Process Controls
Homeostatic Controls

During 1960's and 1970, Lovelock & Margulis were involved in the questions. How will we identify the presence of life on other planets? From a distance? With different properties than life on earth? In studying this issue, the first thought was that life adapted to the environment. However, the presence of life also changes the environment [1].

The common feature seemed to be the difference between steady-state and equilibrium.

$$\text{Life} \Rightarrow \text{Cycles} \Rightarrow \text{Steady-State}$$

And

$$\text{No Life} \Rightarrow \text{Reactions} \Rightarrow \text{Equilibrium}$$

Thus, one method for the detection of life would be the presence of the reactive components in a cycle. Interestingly, this approach does not require many assumptions about the nature of the life that is present. Instead, it centers on homeostasis.

Homeostasis - The maintenance of a dynamically stable state within a system by means of internal regulatory processes that tend to counteract any disturbance of the stability by external forces or influences; the state of stability so maintained.[2]

The Gaia Hypothesis - "The earth is homeostatic with the biota actively seeking to keep the environment optimal for life."

The implication here is that the environment and life evolve together. Self-organization is the process by which this occurs. In self-organization, the system itself organizes the web of pathways linking the components. These pathways provide the feedback loops required for life. Self organization also reinforces those pathways that contribute the most to the systems.[3] The question then arises, how could this develop since the initial organisms would need to know where they are going with regard to the environment? In answer to this, Lovelock proposed "Daisy World."[4]

Daisy World is greatly simplified system that contains many of the relevant characteristics for a describing the Gaia hypothesis. To create the model a number of simplifying assumptions are made, including

1. Daisy World is a right cylindrical planet orbiting around a sun (no inclined absorption of energy)
2. Planet has a clear atmosphere
3. Daisy World has 2 inhabitants "Light Daisies" and "Dark Daisies" with different albedos.

Albedo – Whiteness; The proportion of the solar light incident upon an element of the surface of a planet, which is again diffusedly reflected from it. Hence in extended use, applied to the proportion of light reflected from various surfaces. [2]

For perspective, consider the following albedos:

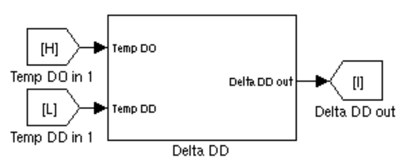
0	Perfect Absorption
0.15	Mars
0.36	Earth
0.57	Saturn
0.76	Venus
1	Perfect Reflection

In this model, two species of daisy are growing, light daisies and dark daisies. The behavior of the two species is similar, so most of the equations occur in pairs. We will use the following subscripts to indicate properties;

DL	=	the light daisies
DD	=	the dark daisies
DO	=	the overall group of daisies
G	=	the planetary soil

If conditions are "right", daisies will grow and cover the ground. Assume an optimal temp for growth of 25^{o} C and an acceptable temp for growth between 5^{o} and 45^{o} C. (Note that growth rate is a function of local temperature for the daisies and that we will have a constant for each species)

This model contains a comparatively large number of heavily interconnected equations. Because of this, if we were to build the model by create and connect the blocks appropriately, the model would look like an explosion in a spaghetti factory (with rectangular meatballs). Instead, the model will be built by creating each equation as a subsystem with the inputs and outputs connected using From and Goto Blocks from the Signal Routing Blockset. For example, the equation for Δ_{DD} is shown as:



Note that each output, a Goto Block, is indicated by a name and also by a letter, 'I' in this case. Any input, a From Block, that would be connect to the must use the same letter. The letter is what Simulink uses internally to link the From and Goto Block.

