

Diffusion intensity can affect the course of evolution in a non-monotonic manner

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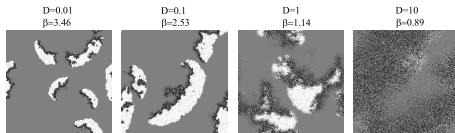
Presented on 23 May 2008
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Evolution & Population structure

- Intergroup selection (Wright '45 Ecology)
 - evolution of altruistic traits
- Spatial pattern formation (Boerlijst & Hogeweg '91 Physica D)
 - evolution \rightleftharpoons self-organization

Evolution & Population structure

- When diffusion goes infinite
How does a system approaches to a well-mixed situation



RNA replicators

■ Product inhibition



- Temperature cycle; e.g. PCR. Not for RNA.
- Short polymer (von Kiedrowskie '86 Ang Chem). Limited information.
- Strand displacement

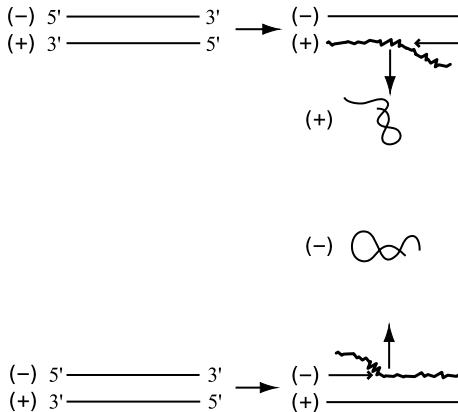
RNA replicators

■ Product inhibition

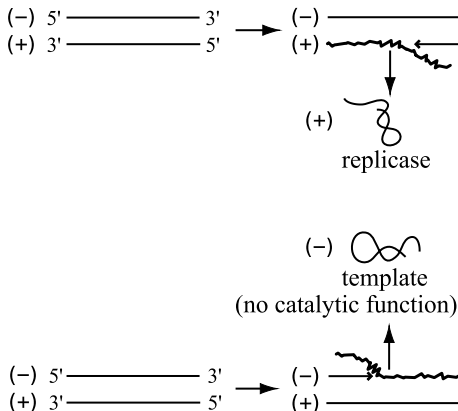


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- **Strand displacement**

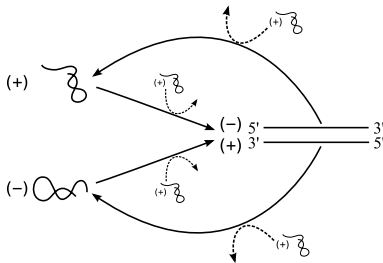
RNA replicators & Strand displacement



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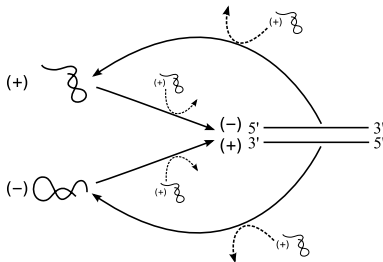


Evolution of Strand preference



- Choice for a template: (+) or (-)?

Evolution of Strand preference



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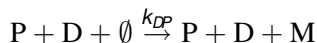
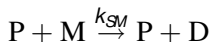
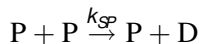
ODE model (1 species)

$$\dot{P} = -k_{SP}P^2 + k_{DM}\theta PD - dP$$

$$\dot{M} = -k_{SM}PM + k_{DP}\theta PD - dM$$

$$\dot{D} = k_{SP}P^2 + k_{SM}PM - dD$$

[where $\theta = 1 - P - M - D$]

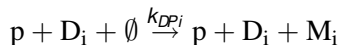
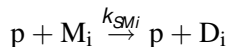
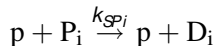


ODE model (many species)

$$\dot{P}_i = -k_{SP_i} p P_i + k_{DM_i} \theta p D_i - d P_i$$

$$\dot{M}_i = -k_{SM_i} p M_i + k_{DP_i} \theta p D_i - d M_i$$

$$\dot{D}_i = k_{SP_i} p P_i + k_{SM_i} p M_i - d D_i$$



Total growth

$$\dot{T}_i = (k_{DMi} + k_{DPi})\theta p \frac{k_{SPi} + k_{SMi}}{k_{SPi} + k_{SMi} + d} T_i - dT_i$$

[where $T = P + M + D$ & $k_{SPi} = k_{SMi}$]

