Gaia and Daisyworld

Modelling imaginary minimal worlds

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Novel Approaches to Networks of Interacting Autonomes

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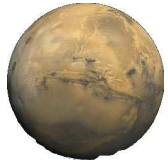
Gaia

"...a complex entity involving the Earth's biosphere, atmosphere, oceans, and soil; the totality constituting a feedback of cybernetic systems which seeks an optimal physical and chemical environment for life on this planet."

Venus: N (<2%) CO2 (95%) No oxygen. Atmosphere in chemical equilibrium



Mars: N (<3%) CO2 (95%) No oxygen. Atmosphere in chemical equilibrium

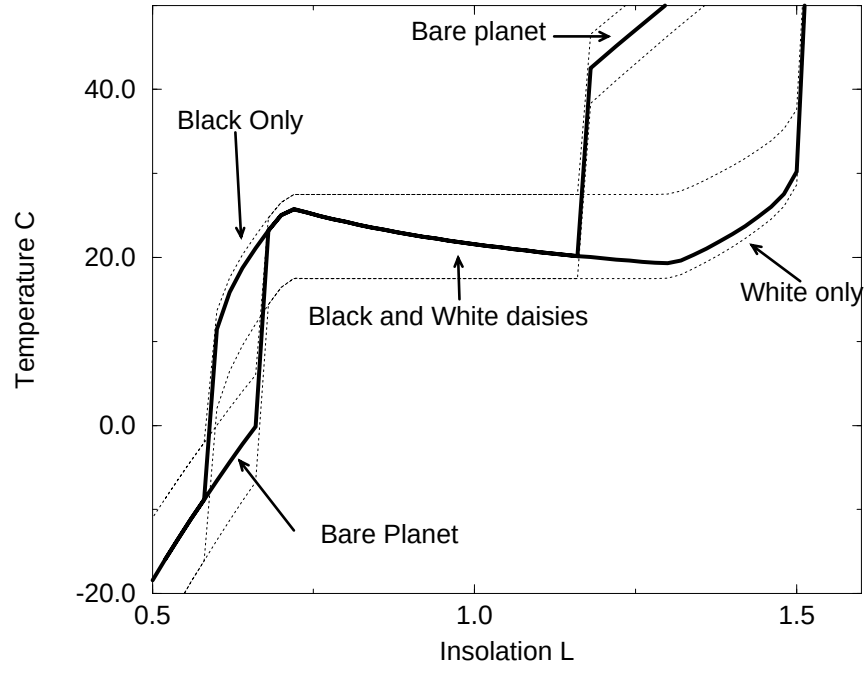
Earth: N (77%), CO2(0.03%) 21% oxygen. Atmosphere not in chemical equilibrium

Stability provided by the presence of life

Temperature Regulation and Daisyworld

Daisyworld is a simple model system that demonstrates regulation.

- Single species - daisies.
- Single characteristic - colour.



