Evolution of Complexity in RNA-like Replicators

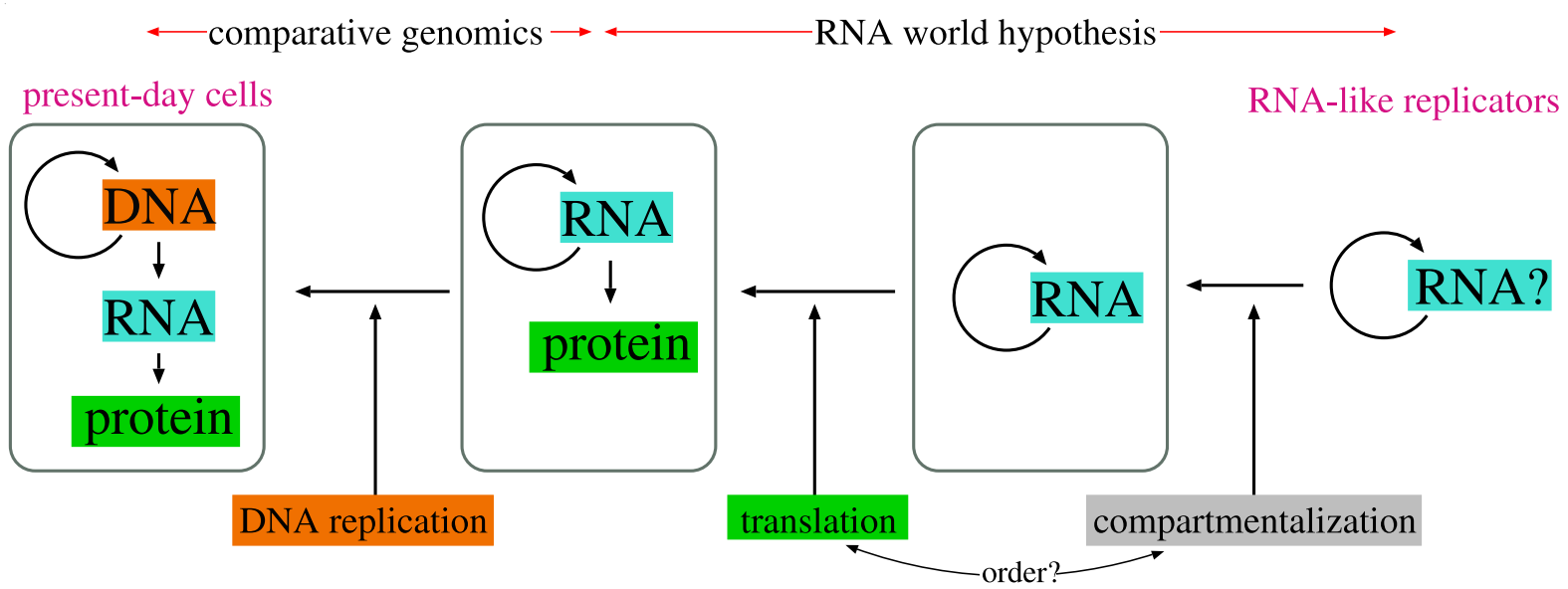
Nobuto Takeuchi Paulien Hogeweg

Theoretical Biology/Bioinformatics
Utrecht University

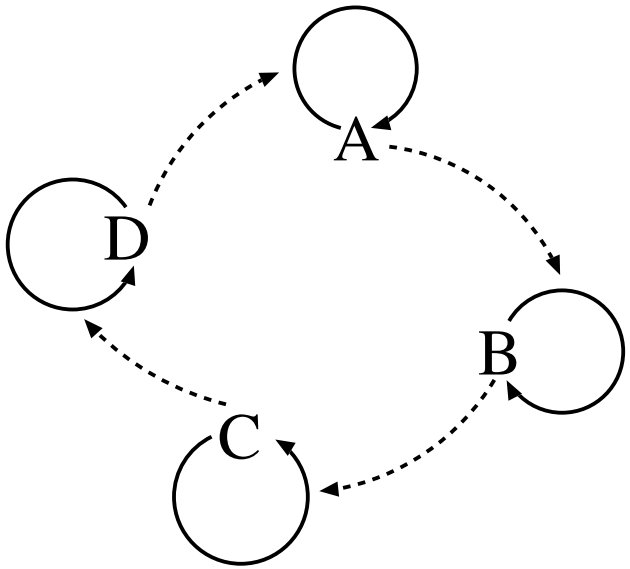
10 May 2007
NVTB annual meeting in Schoorl

The research is supported
by N$\mathcal{W}$O, Exact Science.

RNA World Hypothesis



Hypercycle (preview)



- in well-mixed system (Eigen & Schuster 1971)
- in spatial system with invasion (Boerlijst & Hogeweg 1991)
- in spatial system with mutation (Hogeweg & Takeuchi 2003)

Purpose of the Study

- Hypercycle theory
  - assumes a pre-defined network topology,
  - does not explain the origin.
- Current study
  - takes into account
    - genotype-phenotype map &
    - individual-interactions,
  - asks what kind of replicator networks evolve.

RNA Folding Genotype-Phenotype Map

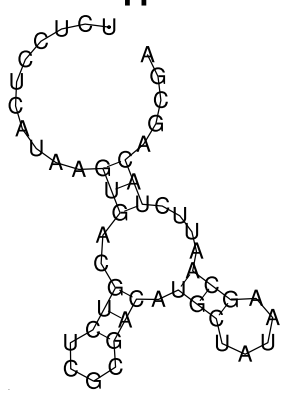
Sequence → Structure (i.e., genotype → phenotype)

UCUCCUCAUAAGUGACGUCUCGCGACAUGCUAUAAGCAAUUCUACAGCGA

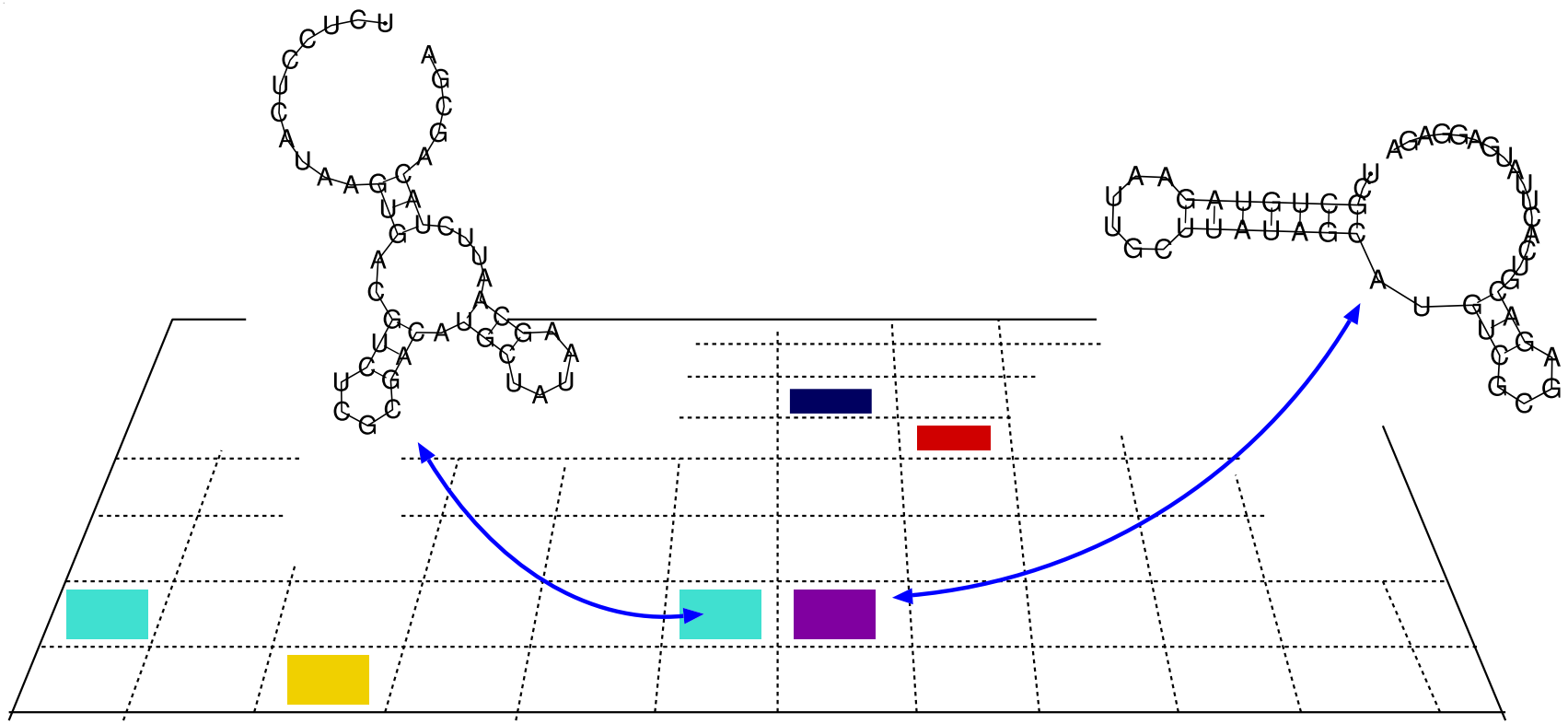
↓

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

||



Replicators living in Surface



Reactions (individual-interaction)