The growth of the daisies is dependant on their local temperature based on the functions

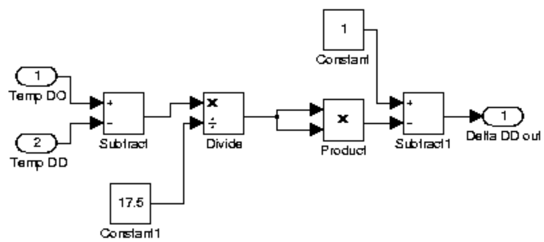
$$\Delta_{DL} = 1 - \left(\frac{T_{DO} - T_{DL}}{17.5} \right)^2$$

and

$$\Delta_{DD} = 1 - \left(\frac{T_{DO} - T_{DD}}{17.5} \right)^2$$

where: Δ_{DD} = the growth factor for the dark daisies
Δ_{DL} = the growth factor for the daisies
T_{DL} = the local temperature of the light daisies [=] °C
T_{DD} = the local temperature of the dark daisies [=] °C
T_{DO} = the optimal growth temperature for all of the daisies [=] 25°C

In Simulink, these two equations are similar (with T_{DD} or T_{DL} used, as appropriate) and appear as shown below



It should be noted that the above equations do not include the limitations that have been placed on the survival temperature range for the daisies.

These values are then substituted into the differential equations describing the growth rates for the two species. Since the model is for a simplified world, we will consider the growth to be a function of the area of the species of daisy (our source of seeds) and the area available to be colonized (the area of open ground). These equations also assume

$$\frac{dA_{DL}}{dt} = A_{DL} \bullet A_G \bullet \Delta_{DL} - 0.30 \bullet A_{DL}$$

$$\frac{dA_{DD}}{dt} = A_{DD} \bullet A_G \bullet \Delta_{DD} - 0.30 \bullet A_{DD}$$

where: A_{DD} = Area of Daisy World covered in dark daisies
A_{DL} = Area of Daisy World covered in light daisies
A_G = Area of Daisy World's soil not covered by daisies

The death rate is 30%. As you create this model in Simulink, this pair of equations has two pairs of bounds. The areas A_{DD} and A_{DL} can never be less than 0 nor greater than 1. These two cases can be handled by the inclusion of a saturation block (located in the Discontinuities Blockset) on the output of integrators. Furthermore, when the local temperature is under 5°C or exceeds 45°C, the growth rates for both the light and dark daisies are 0. This pair of boundaries is handled using an "if … then … else" structure. These blocks are located in the Ports & Subsystems Blockset. The conditions are:

If

  T_{DD} >= 5°C & T_{DD} <= 45°C

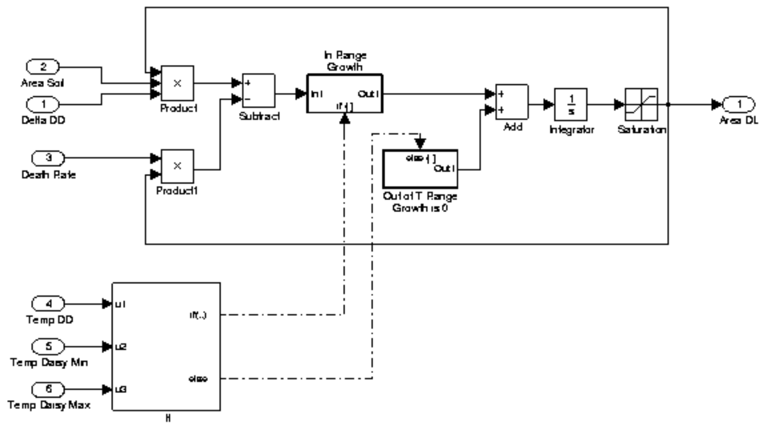
Then

  Allow dark daisy growth

Else

  Dark daisy growth = 0

The resulting Simulink subsystem is:



A similar approach is used for light daisy growth.