Daisyworld in zero dimensions

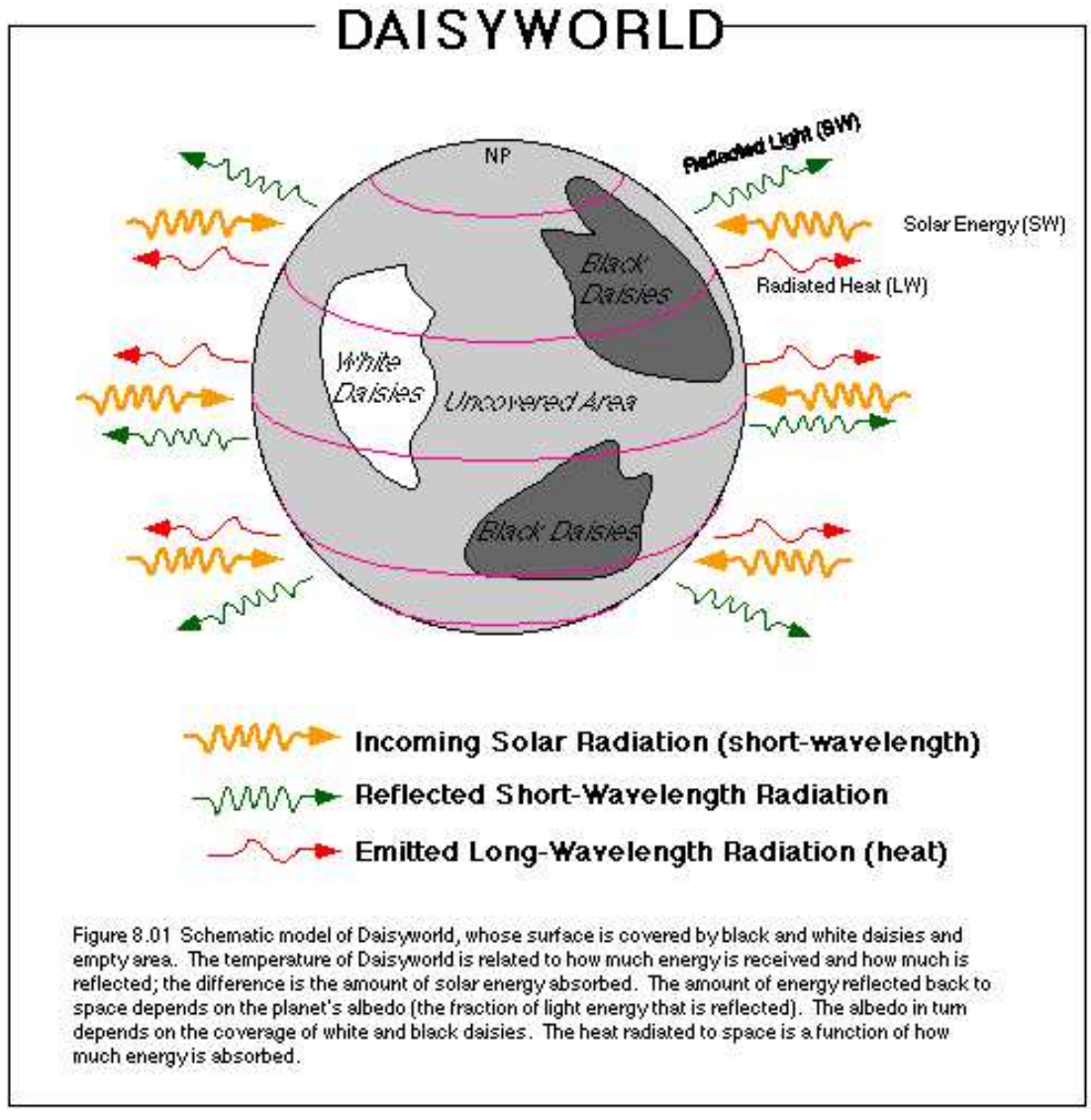


Figure 8.01 Schematic model of Daisyworld, whose surface is covered by black and white daisies and empty area. The temperature of Daisyworld is related to how much energy is received and how much is reflected; the difference is the amount of solar energy absorbed. The amount of energy reflected back to space depends on the planet's albedo (the fraction of light energy that is reflected). The albedo in turn depends on the coverage of white and black daisies. The heat radiated to space is a function of how much energy is absorbed.

Daisyworld in zero dimensions

The original model can be cast as a set of coupled differential equations.
Replicator equations

$$\begin{aligned} \frac{\partial \alpha_w}{\partial t} &= \alpha_w(\alpha_g \beta(T_w) - \gamma) \\ \frac{\partial \alpha_b}{\partial t} &= \alpha_b(\alpha_g \beta(T_b) - \gamma) \end{aligned}$$

where

$$\beta(T) = \begin{cases} 1 - k(T - T_{opt})^2 & 1 - k(T - T_{opt})^2 > 0 \\ 0 & ,\text{otherwise} \end{cases}$$

and $\{\alpha\}$'s are the daisy and ground proportions.

Daisyworld in zero dimensions ctd.

We impose temperature balance

$$\sigma_{SB} T_T^4 = SL(1 - A) \ ,$$

the patch albedo

$$A = \sum_{i=\{b,w,g\}} A_i \alpha_i$$

and the heat transfer between patches

$$T_{\{b,w,g\}} = q(A - A_{\{b,w,g\}}) + T_T$$

Exact Solution possible (Saunders (1994)) reveals the temperature regulation at the fixed points of this system.