- Complex formation happens 3'-end $\rightarrow$ 5'-end
  $\mathrm{X} + \mathrm{Y} \rightleftharpoons \mathrm{C}_{\mathrm{X}3'\sim 5'\mathrm{Y}}$

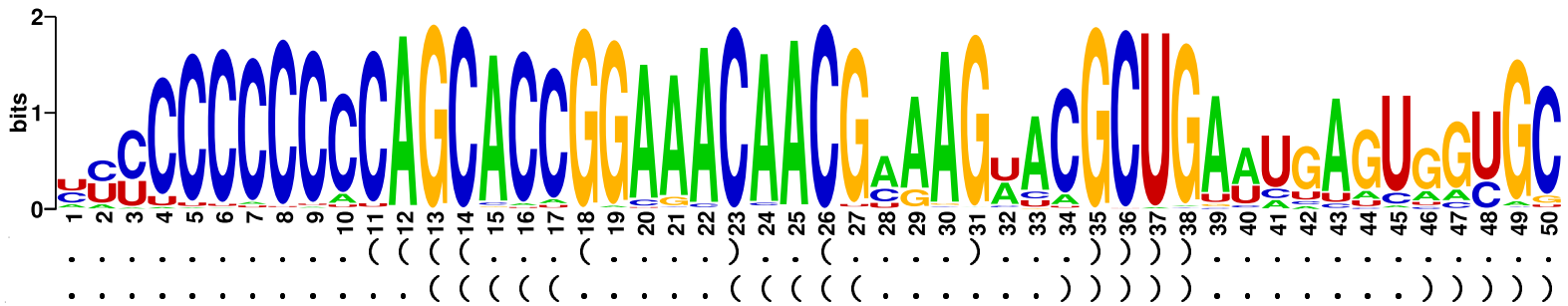
Base pair	Free energy
GC (CG)	-3
AU (UA)	-2
GU (UG)	-1

$k_{\rightharpoonup} = 1 - \exp(0.03G)$
$k_{\leftharpoondown} = \exp(0.03G)$
G = sum of f. energy ($G < 0$)

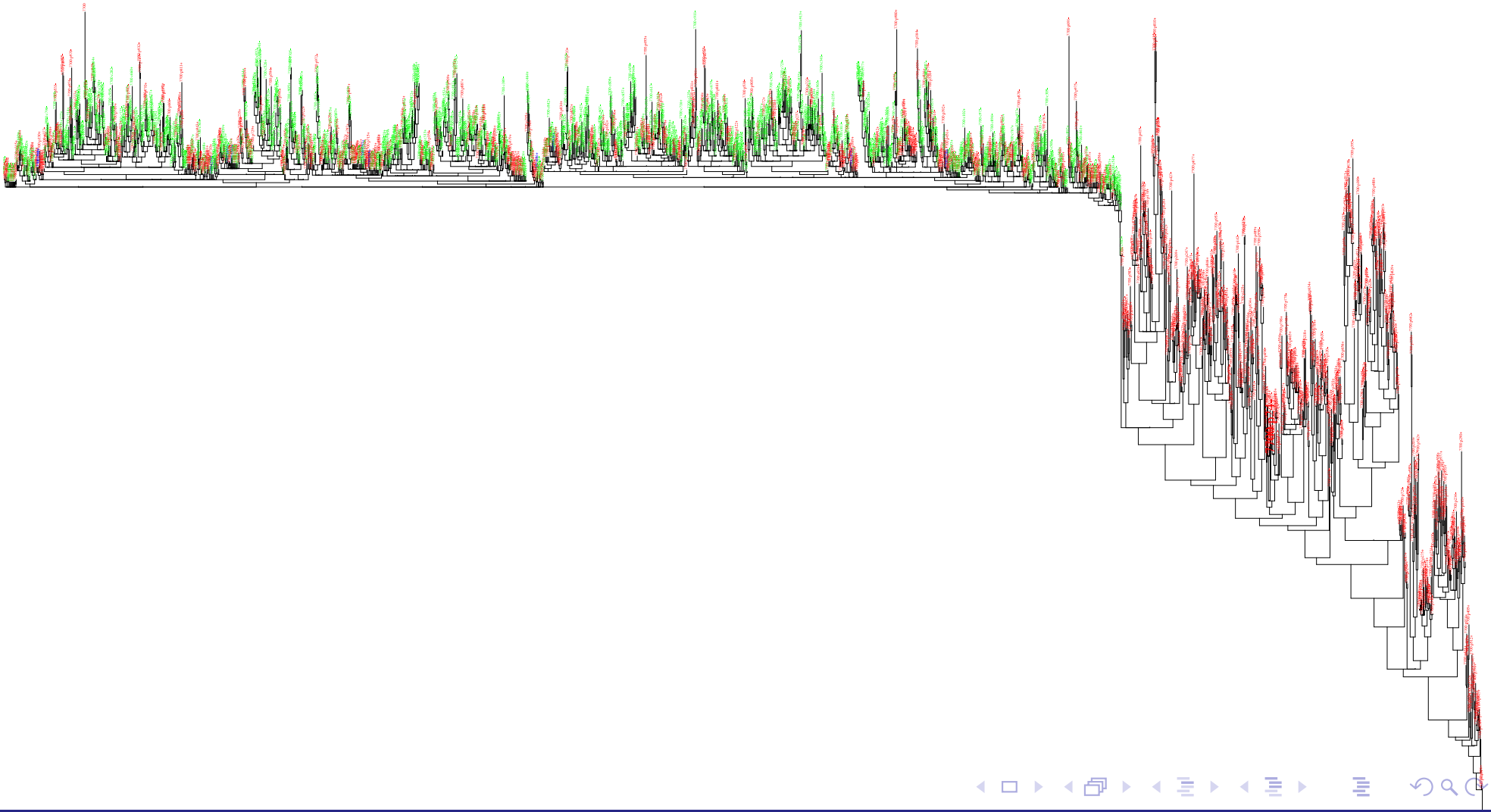
- Replication can happen if the structure of X is right.
  $\mathrm{C}_{\mathrm{X}3'\sim 5'\mathrm{Y}} + \emptyset \rightarrow \mathrm{X} + \mathrm{Y} + \mathrm{Y}^{c}$
- Decay
  $\mathrm{X} \rightarrow \emptyset$

