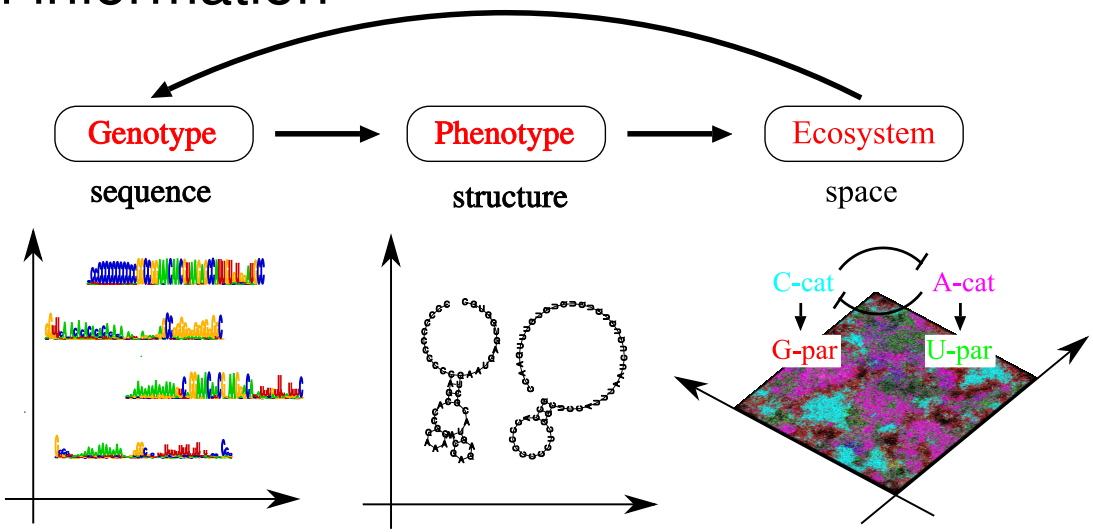
- Weaker parasites, less diversity

Conclusions (prebiotic evolution)

- Parasites can promote diversity
  - previously considered as destabilizing
- The system is stable because of evolutionary safeguard
  - evol. harmful parasites
    $\rightarrow$ evol. escape catalyst
    $\rightarrow$ stabilization of the system as a whole
- Greater mutation prohibits diversity
  - cf. error-threshold

General conclusion

- Evolution of diversity (ecological organization)
- Evolution of information



information $\leftrightharpoons$ (ecological) organization

- $\rightarrow$ Evolution of complexity

Suggestion for Wet Experiments

Current state of art:

- Strong link between molecules & performance of molecules
  - e.g. ligation of primer for PCR, water-in-oil emulsion

$\longrightarrow$ prevent unwanted evolution (parasites)
$\longrightarrow$ prohibit interactions
$\longrightarrow$ good for engineering

Suggestion for Wet Experiments

Suggestions:

- Allow interactions between molecules
  - e.g. selection for production of fluorescent molecules [metabolism rather than replication]
- Spatial extension
  - e.g. chip with small reaction wells, micro-fluidic device

$\longrightarrow$ can accommodate unwanted evolution

$\longrightarrow$ might exhibit evolution of complex interacting molecular systems

$\longrightarrow$ significant for biology