The world temperature is:

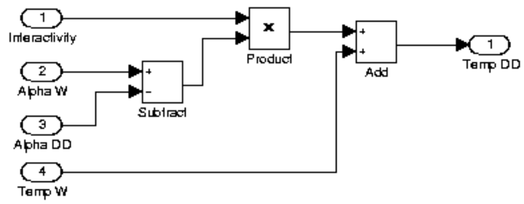
$$T_W = \left(\frac{L \bullet F \bullet (1-\alpha_W)}{S}\right)^{0.25} - 273$$

This is the energy accumulated by the planet (energy coming in – that reflected away)

where:

where:	α_W	=	The weighted average albedo for Daisy World
	F	=	Solar flux of the sun [=]W/(sec•m^2)
		=	9.17 x 10^2
	L	=	Solar luminosity [=] dimensionless
	S	=	Stefans Constant, the relationship between solar energy and temperature [=] W/(m^2•K^4)
		=	5.6703 x 10^{-8}
	T_W	=	Temperature of Daisy World [=] °C

In Simulink, this subsystem appears as

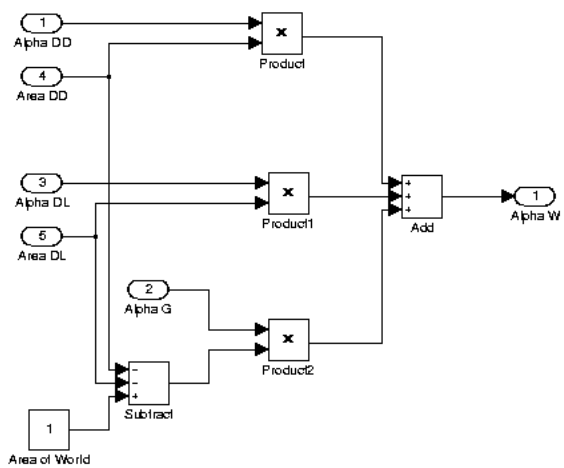


This temperature is based on a weighted average of the world albedo, α_W. This average is

$$\alpha_W = (A_{DL} \bullet \alpha_{DL}) + (A_{DD} \bullet \alpha_{DD}) + (A_G \bullet \alpha_G)$$

where: α_{DD} Albedo of the dark daisies
= 0.25
α_G Albedo of Daisy World's soil
= 0.5
α_{DL} = Albedo of the light daisies
= 0.75

In Simulink, this is



These equations have described the world's temperature. One of the interesting features of this model is that the daisies also alter their local temperature. Since the dark daisies absorb more solar energy, they are somewhat warmer than the light daisies or the soil even for the same solar flux. The relationships between the local daisy temperature and the world temperature ise

$$T_{DL} = I \bullet (\alpha_W - \alpha_{DL}) + T_W$$

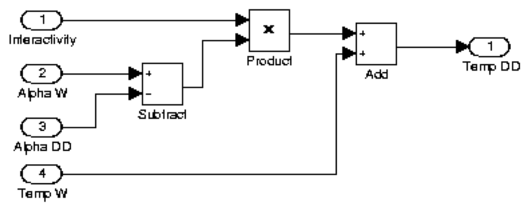
Similarly,

$$T_{DD} = I \bullet (\alpha_W - \alpha_{DD}) + T_W$$

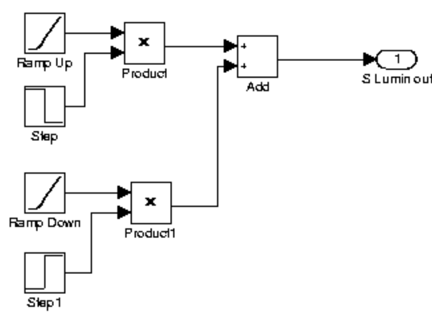
where: I = the interactivity, the degree of interaction between the local temperature and the rest of the world. I can have a range of values.

= 2, extensive interaction between the local temperature and world temperature. More uniform world temperature
= 20, a moderate value for I that we will use in the model
= 100, little interaction between the world temperature and the local temperature