Phylogeny: mut. rate = 0.014

Patterns in Sequence

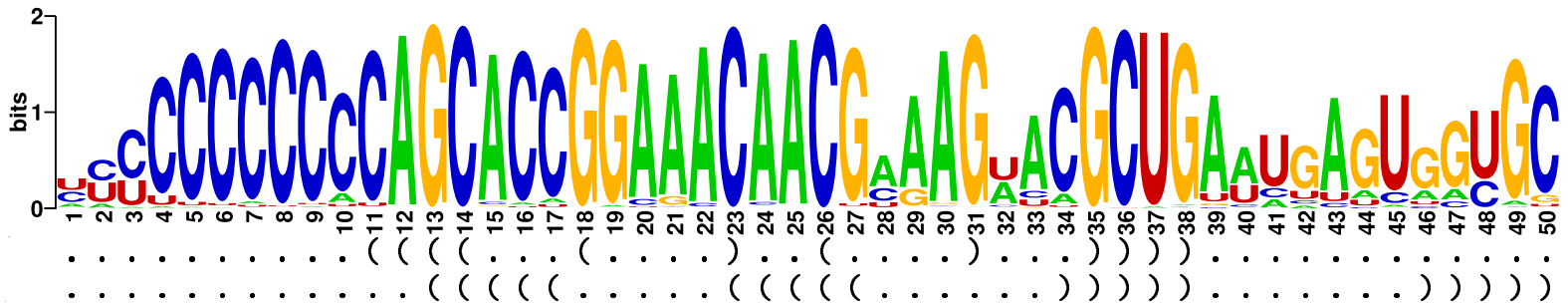


Phylogeny: mut. rate = 0.013



Patterns in Sequence

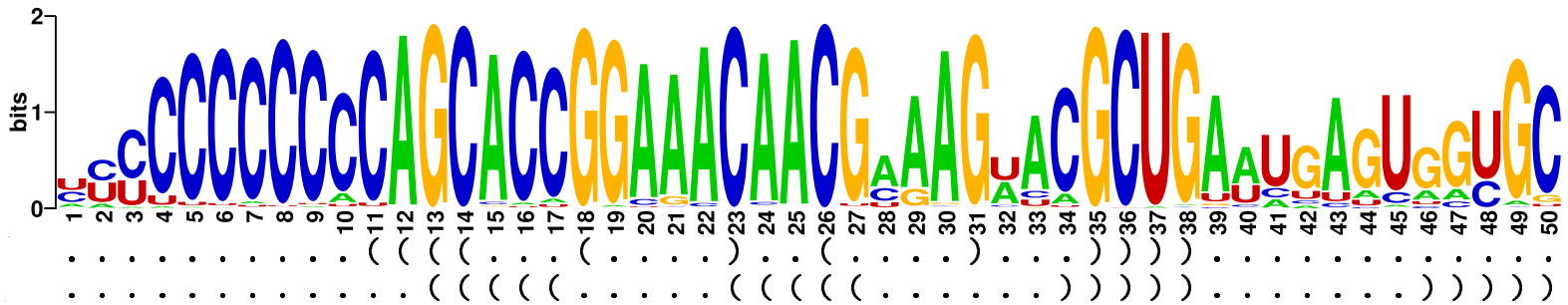
- Catalyst



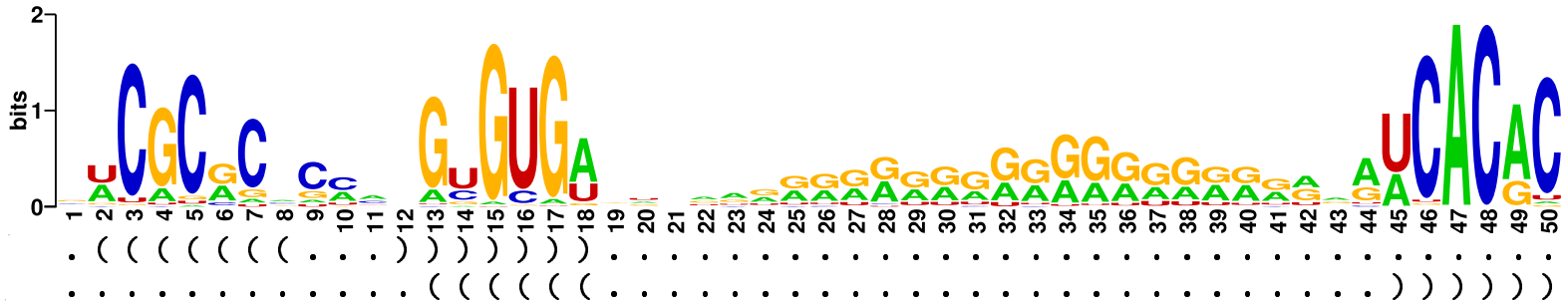
- Non-catalyst

Patterns in Sequence

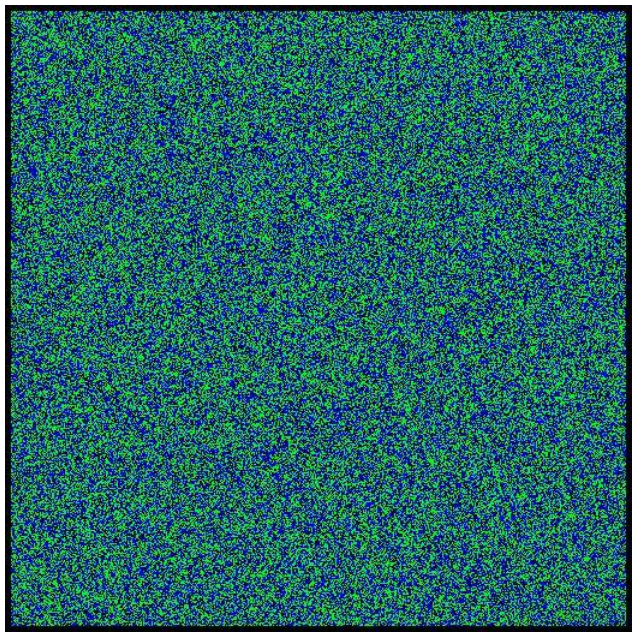
- Catalyst



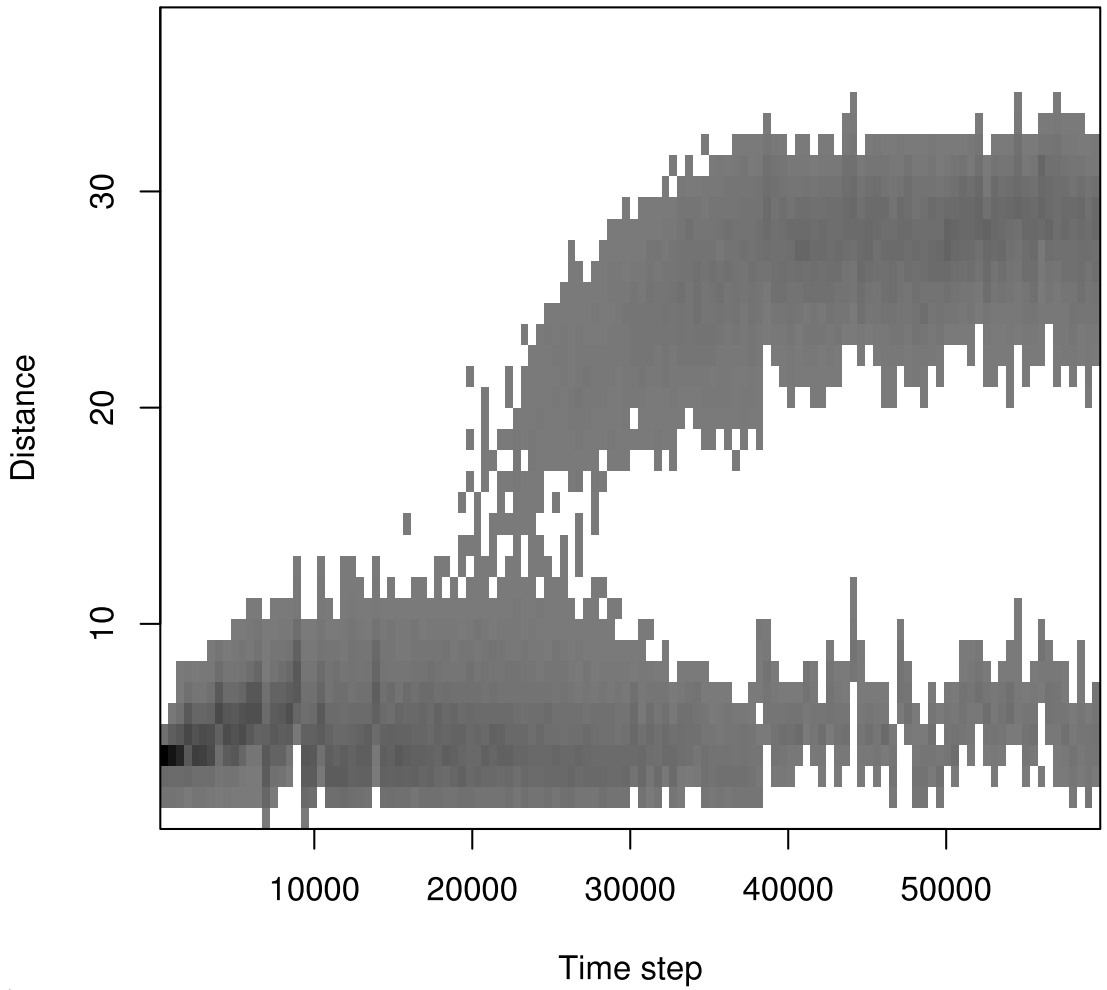
- Non-catalyst



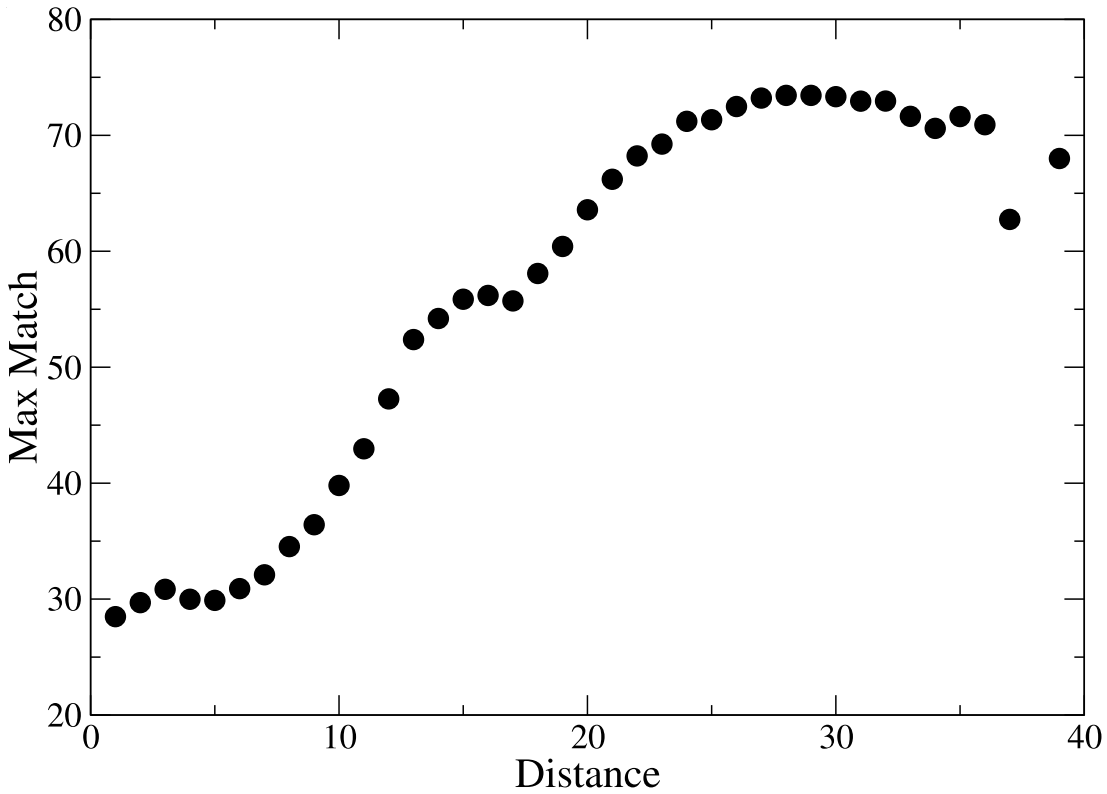
Observation of Speciation: Spatial Pattern Dynamics (m=0.01)



