Prebiotic evolution:
Circumventing Information threshold(?)

emergence of higher levels of selection
Minimal model of evolutionary dynamics:
Replicator equation → quasispecies

2 caveats to the evolution of complex replicating systems

- **Error catastrophe**
  Replication should have high enough fidelity for Darwinian evolution to work
  “survival of the fittest” not a tautology
  Implies only limited information accumulation

- **Parasite (cheater) catastrophe**
  In multispecies cooperative systems
  non cooperative populations tend to destroy the system
  (hypercycle no solution to information threshold)

*Limitation of individual and ecosystem complexity*
Hypercycle properties

\[ X_{i+1} + X_i \rightarrow 2X_{i+1} + X_i \] [Eigen & Schuster '79]

- Selection LOCAL on amount of catalysis received
- Growth and contraction of cycles

However

- Once only selection/survival of the first
- No selection for GIVING catalysis: Parasites
Nothing in biology makes sense except ....

......in the light of Evolution (Dobzhansky 1973)

BUT SO FAR

evolved biological complexity does not seem to make sense in the light of evolution.

HOW TO DEBUG?
Nothing in biology makes sense except ....

- ......in the light of Evolution (Dobzhansky 1973)

- ......in the light of CA (s.l.)
  - local interactions
  - micro-macro transitions
  - non-linear dynamics etc.
  - ”simple rules – > complex behavior”

nothing in biology makes sense except in the light of Both
Hypercycle model (Eigen and Schuster '79): cycle only possible topology

\[ X_{i+1} + X_j \rightarrow 2X_{i+1} + X_j \]

\[ \frac{dX_i}{dt} = a_iX_i + b_iX_iX_j - \Omega_i \]

CA model: Boerlijst and Hogeweg

1992
Spiral waves: generic patterns in oscillating systems
Hypercycle model prototype of multilevel selection

\[
X_{i+1} + X_i \rightarrow 2X_{i+1} + X_i \quad [\text{Eigen & Schuster ‘79}]
\]

- 3-member
- 4-member
- 5-member
- 9-member

chaotic waves (N=4)  stable spiral waves (N> 5 (9))
PARASITE INVASIONS AND EXTINCTION
spiral dynamics

regrowth from core

diffusion (low, none, high)

’inclusive fitness’
Properties of Spirals

- **Faster Rotating Spirals**: Take over the domain of slower rotating ones
- **Core of Spiral**: produces all offsprings in long run
positive selection for early death
Selection for higher decay

FIGURE 6  Number of molecules 4000 timesteps after infection with a decay mutant (Boerlijst & Hogeweg)
FIGURE 3  Stability results for various parameters of species 1, after 1000 timesteps.
Conclusion

Hypercycle properties: in spatial model everything differs from well mixed system

- Limitcycle $\rightarrow$ spiral wave patterns ($\gg$ 5 stabiel)
- CAN be resistant to strong parasites
- Local interactions $\rightarrow$ Selection non Local
- Not “once only selection”
- Spiral waves enslave molecules
- Positive selection for: early death, giving catalysis
- evolution towards 'edge of chaos' ('border of order')

Multilevel evolution
Did we solve the Information threshold problem?

NO......

because in PDE hypercycles not resistant to parasites?...NO

because spirals do not exist?.... NO
Shortcut mutants

\[
\begin{align*}
5 & \rightarrow 4 \quad \Rightarrow \quad 5 \\
7 & \rightarrow 6 \quad \Rightarrow \quad 6 \\
6 & \rightarrow 5 \quad \Rightarrow \quad \|
\end{align*}
\]
Limited stability of Spatial Hypercycle with mutations!
conclusions

- Hypercycles NOT a solution to the information threshold also in spatial eco-evolutionary setting.
- Emergent spiral patterns comprise a higher level of selection.
- Changes all selection pressures of the lower level
  - prevents parasite invasion, selects early death ....

  multilevel selection (type 1)

HOWEVER

the spirals are not themselves replicating entities
Once destroyed the system dies
Multilevel evolution

- CA Universe: (cf. Crutchfield, Wolfram)
  Micro $\rightarrow$ Macro (.....$\rightarrow$.....$\rightarrow$..... etc )
  \textit{STATIC (simple) 'rockbottom'}

- BUT: In evolving systems also Macro $\rightarrow$ Micro:

\begin{figure}
\centering
\includegraphics[width=\textwidth]{chart.png}
\caption{Relation between local interactions and spatial pattern formation in eco evolutionary models}
\end{figure}

\textbf{lowest level}

\textit{does not make sense except in the light of higher level processes}
Hypercycle model has in fact Contrived initial conditions (multiple species/ specific catalytic interactions)

Here we simplify

Non-cyclic interaction structure.

Ongoing mutations instead of invasion dynamics
Evolution of Replicases (and parasites)

\[ X_i + X_j \xrightarrow[k_{ai}]{k_{dis}} C_{X_j, X_i} \xrightarrow[\rho, \theta]{\rho, \theta} 2X_j + X_i \]

Evolve \( k_{ai} \)

well mixed: extinction

in space: minimization of \( k_{ai} \)

Role of parasites

- evolve parasites in fixed replicase population
- evolve replicases with different fixed parasitic population
- co-evolve replicases and parasites

Takeuchi & Hogeweg 2009; Colizzi & Hogeweg 2016
Evolving parasite strength
emerging higher level of “Darwinian entities”

Minimal replicator system
with parasitic L’s
replicated when unfolded
'functional' when folded

\[
\begin{align*}
\dot{R} &= -2k_R R^2 + [2(1-k_R) + 3\kappa\theta + 2d] C_R - k_L RL \\
&\quad + [(1-k_L) + \kappa\theta + d] C_L - dR, \\
\dot{L} &= -k_L(1-l)RL + [(1-k_L) + 2\kappa\theta + d] C_L - dL, \\
\dot{C}_R &= k_R R^2 - [(1-k_R) + \kappa\theta] C_R - 2dC_R, \\
\dot{C}_L &= k_L(1-l)RL - [(1-k_L) + \kappa\theta] C_L - 2dC_L,
\end{align*}
\]
Classical problem
ODE model of RP system
evolutionary extinction (increase of $k_L$ and decrease of $l$)

\[ \dot{R} = -2k_R R^2 + [2(1-k_R) + 3\kappa\theta + 2d]C_R - k_L RL \]
\[ + [(1-k_L) + \kappa\theta + d]C_L - dR, \]
\[ \dot{L} = -k_L (1-l) RL + [(1-k_L) + 2\kappa\theta + d]C_L - dL \]
\[ \dot{C}_R = k_R R^2 - [(1-k_R) + \kappa\theta]C_R - 2dC_R, \]
\[ \dot{C}_L = k_L (1-l) RL - [(1-k_L) + \kappa\theta]C_L - 2d, \]

$\kappa_R = 0.6$

$\nu$ intrinsic advantage of parasite ($L$)
CA model of RP system
evolutionary stable (long transient)

Asynchronous CA choose random patch and random NB
perform reaction or diffusion
reaction: (complex formation (coupling 2 gp), replication and decay)
with prob. according to individual (evolving) parameters of parasites: $K_l$ and $l$
long term evolution: towards smaller waves