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A Hierarchical Model for Distributed Seismicity

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A cellular automaton model for the interaction between seismic faults in an extended region is presented. The model, which is called HBM, consists of a hierarchical tree structure of levels; each level has a different number of boxes. Faults are represented by boxes, and faults of different area are boxes with different number of sites. With respect to the organization of the model, boxes of equal size are in the same level, and the more sites they have, the higher they are placed in the hierarchy. Interaction between faults is also assumed to be hierarchical.

Stress particles are randomly added to the system –simulating the action of the external tectonic forces, in such a manner than the probability of receiving a stress particle by a box is directly proportional to the area of that box. The particles fill progressively the sites of the boxes. When a box is full it topples and the particles are in part redistributed and in part lost. This process is called relaxation. A box relaxation simulates the occurrence of an earthquake in the region. The redistribution of particles occurs mostly in the vertical direction (upwards and downwards); however, a small fraction of the load is transferred to the nearest neighbors in the same level of the relaxing box to simulate long-range interactions. If particles transferred to a box fill it, it also topples producing new relaxations. The largest box relaxed between the external addition of two stress particles defines the magnitude of the resulting main-shock.

This model is consistent with the definition of magnitude, i.e. earthquakes of magnitude m take place in boxes with a number of sites ten times bigger than those responsible for earthquakes with a magnitude $m-1$, which are placed in the immediate lower level of the hierarchy. It is assumed that the bottom level of the model contains the boxes whose relaxation corresponds to earthquakes of magnitude $m = 1$. So, the number of levels of the system is directly related to the maximum earthquake magnitude expected in the simulated zone. The model has two parameters, c and u. Parameter c, called the coordination number, is a geometric parameter. It represents the number of boxes in a level m connected to a box in level $m+1$; parameter u is the fraction of load that rises in the hierarchy due to a relaxation process. Therefore, the fraction $1-u$ corresponds to the load that descends in the same process.

The only two parameters of the model are fixed taking into account three characteristics of natural seismicity: (i) the power-law relationship between the size of an earthquake and the area of the displaced fault; (ii) the fact, observed in Geology, that the time of recurrence of large faults is shorter than that of small faults; and (iii) the percentages of aftershocks and mainshocks observed in earthquake catalogs.

The model shows a self-organized critical behavior. It becomes manifest from both the observation of a steady state around which the load fluctuates, and the power law behavior of some of the properties of the system like the size-frequency distribution of relaxations (earthquakes). The exponent of this power law is around -1 for values of the parameters consistent with the three previous phenomenological observations.

Two different strategies for the forecasting of the largest earthquakes in the model have been analyzed. The first one only takes into account the average recurrence time of the target earhquakes, whereas the second utilizes a known precursory pattern, the burst of aftershocks, which has been used for real earthquake prediction. The application of the latter strategy improves significantly the results obtained with the former.

In summary, a conceptually simple model of the cellular automaton type with only two parameters can reproduce simultaneously several characteristics of real seismicity, like the Gutenberg-Richter law, shorter recurrence times

for big faults compare to small ones, and percentages of aftershocks and mainshocks of around 66% and 33% respectively. Besides, a premonitory pattern has been successfully applied.