Observation of Speciation: Distance of Non-catalyst

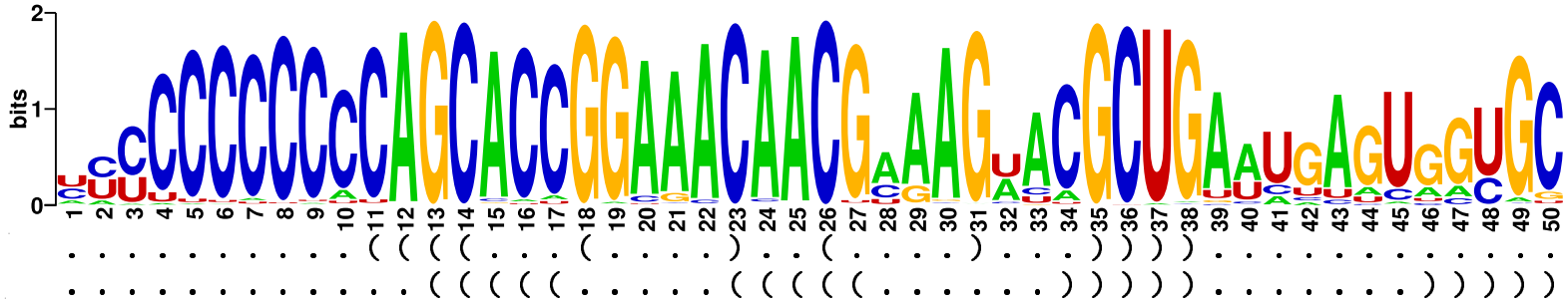


Meaning of Speciation

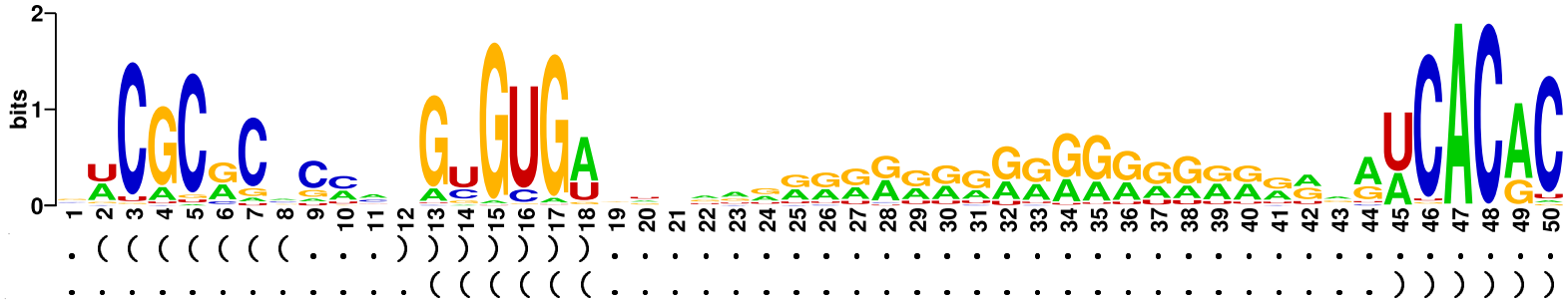


Making Sense of Patterns in Sequence

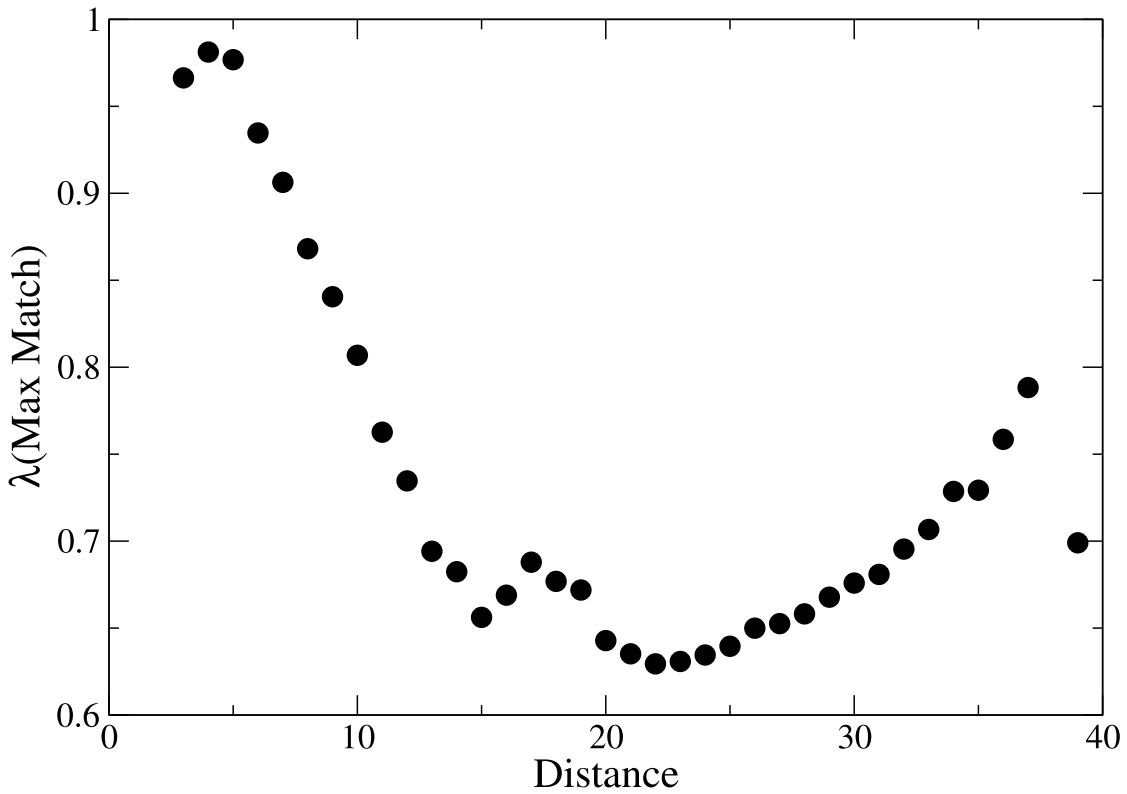
- Catalyst



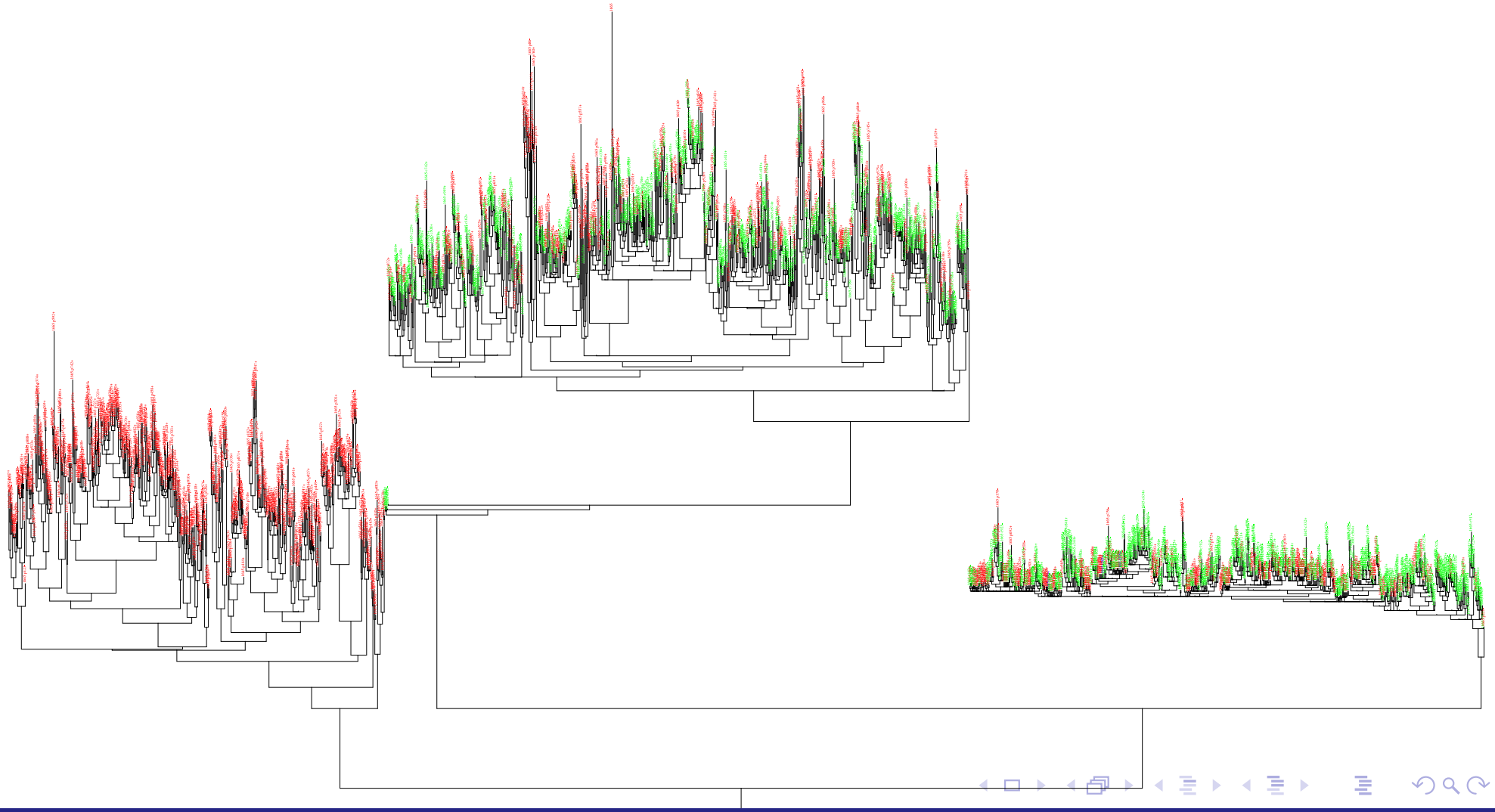
- Parasite



Valley of Neutrality

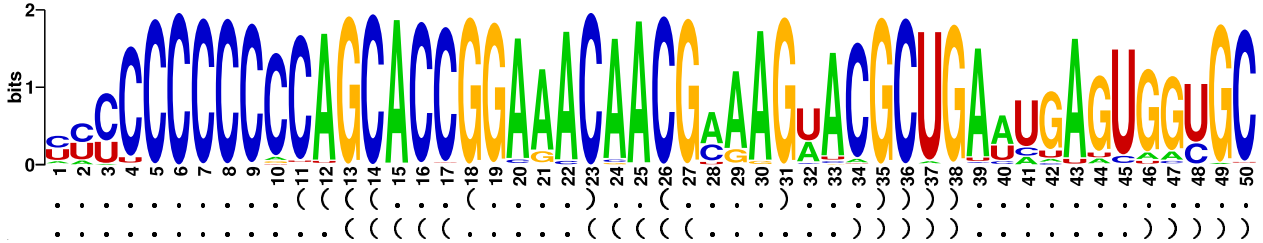


Phylogeny: mut. rate=0.01

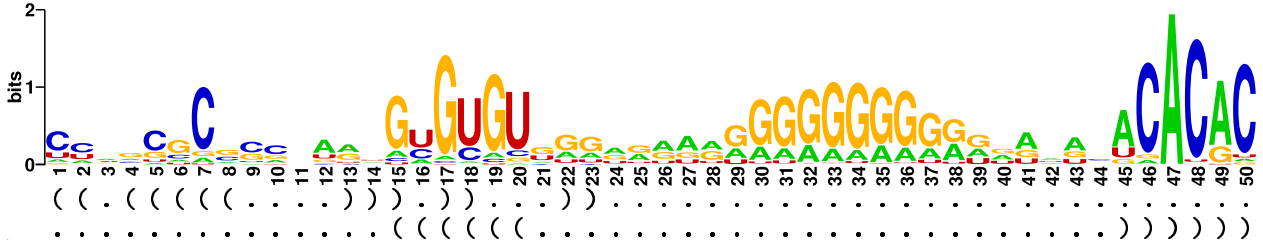


