Formation of species diversity

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Characteristics of Evolution

- Whole specie is represented by single fitness
- Fitness represents the ability to survive in dependence on the genetic material
- The evolution barrier is determined by the difference between the fitnesses of the species
- Height of barrier is the amount of genetic material which has to be changed by mutation
- Duration of mutation grows exponentially with barrier height → Assumption: only specie with smallest fitness will mutate
- Mutation of one species changes fitness landscape of all other dependent species too

Evolution of the least fit rather than survival of the fittest

Observation:

- Evolution is characterized by periods of less activity followed by outbursts of mutations and instabilities
- These changes happen on all scales

Assumption: Selforganized criticality

- Tendency of large dynamical systems to develop a critical state independent of external forces from which avalanches of changes start
- Such changes are present on each length scale
- Prototype is the sandpile

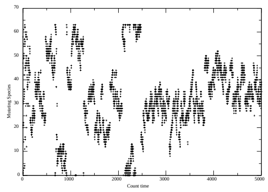
The Bak-Sneppen model [1]

- Species are numbered according to their evolutionary distance
- Each specie is assigned a value out of an infinite [1] or finite [2] set of equally distributed random number called fitness
- Least fit specie is selected to mutate into a new random choice of fitness
- Its two neighbors are assumed so closely connected that the mutation influences their adaptation too and their fitness is also newly chosen
- Procedure is repeated

Besides evolution this simple model is applied fruitfully to a variety of problems, e.g.: Mutation in bacterial populations [3], aging [4], economics [5],

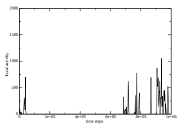
Avalanches of Evolution

Time evolution of mutations



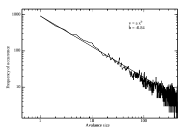
Location of mutations versus time for 64 species and 5000 time steps
In a region of species period of activity is abruptly followed by long periods of inactivity, called punctuated equilibrium

Punctuated equilibrium



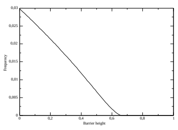
Number of mutations vs time averaged over 10 consecutive species

Avalanche of evolution

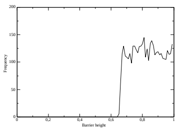


Distribution of avalanche vs sizes which is defined as the number of subsequent mutations below this threshold, here below punctuation of barrier $B = 0.65$

Selforganized Criticality



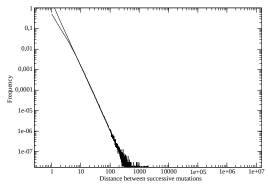
Distribution of minimal barriers, upper limit 0.67 corresponds to maximal waiting time between two successive mutations



After long time (critical state) the barrier heights are equally distributed above 0.67 with mean fitness 0.83

- Almost all species have fitness larger than 0.67 after long transient time for infinite Bak-Sneppen model
- For fitness values less than 10 no critical threshold appears anymore [2]
- High number of biodiversity is essential for self-organized criticality

Distribution of distances between successive mutations



4000 species are simulated over 10^8 time steps. After initial phase the distribution follows a power law $\sim x^{-3.15\pm0.1}$

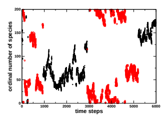
Diversity of species ?

- Evolution is essentially characterized by occurrence of new species
- Necessary condition for branching of one specie is different mutation frequency e.g. caused by environmental separation
- Changed environmental boundaries may cause spatial separation of two species which intimately connected before

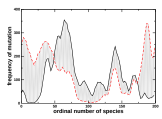
Modified Bak-Sneppen model

By small modification of the Bak-Sneppen model we can simulate this condition for the formation of new species:

- We simulate this by assuming that one of nearest neighbors is disconnected when specie is mutating
- We separate Bak-Sneppen model into two equal-sized subgroups which are connected by mutation of least fit specie
- Within each subgroup usual procedure of mutating both neighbors holds while between two subgroups only least fitness selection
- We reorder both subgroups that odd ordinal numbers are assigned to one subgroup and even numbers to the other subgroup
- Then the modified Bak-Sneppen model consists in changing the corresponding next nearest neighbors instead the nearest neighbors, still establishes an isotropic model [6]



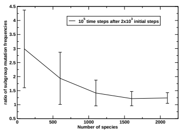
Location of mutations versus time steps for 200 species and 6000 time steps after 2000 initial time steps. The species of the two subgroups are denoted by crosses (black) and circles (red)



Frequency of mutation versus specie, species belonging to one subgroup are connected by a solid and a dashed line, respectively

Branching of Evolution

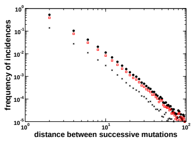
Species in the two subgroups mutate with different frequencies to be see from average mutation frequency per species for each subgroup



The ratio of mean frequency of mutation of the subgroups versus number of species

- With increasing number of species both subgroups show same mutation frequency and become indistinguishable
- For finite number of species, one group shows more mutations than the other, more pronounced for larger times
- We can understand this behavior from self-organized criticality: Since after a certain time a certain fitness threshold is passed by most of the species, an initially occasional asymmetry between the subgroups is growing until it saturates. It has to be remarked that the actual value of the fitness threshold scales with the finite number of species [7] itself.

Each subgroup shows separately self-organized criticality



The frequency of distances between two successive mutations for the total system (circles) and each subgroup (crosses and squares). 2000 species are simulated for 10^6 time steps after 10^6 initial time steps. The same critical power law appear with exponent ~ -3.

Summary

- We modify the Bak-Sneppen model to simulate separation of species by environmental borders
- Due to the blocking of the interaction between two neighboring species the system separates into two subgroups with different mutation frequency
- This different mutation frequencies can lead to different development in each subgroup
- The branching of species will be the result

This work has resulted from a regular training period for the 6th semester of physics and submitted for publication

References

[1] P. Bak, K. Sneppen, *Phys. Rev. Lett.* **71**, 4083 (1993).
[2] R. N. Onody, P. A. de Castro, *Int. J. of Mod. Phys. C* **14**, 911 (2003).
[3] R. Donangelo, H. Fort, *Phys. Rev. Lett.* **89**, 038101 (2002).
[4] S. M. de Oliveria, D. Alves, J. S. S. Martins, *Physica A* **285**, 77 (2000).
[5] M. Ausloos, P. Clippe, A. Pekalski, *Physica A* **332**, 394 (2004).
[6] U. Tirnakli, M. L. Lyra, *Physica A* **344**, 712 (2004).
[7] G. J. M. Garcia, R. Dickman, *Physica A* **342**, 164 (2004).