A simple dynamic argument for biospherical self-regulation

Lee Worden and S. A. Levin, paper in preparation
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Background

Lovelock, J. E. and L. Margulis, 1974. Atmospheric homeostasis by and for the biosphere: the Gaia hypothesis. *Tellus* **26**:2–10.

- Title summarizes the claim.

W. F. Doolittle, 1981. Is Nature really motherly? *CoEvolution Quarterly*, Spring 1981:58–63.

By analogy to the "selfish gene", problem of "selfish species".

R. Dawkins, 1982. *The Extended Phenotype*, Oxford University Press.

Whole-planet self-regulation requires selection acting on the whole-planet scale. Without selection on planets, what is there to prevent a **tragedy of the commons** scenario?

Two competing hypotheses:

Gaia

The biosphere maintains a good climate for itself

Tragedy of the commons

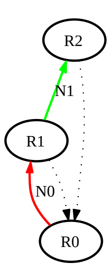
climate control = the common good

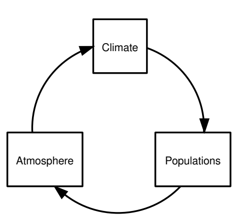
contributing to the common good is costly

self-interest → don't contribute, be a free rider

⇒ the common good can't be maintained.

"Greenhouse world" model design





Model equations: population dynamics

Population N_i consumes resource R_c, produces resource R_p.

$$\frac{dN_i}{dt} = \gamma \; N_i \; R_c \; r(\tau_i, T) - m \; N_i$$

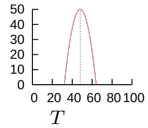
Resource R_j is consumed by some populations, produced by some. Resources reduce spontaneously to simpler resources.

$$\begin{aligned}\frac{dR_j}{dt} = & \sum_{N_i \text{ produces } R_j} (1-\gamma) \; N_i \; R_c \; r(\tau_i, T) \\ & - \sum_{N_i \text{ consumes } R_j} (N_i \; R_c \; r(\tau_i, T) - m \; N_i) \\ & + \sum_{R_k \text{ reduces to } R_j} R_k \quad - \quad R_j\end{aligned}$$

Model equations: climate

Global temperature determines populations' survival

$$r(T,\tau) = r_0\left(1 - \frac{(T-\tau)^2}{\sigma^2}\right)$$

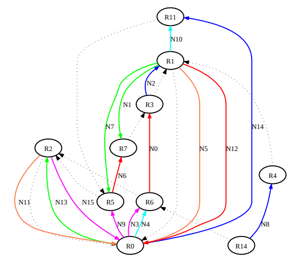


Population dynamics determine temperature, via atmospheric concentrations

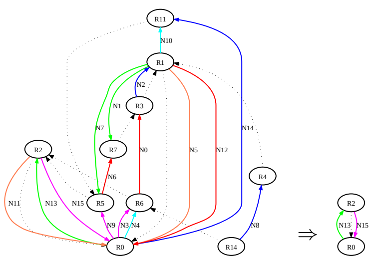
$$\frac{dT}{dt} = \Lambda\,(T^* - T)\,, \qquad T^* = 100\,\frac{\sum h_j R_j}{M}$$

"Heating" h_j (from 0 to 1) is how much resource R_j contributes to raising the temperature.

When I throw together a randomly assembled community



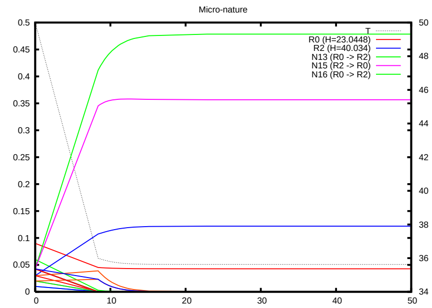
Typically some species come to an equilibrium



Many of them go extinct before the whole community finds stability.

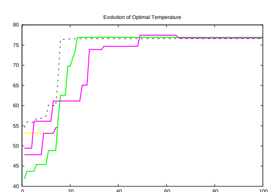
Afterward, it is a Gaia-like planet, at least in the short term.

Model dynamics



Adaptive dynamics

$$\dot{\tau}_i \;=\; \alpha\, N_i^* \frac{2m}{\sigma^2}\frac{T^* - \tau_i}{1 - (\frac{T^* - \tau_i}{\sigma})^2}$$



Some populations go extinct along the way.

At the end, a convergence stable ESS.

The endpoint of the process: no tragedy

The result: **Stable "cooperation" without "free riders"**, i.e. **Gaia**.

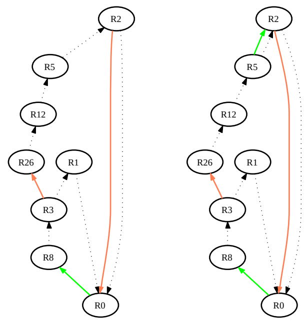
In two ways:

1. the community maintains the climate at an equilibrium that it likes. (could be persistent fluctuation, but it's generally equilibrium.)

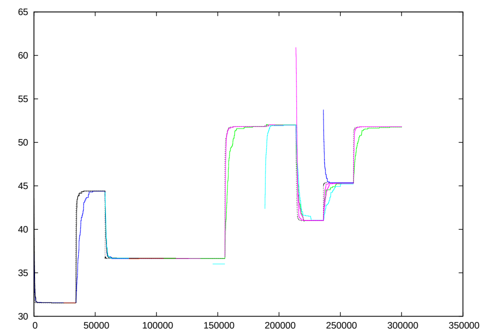
2. when variants arise, they don't undermine that self-regulation.

Long-term changes in model community structure

When everything stops evolving, introduce a new species type



Long-term coevolution of populations and climate



Periods of stability, punctuated by changes in structure

Introduction of a new species usually causes

- sudden change in climate
- one or more extinctions
- discovery of a new equilibrium

When the new type is added, the community often no longer has the Gaia property. After its crisis (if some populations survive), it regains the Gaia property.

What's going on?

Community structures that can't negotiate an agreeable climate can't last.

The system's dynamics always finds a stable attractor.

That's all it takes to **weed out non-Gaian community structures** and **select Gaian ones**.

A **"sequential selection"** process

(Lenton, T. M., K. G. Caldeira, and E. Szathmáry, 2004. What does history teach us about the major transitions and role of disturbances in the evolution of life and of the earth system? *Earth System Analysis for Sustainability*, Dahlem Workshop Report, volume 91, MIT Press, pp. 29–52.)

Recap

In the Greenhouse World models, **Gaian self-regulation is consistently observed**, and "tragic" situations are transient.

A newly identified **sequential selection** process leads the biosphere to a stable solution, producing self-regulating planets without "free riders" — simply because self-regulation is identified with the attractors of the system.

Sequential selection does what Dawkins said only Darwinian selection could do.

The tragedy of the commons framework does not have predictive power.

What is sequential selection?

Sequential selection takes the place of natural selection, and produces stable self-regulation — an "adaptation" on the scale of the entire planet.

Sequential selection is something like natural selection. But it's not natural selection or any other "level of selection" — this is a different kind of "adaptation" acting on the whole system.

Unlike natural selection, it doesn't require a population of coexisting planets.

Caution

Note that sequential selection does not offer a way out of our planet's current climate crisis. Catastrophic climate change and massive extinction events are part of the sequential selection process. The current climate destabilization is real, and it is our urgent responsibility to address it before it becomes even worse than it is already going to be.

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