Patterns in Sequence

- Catalyst C-strategy



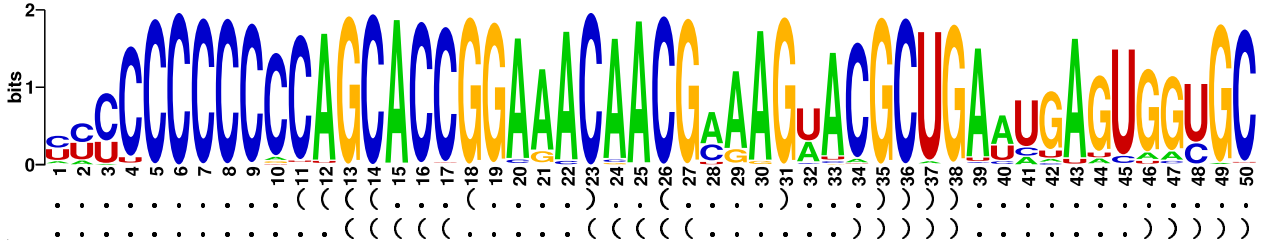
- Parasite



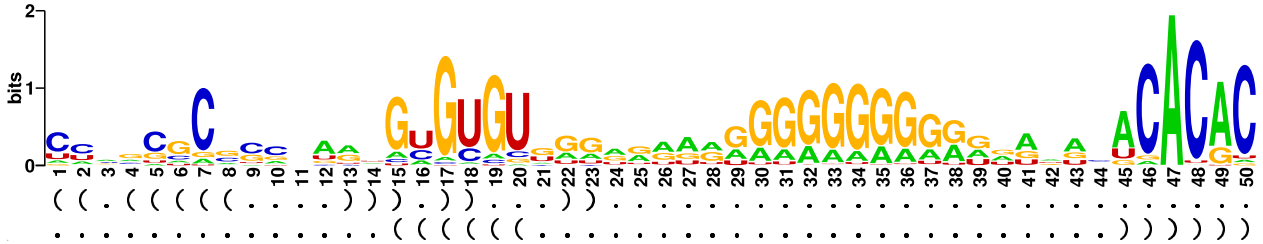
- Catalyst A-strategy

Patterns in Sequence

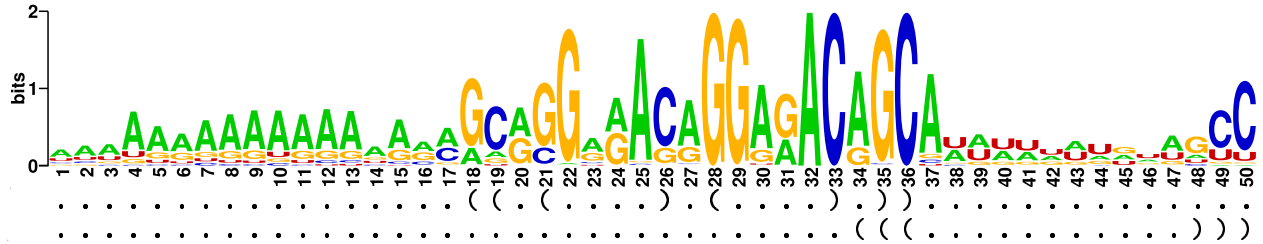
- Catalyst C-strategy



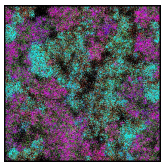
- Parasite



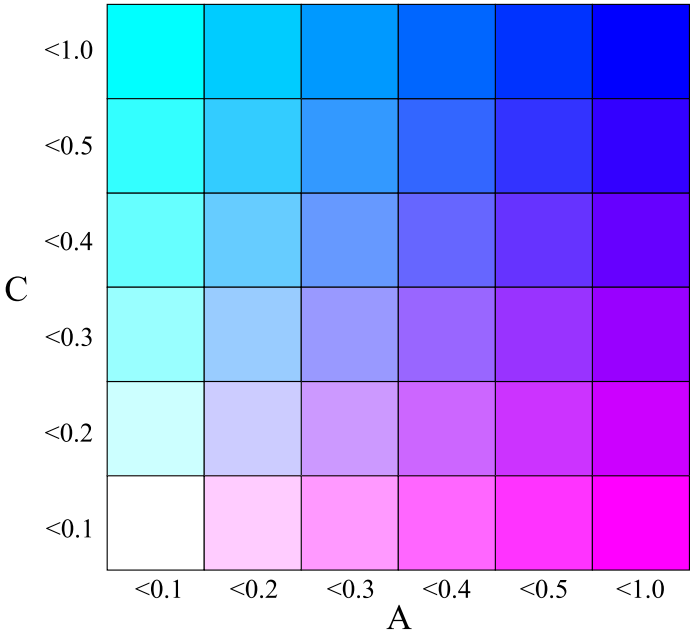
- Catalyst A-strategy



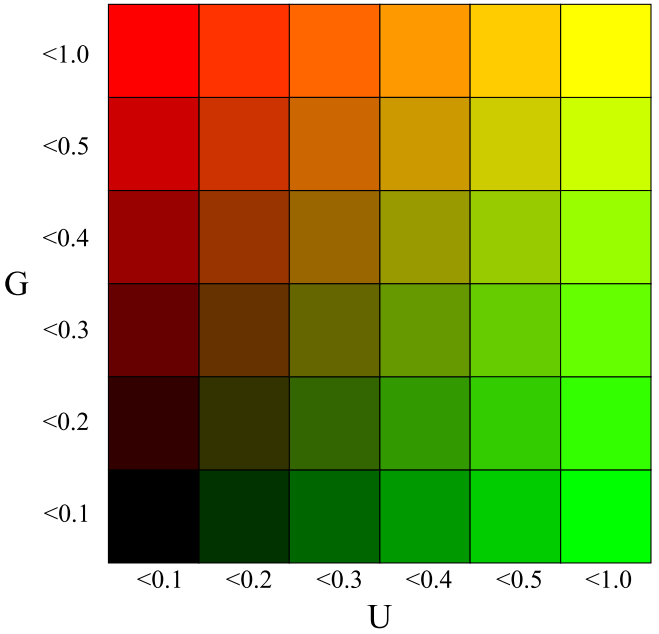
Dynamics of Patterns: Mechanism of Coexistence



