BAK-SNEPPEN MODEL OF EVOLUTION

Bak, Per and Kim Sneppen, 1993, Punctuated Equilibrium and Criticality
in a Simple Model of Evolution: Physical Review Letters, Vol. 71, No. 24, p 4083-4086

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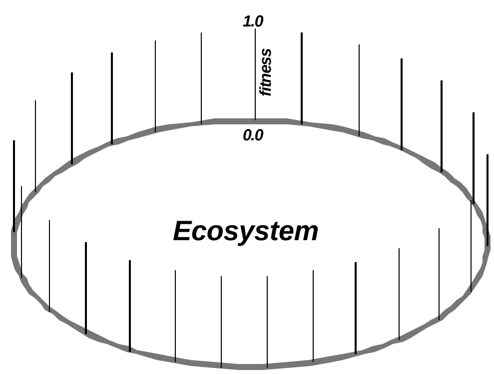
SETUP AND RULES: (Help File One)

The Bak-Sneppen (B-S) evolutionary model is an "ecosystem" in which the fitness of each "species" changes because of its relationships with other "species", following two simple rules. The model parameters include the following:

< The model contains some number of species, usually 50-200, each represented only by its total fitness, a number ranging from 0.0 to 1.0.

< Visually, each species is represented by a vertical line. The higher the fitness the longer the line, up to maximum fitness (length = 1.0). Only a dot marking the top of the fitness line is visible in the computer simulation; with full lines it is harder to see what is happening.



< The species fitness lines are laid out side-by-side in a row, but the row ends wrap; that is, an event that moves off the left side appears on the right side, and vice versa. Imagine it as a circle of vertical lines, and the entire circle represents the "ecosystem."

< ***Rule One*** - find the species with the lowest fitness and randomly change its fitness.

< ***Rule Two*** - at the same time the lowest fit species is changed, also randomly change the fitness of the species to the immediate left and right.

The question is, does any interesting behavior arise from such a simple system, especially behavior that mimics biological behavior?

Rationale for the Rules

RULE ONE - *change the lowest fitness species.* When a species has overall low fitness there are many ways it can improve its fitness, so almost any change is beneficial. If we think of fitness as a barrier that must be crossed, for a low fitness species there are numerous low barriers. As fitness increases, however, there are fewer ways to improve; the barriers get higher and it is increasingly more difficult to improve fitness. A high-fitness species' fitness is relatively stable; most changes are likely to be detrimental.

Or, if a species has high fitness, and fitness changes are random, there is more room for the random change to go down, and thus it is easier to go down. Conversely, it is more difficult to go up.

Thus, Rule One - change the species that is easiest to improve.

RULE TWO - *also change the fitness of the two nearest neighbors.* Species do not exist in isolation; they are always part of a community. For example, as predator and prey, or as two organisms competing for the same food source. Therefore, a change in one species changes the fitness of the species it interacts with, and the species most affected are the ones it most closely interacts with.

Thus, Rule Two - if one species changes fitness, change the fitness of the nearest interacting species.

But why change the fitness at random? In evolution doesn't fitness always go up?" Not necessarily. A mutation, for example, occurs at random, and it may be beneficial, or not beneficial. Plus, if one species changes its fitness the result could be to increase or decrease the fitness of the nearest species it interacts with. Since all the changes are unpredictable they can be simulated by changing the fitnesses at random.

HOW THE MODEL BEHAVES: (Help File Two)

Set the model running and observe the following behavior:

1. The model begins with all species assigned a random fitness. In the model this appears as a scatter of dots showing just the tops of each vertical fitness line.

2. The acting out of Rules One and Two are seen as flurries of dots blinking on and off, scattered at first, but later concentrating in zones about 10 to 20 species wide. These are the tops of the fitness lines changing length as fitness changes.

3. ***Threshold fitness*** is the highest level the lowest fitness has reached. Threshold fitness is shown by a horizontal line that rises with time, and although flurries of activity drop below this line the line only goes up, never down. Threshold fitness is the highest critical steady state the system has self-evolved to at this point in the run. (Note that the critical threshold line does not ***do*** anything in the model. It is drawn just to show us visually the highest level the lowest fitness has achieved.)

   The threshold fitness line can move up only when the lowest fitness across the entire ecosystem happens to fall above the line. When the threshold fitness is low, this is easy to accomplish, but as the threshold fitness rises it gets more and more difficult for *all* the random changing fitnesses to happen to fall above the threshold at the same time.

4. Thus, the threshold fitness line rises rapidly at first and then slows as it approaches fitness about 0.66. Fitness does creep above 0.66 but it takes exponentially longer periods of time for each incremental step upward, out to millions of iterations and hours of running time.

5. An ***avalanche*** is a cascade of fitness changes below the threshold (i.e. all the blinking dots below the line), although this behavior also results in random fitness changes above the line. An avalanche lasts as long as any activity remains below the threshold, and the length of the avalanche is the number of mutations below the threshold. An avalanche is over when the lowest fitness species rises to or above the threshold line; if the lowest fitness rises above the threshold line the line moves up to the new value.

Because mutations dropping below the threshold set off avalanches, the higher the threshold the easier it is for an avalanche to begin, and the longer it lasts (i.e. the longer it takes for all the fitness changes to get to a state where, by chance, the lowest fitness happens to climb above the threshold).

6. As the critical threshold is approached, about 0.66, the zones of activity shift left and right, sometimes by sidestepping, sometime in leaps. The inactive zones in between are parts of the ecosystem in stasis (undergoing little or no change).

7. And, of course, because each run of the model begins at random and all the changes from Rules One and Two are random, each run is different. Some runs have to struggle to get their fitness above 0.66, while for others it occurs quickly, and in some cases the fitness rises quite high, close to 0.70, even if it does take a long time.

We do not expect random processes to produce an organized outcome; random events should remain, well, random - unorganized. Organization takes purpose, design, or at least causes that have a preferential (deterministic) direction. Or at least that is what we have been led to believe.

What the B-S model illustrates is that even random processes can result in self-organization to a critical state, and behavior that shows patterns similar to those in the natural world. None of the changes observed in the system are *designed* to increase the critical threshold, but Rule One and Two will lead inevitably to the critical threshold rising.

What the self-organized critical threshold does is poise the system where avalanches of behavior precipitate over and over, with each avalanche leading to the system having to reclimb to the fitness threshold. As Bak and Sneppen state in their paper (1993, p 4085), *"Life is synonymous with volatility and evolution, rather than stability and fitness."*

WEB SIMULATION

When we searched the web for Bak-Sneppen we got a lot of hits. One of them has a nice little Applet of the Bak-Sneppen model running.

http://theorie.physik.uni-wuerzburg.de/~kinzel/bak.html

Go look it up and watch it for a while. Frankly, when Steve and I first observed it we could not figure out what it was doing, or how it worked, or what it was trying to show. After reading the above you will probably understand it better that we did at first. But, Steve has written a much nicer program, and our next step is to run some experiments with it.