Dynamic Faulting Simulation with Cellular Automaton Model

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Earthquake dynamics are believed to exhibit self-organized criticality (SOC). The apparent unrest of dynamic stress changes of the crust to stress perturbations exhibits similar SOC behavior. Cellular Automaton Model (CAM) is implemented in simulating dynamic faulting processes. Early stage investigation aims in probing system dynamics by seeking any available simulation schemes including granular material, lattice-gas and lattice-solid approaches. The simulation can be realized through iterative application of rules that encapsulate the essential physics of the system by allowing uniform stress increment but rupture can be initiated and re-distributed fractally depends on the pre-defined rock strength. Automata rules control the stress concentrations that form ahead of growing ruptures and can be physically justified by assuming that failed cells have not yet healed and thus cannot support stress. We assume ruptures occur instantaneously under two distinct timescales - tectonic loading and rupture timescales. The occurrence of the faulting/fracturing can be modeled base on the dispassion (relaxation) factor and stress transfer ratio that controls the onset of instability and size of nucleation zone. Only fractional part of stress on the failing cell is redistributed to mimic dissipation where energy is lost for fracture opening, generation of seismic waves and heat generation. CAMs allow cells and eight nearest neighbors to fail repeatedly or only fail once in a single event. The event size corresponds to the total number of cells failed in a single step. The heterogeneous automaton allows redistributes stress to the unbroken nearest neighbors and hence produce more realistic stress concentrations. A Large event can be initiated from many small ones which expand as the result of interactions between tectonic loading, stress concentration, growing of rupture-front, broken or unbroken cells and local variations in fault strength. The distribution of rock strength can be homogeneous, random or fractal. No additional increment of stress is added until after rupture has ended. Spatial and temporal power-laws which statistically exhibit magnitude-frequency (size-number) distributions can be analysis from synthesized earthquake catalogs. More complex fault models to describe the geometry of nature faults can be characterized by fractal statistics with different scales.

CAM simulation encapsulates the essential physics of the system. The apparent sensitivity of crust to small stress perturbations and the occurrence of triggered earthquakes suggest that the Earth’s crust behaves similarly critical. The distribution of rock strength can be homogeneous, random or fractal. The faults are zones of weakness within the crust and individual faults may have strength fluctuations due to short-range, local variations in pore pressure and surface roughness. Alternatively, long-range elastic/visco-elastic interactions can be incorporated as well. The fault strength with surface roughness can be described with fractal dimension of 2.3. The accumulated stress is distributed to its eight surrounding neighbors with the pre-defined dispassion factor and stress transfer ratio. Tectonic loading can be uniform, random or fractal too. Cellular automaton models allow cells and eight nearest neighbors to fail repeatedly or only fail once in a single event. The heterogeneous automaton allows redistributes stress to the unbroken nearest neighbors and hence produce more realistic stress concentrations. Automata rules control the stress concentrations that form ahead of growing ruptures and can be physically justified by assuming that failed cells have not yet healed and thus cannot support stress. Only 75% of stress on the failing cell is redistributed to mimic dissipation (relaxation) where energy is lost to seismic waves and heat generation.

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