Catalyst's color

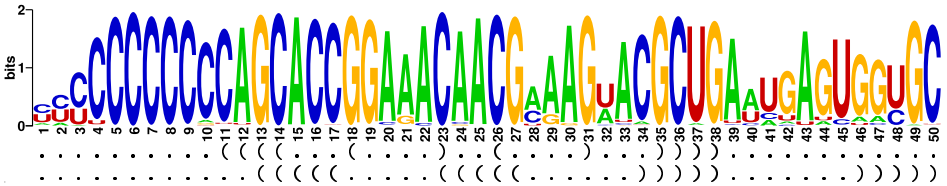


Parasite's color

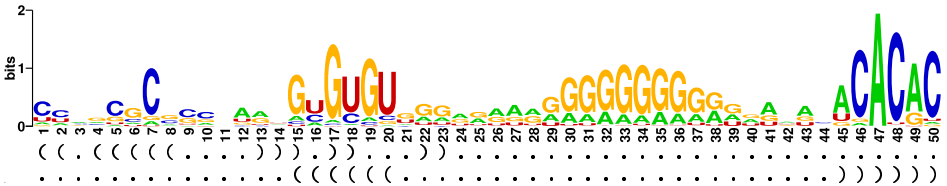


Sequence Patterns and Ecotypes

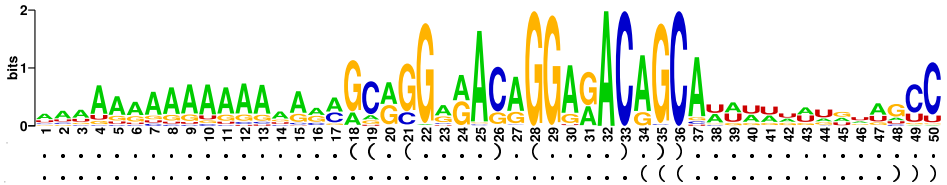
C-Catalyst

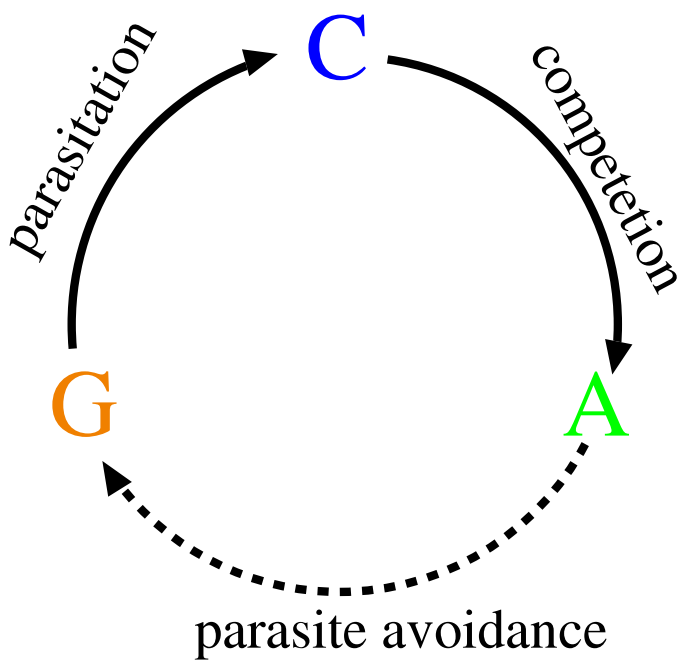


G-Parasite

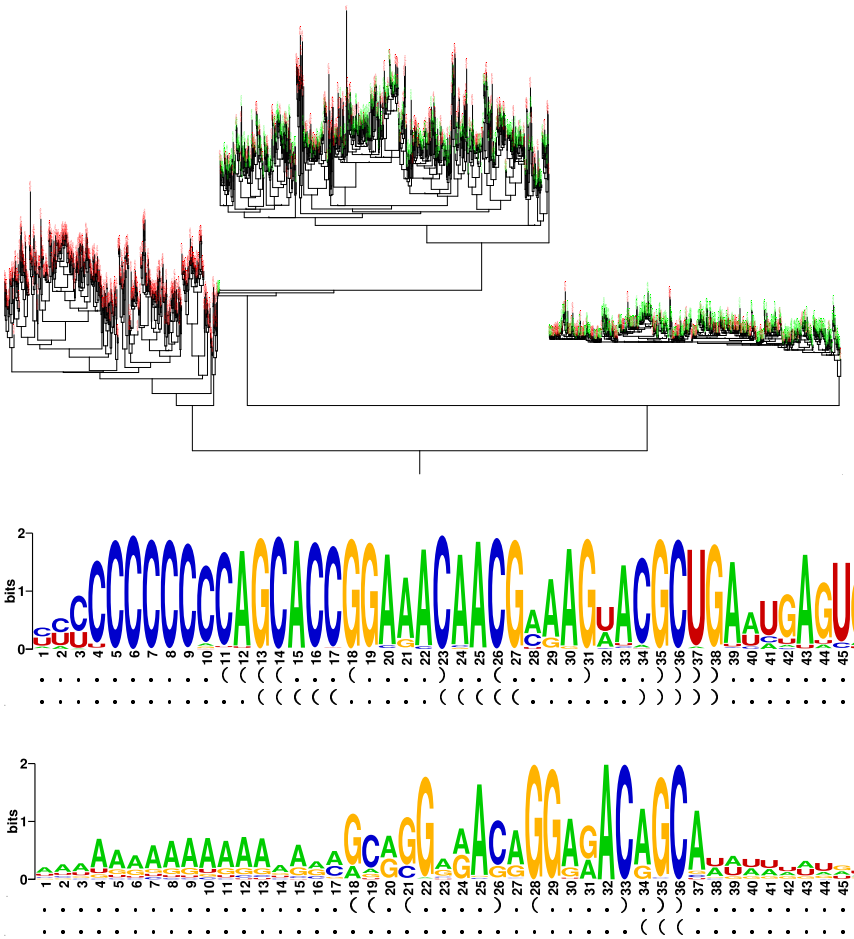


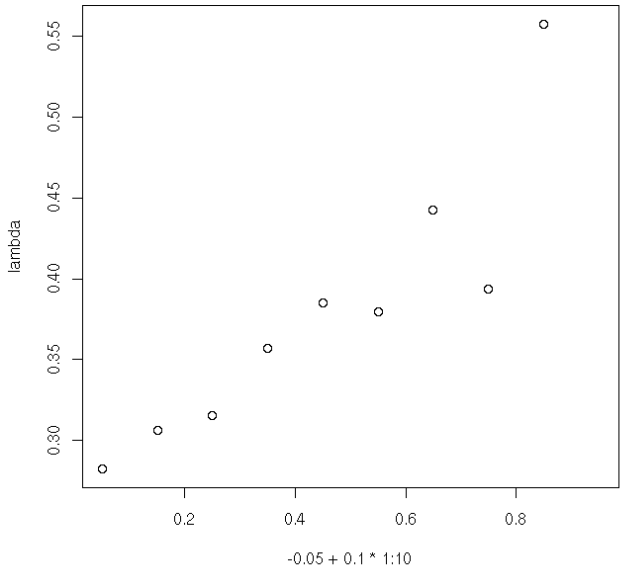
A-Catalyst



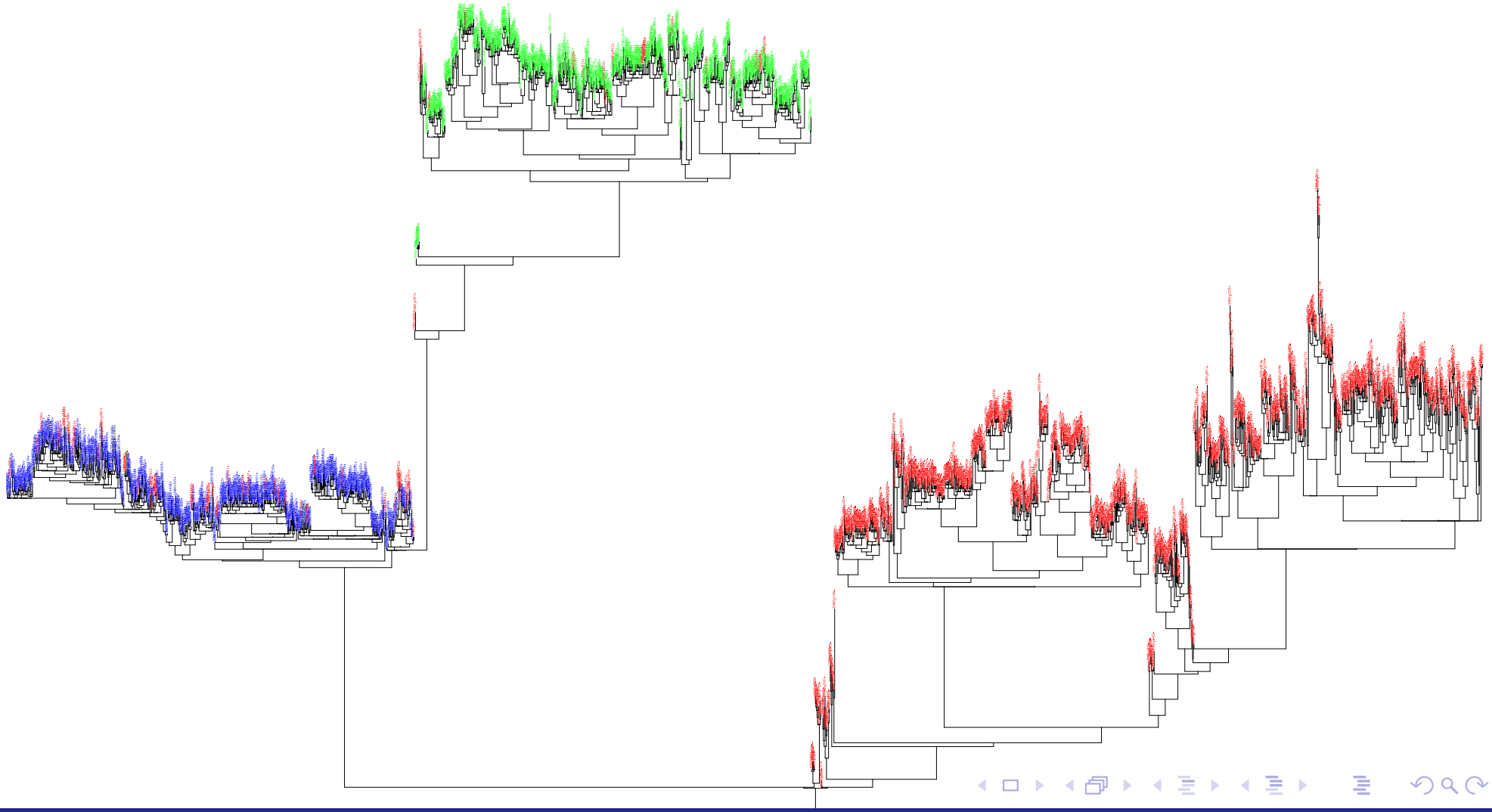


Sequence Variability and Structural Patterns