Cellular Automata model

■ CA

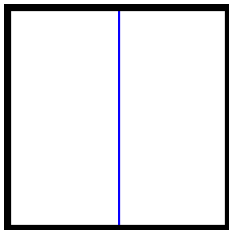
- 2D square grid (toroidal)
- One square can contain one molecule or be empty
- Local interactions (reaction & diffusion)

■ Evolution simulation

- $k_{SP} = k_{SM}$ & same decay rate
- Mutation: $0 \leq k_{DM}/(k_{DP} + k_{DM}) \leq 1$
[this ratio is denoted by r]

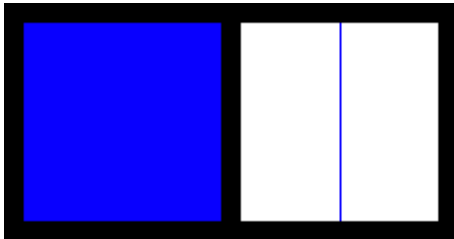
Simulations

$$\Delta = \infty$$



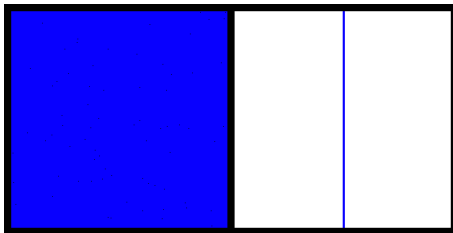
Simulations

$$\Delta = 100$$



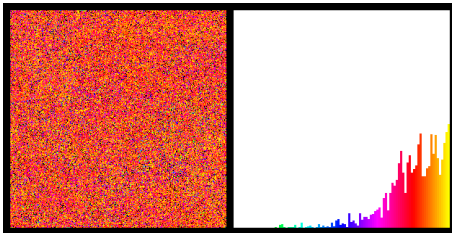
Simulations

$$\Delta = 10$$



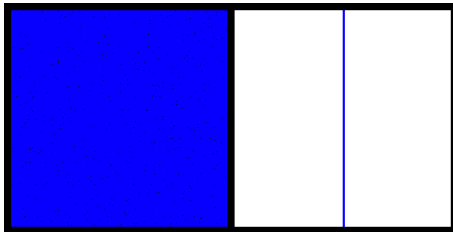
Simulations

$$\Delta = 1$$



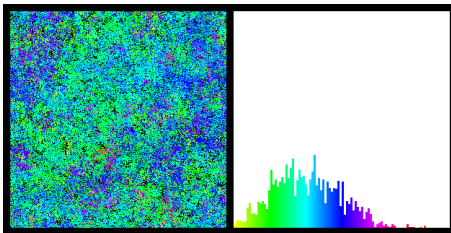
Simulations

$$\Delta = 0.1$$



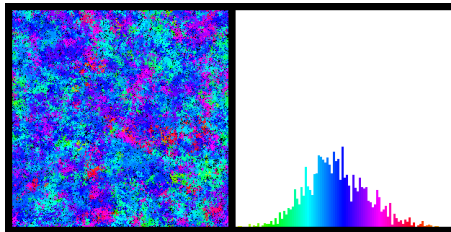
Simulations

$$\Delta = 0.032$$



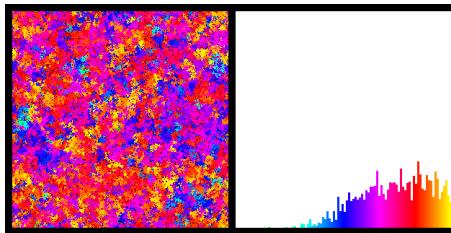
Simulations

$$\Delta = 0.005$$

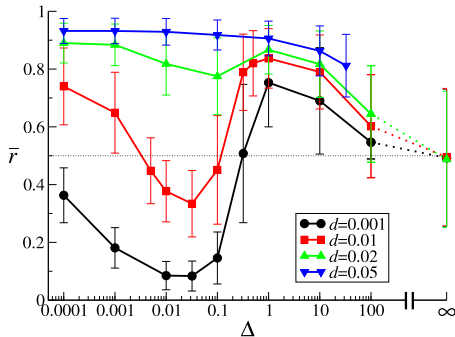


Simulations

$$\Delta = 0.0001$$

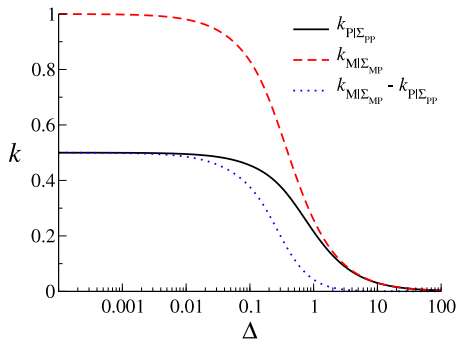


Strand preference as a function of Δ

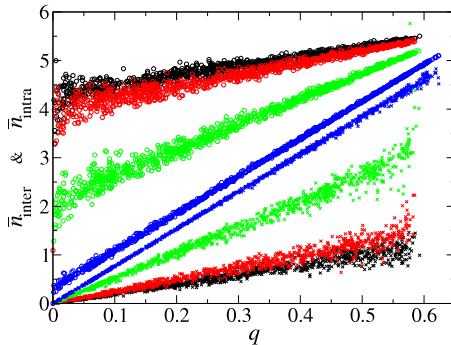


$$[r = k_{DM}/(k_{DP} + k_{DM})]$$

