Complexity: crackling nosie, avalanches and hysteresis.

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Plan

1 Inspiration

2 Model: magnet with random fields

3 Scaling laws

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References

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2. J. P. Sethna, K. A. Dahmen, and C. R. Myers, “Crackling noise”, Nature **410**, 242 (2001).
3. M. E. J. Newman, “Power laws, Pareto distributions and Zipf’s law” https://arxiv.org/abs/cond-mat/0412004
4. G. Durin, and S. Zapperi, “The Barkhausen effect” https://arxiv.org/abs/cond-mat/0404512

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Physics of crackling

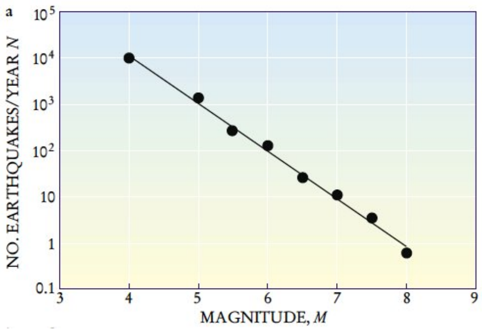
- system responds through discrete, impulsive events
- events span huge range of sizes
- unimportant microscopic details $\Rightarrow$ simple models, universality

Different systems

- fireplace
- earthquakes
- crampled paper, breaking wooden stick
- magnetic material in an external field

Gutenberg-Richter law '50

- relation: frequency versus magnitude $N \propto 10^{-\alpha M} \propto E^{-2\alpha/3}$
- power laws are associated with scale invariance
- scale invariance: phenomena that span overy many length scales



Avalanches and SOC

- Bak's explanation: systems end up naturally at the critical point
- the process is named "self organized criticality" (SOC)
- *however: sandpile models don't crackle*

Recent developments

Physics of crackling – dynamical critical phenomena beyond SOC – studied for

- fluids invading porous materials
- flow of granualr matter
- fracture in disordered materials
- bubbles in foams
- cascading failures in power grids

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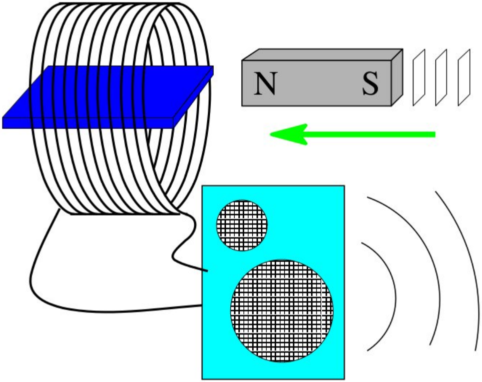
Barkhausen noise experiment



- magnetic domains flip over in an external $H(t)$
- mag. field jumps are turned into electric signal

Random field Ising model

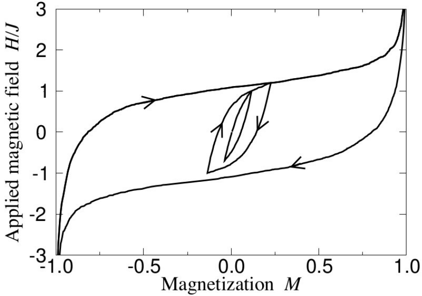
The energy function is

$$\mathcal{E} = -J \sum_{<i,j>} s_i s_j - \sum_i (H(t) + h_i) s_i$$

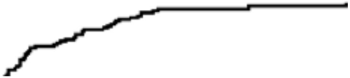
- local, Gaussian distributed h_i, with standard deviation R
- all spins pointing down initially (no thermal noise) $s_i = -1$
- slowly increasing $H(t)$
- spin flips over – only to decrease energy

Hysteresis

$\longrightarrow$ magnetizations lags behind the field



$\longrightarrow$ growing in a series of sharp jumps



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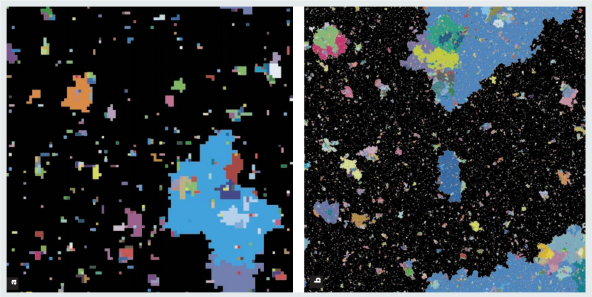
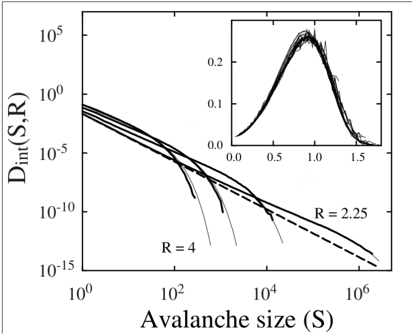
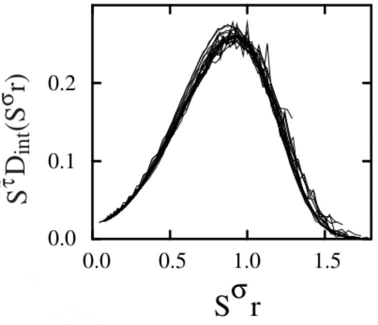
Self-similarity



- cross-section of 3D simulation for 100^3 and 1000^3 spins at R_c
- black background is the avalanche spanning over whole system
- at criticallity system looks similar on all scales

Scaling laws





- number of avalanches D of a given size S follow a power law
- stright line only at criticality ($R_c = 2.16$)
- *universality:* rescaled plots follow a common curve (different R)