Daisyworld in two dimensions

Daisyworld using cellular automata.

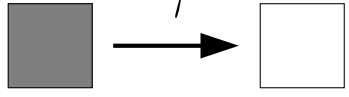
Implement a temperature diffusion equation.

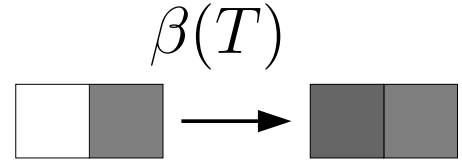
$$C\frac{\partial T}{\partial t} = D\nabla^2 T + SL(1-A) - \sigma_B^{\ell} T$$

Heat Capacity **Diffusion** **Absorbtion** **Radiation**

Use a linear Stefan-Boltzmann law for speed.

The daisy field evolves stochastically by spreading and evolving from neighbouring sites.

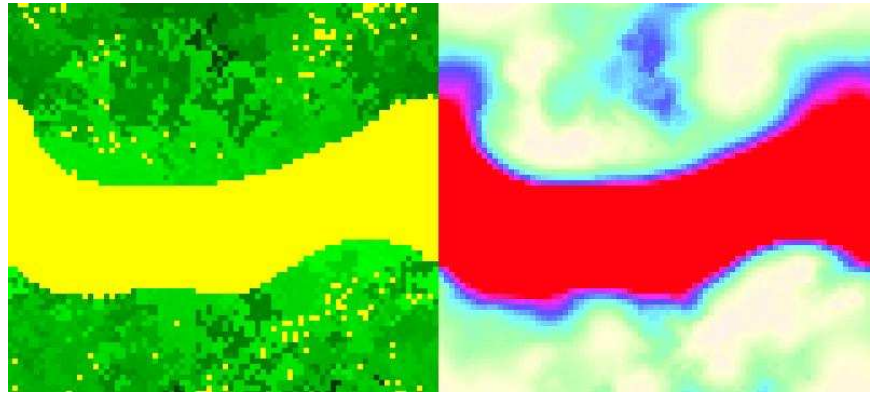




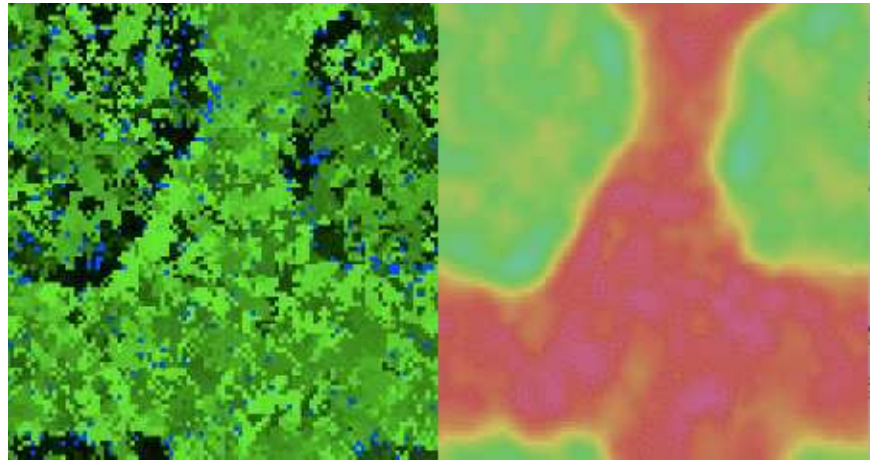
This model is *more* stable than the zero dimensional model.

Results

Catastophic desert formation



Maximisation of replicating life



Complications

Neo-darwinism: every gene for itself

Gaia theory: Life modifi es its environment to be favourable for life

Seems Gaia is robust: Work in progress

Discussion

- Daisyworld is a primitive model system that gives insights into complex behaviour.
- The regulatory behaviour emerges spontaneously as a result of feedback and replication. Not such an implausible scenario for any form of life.
- Principle – look for planetery life by looking for planets out of equilibrium.
- Not many experiments: Earth, Mars, Titan?, Jovian Moons?...
- Extending models of Gaian Systems and Daisyworld only method of verification.