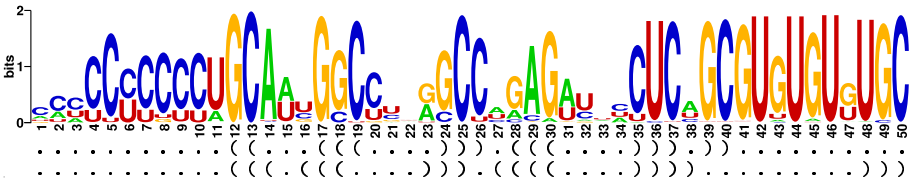


Phylogeny: mut. rate=0.005

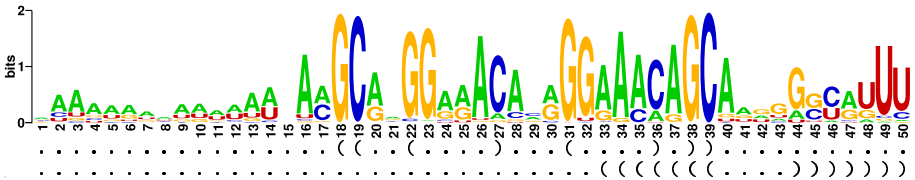


Patterns in Sequence

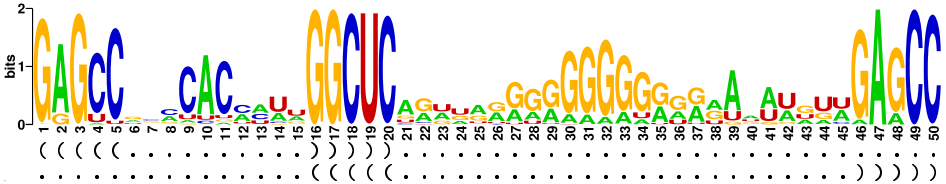
C-Catalyst



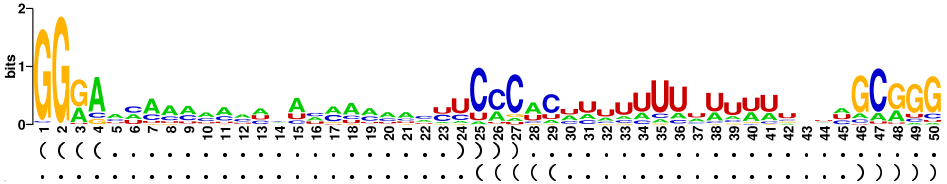
A-Catalyst



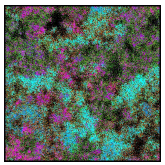
G-Parasite



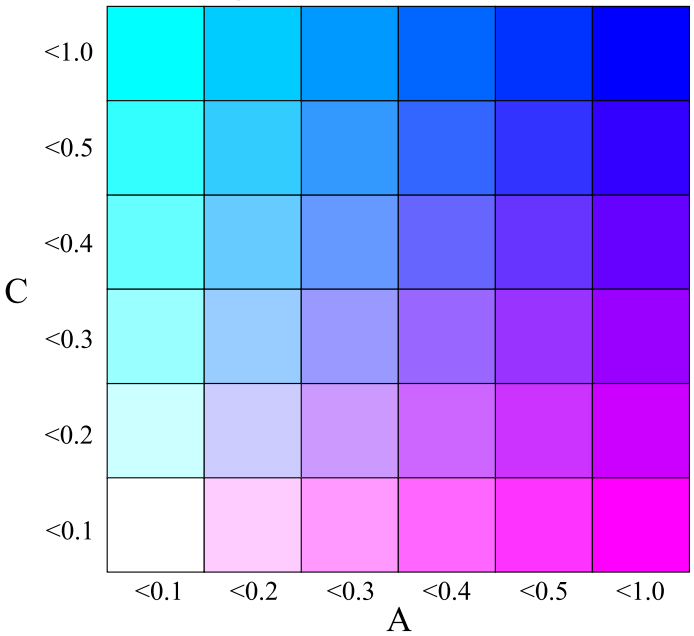
U-Parasite



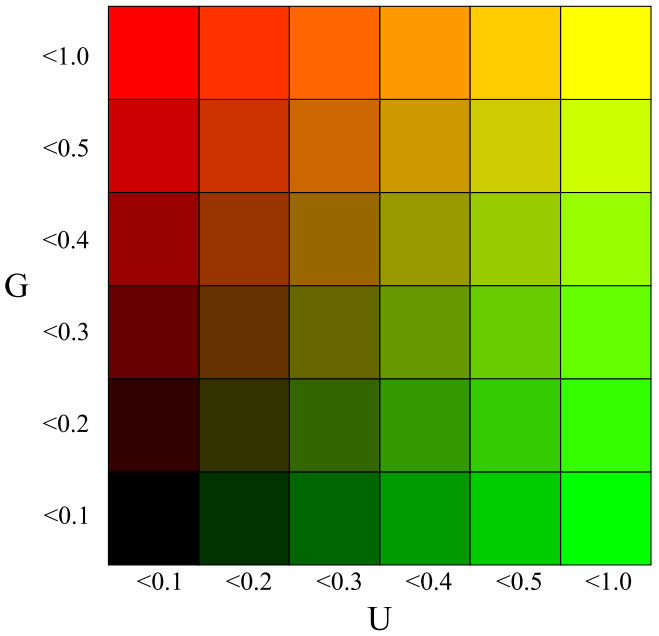
Dynamics of Patterns: Mechanism of Coexistence