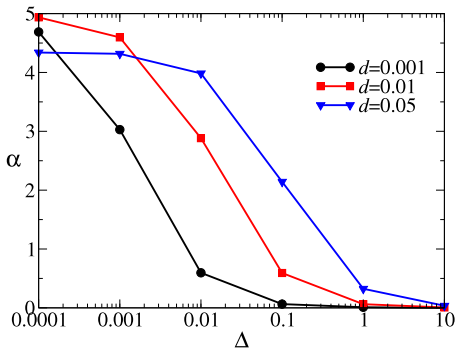
Advantage of producing M



Advantage of producing P

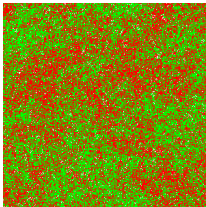


Advantage of producing P

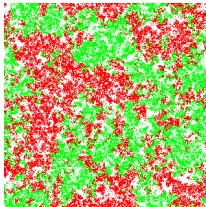


Advantage of producing P

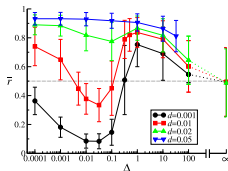
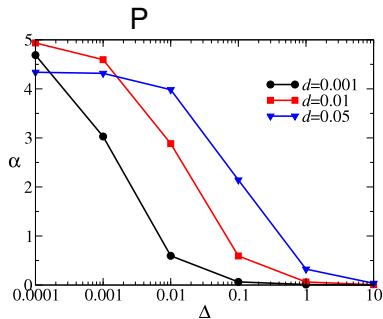
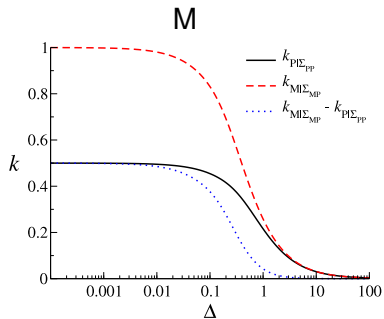
$d=0.001$



$d=0.05$

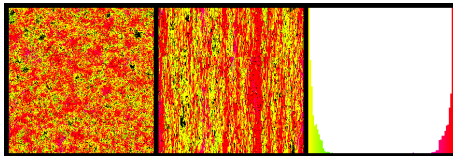


$$\sqrt{\Delta/d}$$

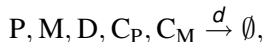
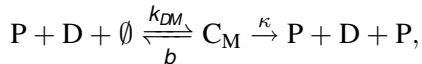
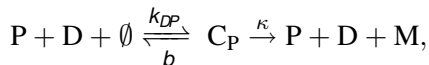
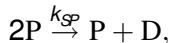
P/M \rightarrow D \rightarrow P/M

Additional results: Speciation

- If k_{SP} & k_{SM} also evolve

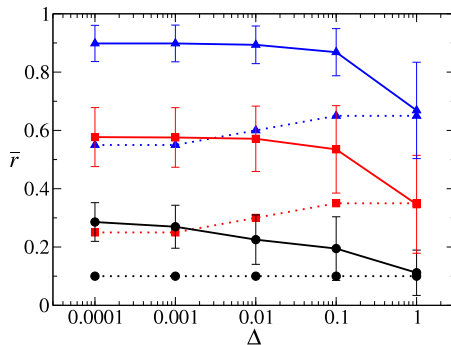


Complex formation



- Complex formation disadvantages replicases
(Takeuchi & Hogeweg '07 J Mol Evol)

Complex formation



Discussion

- cf. Classical group selection theory (Wilson '75 PNAS)
 - local & global time-scales are related via diffusion

- Simplification (caveat)
 - replicases don't discriminate different species
(cf. Takeuchi & Hogeweg '08 Biol Direct)