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Cellular Automaton with nonlinear Viscoelastic Stress Transfer to Model Earthquake Dynamics

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Earthquakes may be seen as an example of self-organized criticality. When we transform the Gutenberg-Richter law of earthquake magnitude, the seismic moment, as a measure of the energy released, yields a power law distribution indicating a self-similar pattern. The earthquake dynamics can be modelled by employing the spring-block system, which features a slowly-driving force, failure threshold and interactions between elements as in a complex system. In this approach the earthquake fault is modelled by an array of blocks coupling the loading plate and the lower plate.
For computational simplicity, the spring-block model has been mapped to various cellular automata.
However, the spring-block model (including the cellular automata version) with its underlying physics, is not sufficient to reproduce some of the empirical scaling laws for real seismicity. In particular, a robust power law time-dependence of the aftershock rate function can not be observed, which indicates the need to introduce new physical mechanisms for the aftershock triggering.

Taking into account the rheology of the fault zone, we introduce the nonlinear viscoelastic stress transfer into the interactions between blocks and the tectonic loading force in a basic spring-block model setting. The shear stress of the viscous component is a power-law function of the velocity gradient with an exponent between 0 and 1, showing a shear weakening effect. As a result, the stress transfer function takes a power-law time-dependent form. It features an instantaneous stress transfer during an instantaneous avalanche triggered by the global loading, as well as a power-law relaxation term, which could trigger further aftershocks.

In this nonlinear viscoelastic model, avalanches (earthquakes) triggered either by the global loading or the relaxation exhibit a robust power-law frequency-size distribution. Maximum-likelihood fitting of temporal rates of stacked sequences shows a power-law time decay, which agrees with the modified Omori law. Our results also show that the nonlinearity of the viscoelastic interactions plays a key role in determining the type of the stress transfer function. Our study suggests that the nonlinear viscoelastic stress transfer might be a possible triggering mechanism for real aftershocks.

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