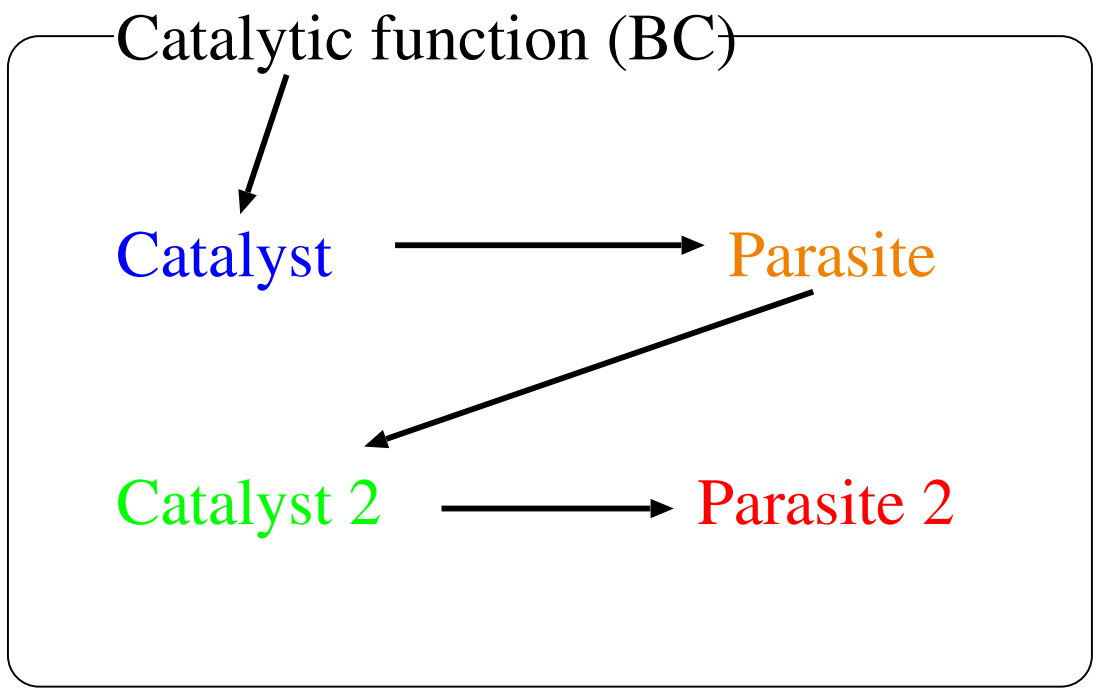
Catalyst's color



Parasite's color



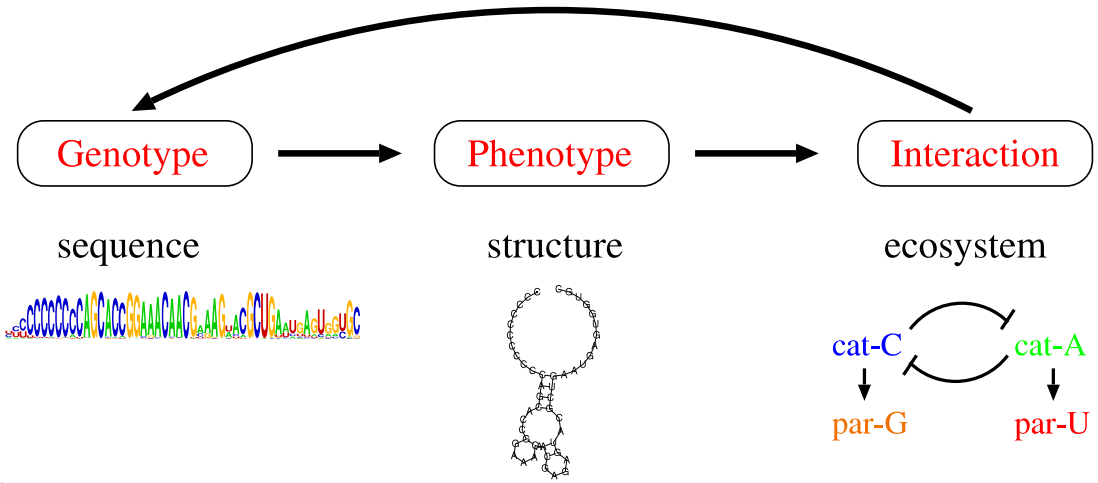
Sequential Generation of Ecological Meaning (Niche)



Implication of Results in Prebiotic Evolution

- Origin of diversity in replicator ecosystem
  (cf. origin of Hypercycle)
- Evolution of parasites “species”
- Parasites may play a role as a carrier of new function
  Replicase-parasite $\longrightarrow$ replicase-enzyme
  (see also Hanczyc & Dorit 1998)

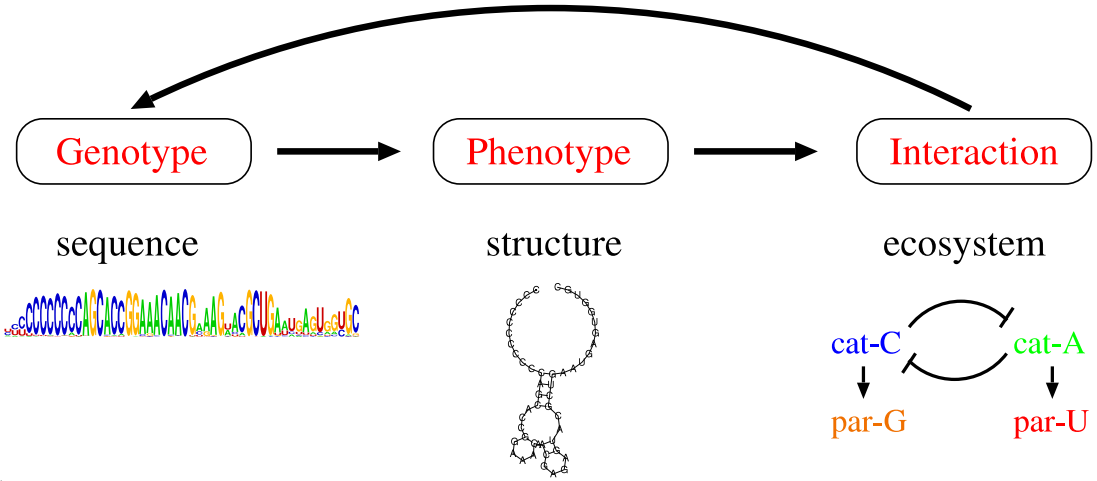
Evolution as Information Generator

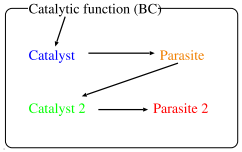


(information = genotypic/phenotypic patterns that make sense in ecological context)

- Evolutionary *generates* information *from within the system*
  (cf. genetic algorithm: *optimization* toward *predefined* functionality)

Evolution as Information Generator



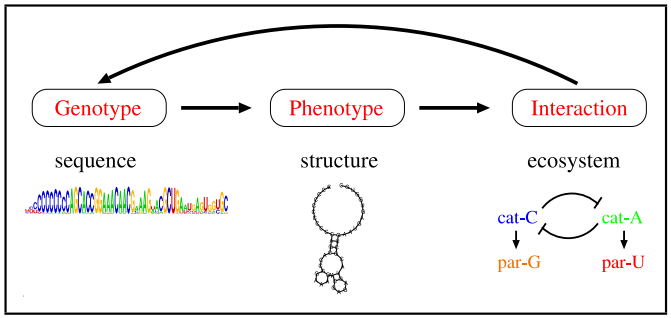


(information = genotypic/phenotypic patterns that make sense in ecological context)

- Evolutionary *generates* information *from within the system*
  (cf. genetic algorithm: *optimization* toward *predefined* functionality)

Evolution of complexity

- Evolution as information generator
  - Genotype-phenotype map (cf. species
  - Individual-interaction (cf. fitness



- $\longrightarrow$ Evolution of complexity