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Two power-law scaling regimes in long-range sandpile automata

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The regional Gutenberg-Richter earthquake size distribution is well-known to consist of two power-law scaling regimes, one for small magnitude earthquakes and another for large magnitude earthquakes. The transition between these scaling regimes is related to the width of the seismogenic zone, a characteristic scale for regional seismicity. Cellular automaton earthquake models typically produce a size distribution with only a single scaling regime and an exponential decay for the largest events. We introduce a new long-range version of the classical Bak and Tang (1987) sandpile automaton. Unlike its nearest-neighbour predecessor, failing sites share the sand stored at that site equally amongst all sites within a specified interaction distance. Numerical simulations with models consisting of over 1 million sites demonstrate that the long-range automaton produces event size distributions with two scaling regimes, the transition between these being dependent upon the interaction distance.

Like the original sandpile automaton, this new model evolves into a self-organised critical (SOC) state where the model remains. There is no evidence for the accelerating energy release (AER) and spatial correlation evolution postulated in the Critical Point Hypothesis for earthquakes. We further demonstrate that AER and spatial correlation evolution can be obtained from these models with the introduction of an additional cellular automaton rule that inhibits the re-loading of failed sites during a given avalanche. Various methods may be applied to achieve this including redistribution of sand only to previously unfailed sites, reduction of the strength of failed sites so that they re-fail during avalanches, or artificial dissipation of the sand redistributed to failed sites. The consequence of such rules is the formation of low-stress

correlations following large events. Such low-stress correlations persist for some time, temporarily perturbing the model from SOC until such time as it re-organises back to the SOC state. The approach to criticality is marked by AER and an increasing spatial correlation length as evidenced by an increase in the size of events.

This research demonstrates that the existence of a characteristic scale in self-organising systems results in two power-law scaling regimes of the event size distribution. In order for cellular automaton to produce dynamics consistent with the Critical Point Hypothesis, an additional cellular automaton rule must be applied that inhibits the reloading of failed sites during an avalanche. For crustal fault systems, we postulate that the static stress shadow (the region of negative Coulomb Failure Stress) surrounding a ruptured fault provides the necessary low-stress correlations to perturb the region from self-organised criticality.