In Simulink, these equations appear as



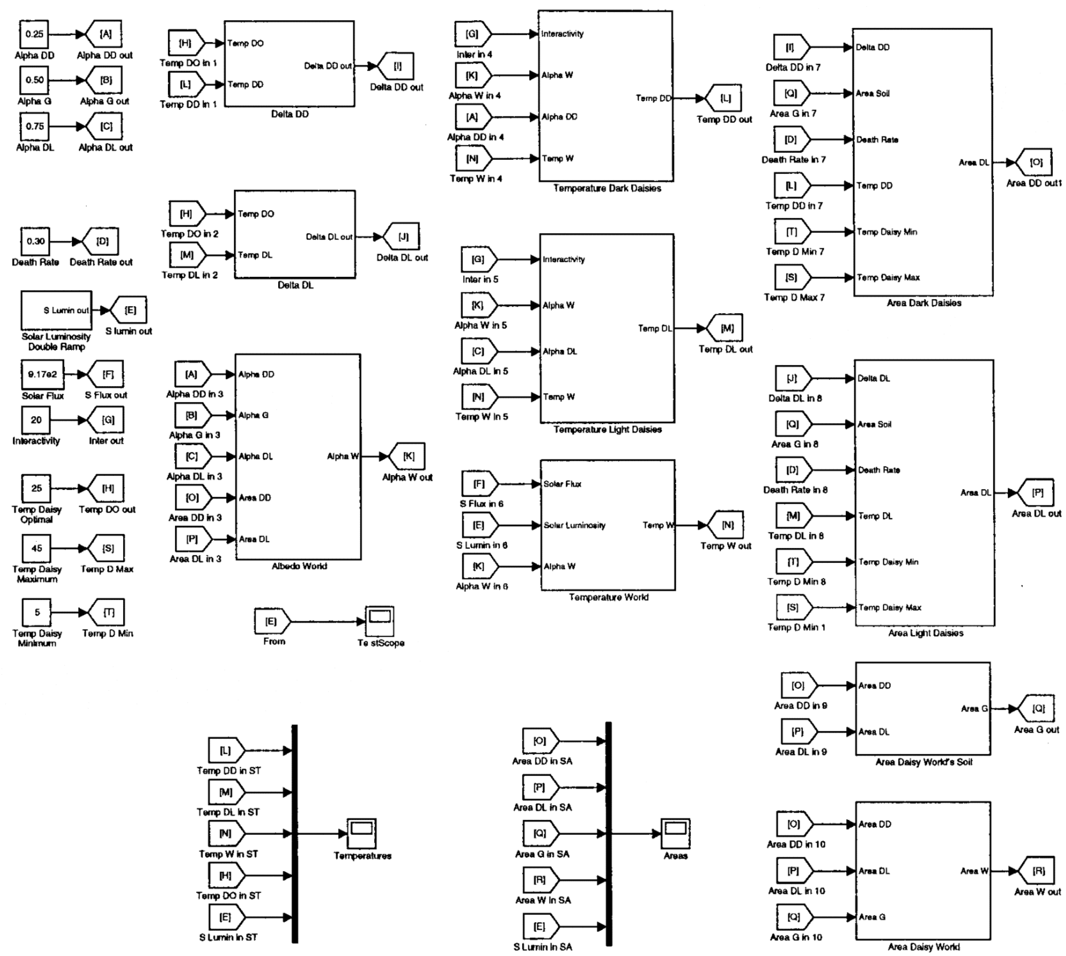
The final equation to be input into the model is the solar luminosity. This is the input that makes the model's output interesting. The solar luminosity is the ratio of the sun on Daisy World to that of our sun. One way to examine the behavior of the system is to start with a luminosity of 0, ramp up the luminosity to 1.5, then ramp back down to 0 over a total of 300 time units. This input can be created in Simulink as a subsystem with no input, only an output, as shown below.



The assembly of the entire model is shown on the next page.

The overall key to the temperature regulation is the fact that dark daisies do well at low solar fluxes and light daisies do well at high solar fluxes. Why? Consider the case where the world is not affected by the biota.

DaisyWorld



/Applications/MATLAB71/DaisyWorld.mdl

References

[1] F. Capra, *The web of life : a new scientific understanding of living systems*, 1st Anchor Books ed. New York: Anchor Books, 1996.

[2] "OED Online," vol. 2005. Oxford, UK: Oxford University Press, 2000.

[3] R. J. Beyers and H. T. Odum, *Ecological microcosms*. New York: Springer-Verlag, 1993.

[4] B. M. Hannon and M. Ruth, *Modeling dynamic biological systems*. New York: Springer, 1997.