PHY 411-506 Computational Physics II

Chapter 12: Interdisciplinary Topics

Lecture 3

Friday April 11, 2008

LECTURE OUTLINE

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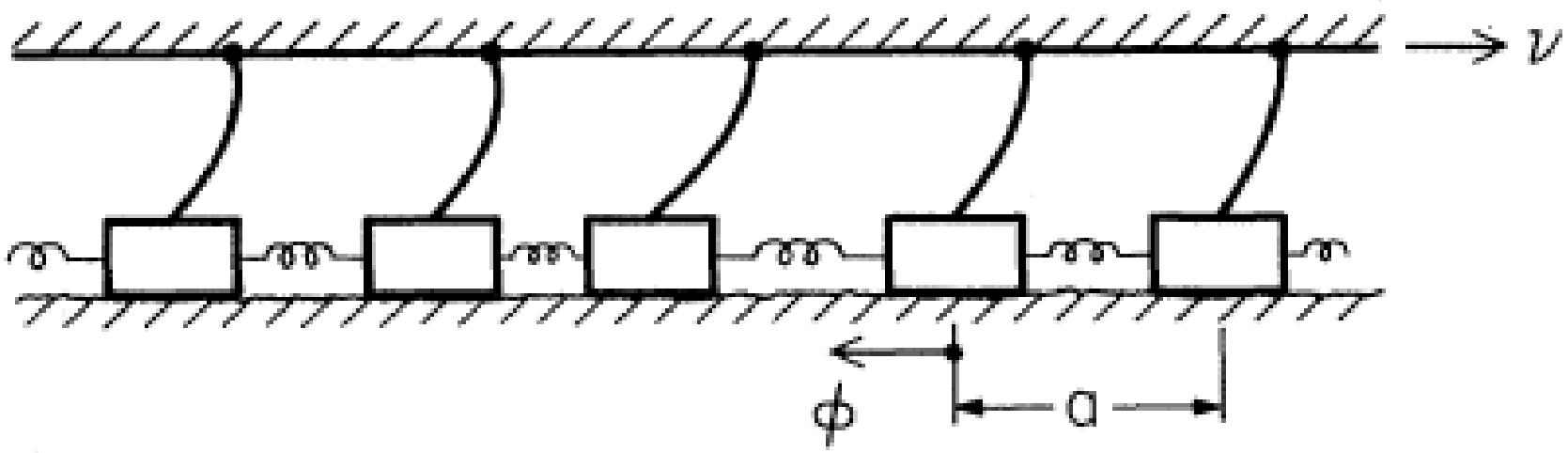
Earthquakes and Self-Organized Criticality

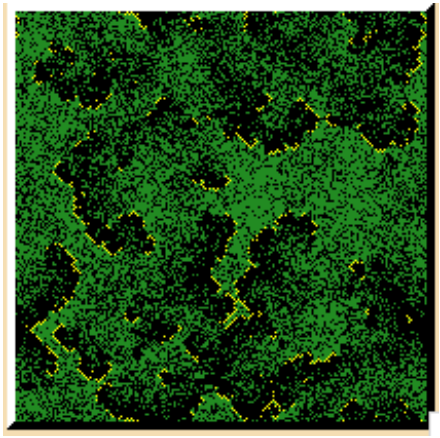
Earthquakes and the Gutenberg-Richter Law

- Every year, very large numbers of earthquakes occur around the world
- The magnitude of an earthquake is measure on the Richter Scale
- The distribution of earthquake magnitudes obeys the Gutenberg-Richter Law
- Carlson, Langer and Shaw, Rev. Mod. Phys. **66**, 657 (1994) review dynamics of earthquake faults using a simple physical model of masses and springs



Self-organized Criticality

- Wikipedia Self-organized criticality
- Per Bak Wikipedia, Remembrance by Lee Smolin
- Bak, Tang and Wiesenfeld, Phys. Rev. Lett. **59**, 381 (1987) uses SOC to explain $1/f$ noise.
- Per Bak and Chao Tang, J. Geophy. Res. **94**, 15635 (1989) uses a simple probabilistic cellular automaton model to explain the Gutenberg-Richter law.
- Per Bak, Computers in Physics, **5**, 430 (1994), SOC in cellular automaton models of sandpiles, earthquakes, forest fires, etc.
- See Mike Creutz's Xtoys programs

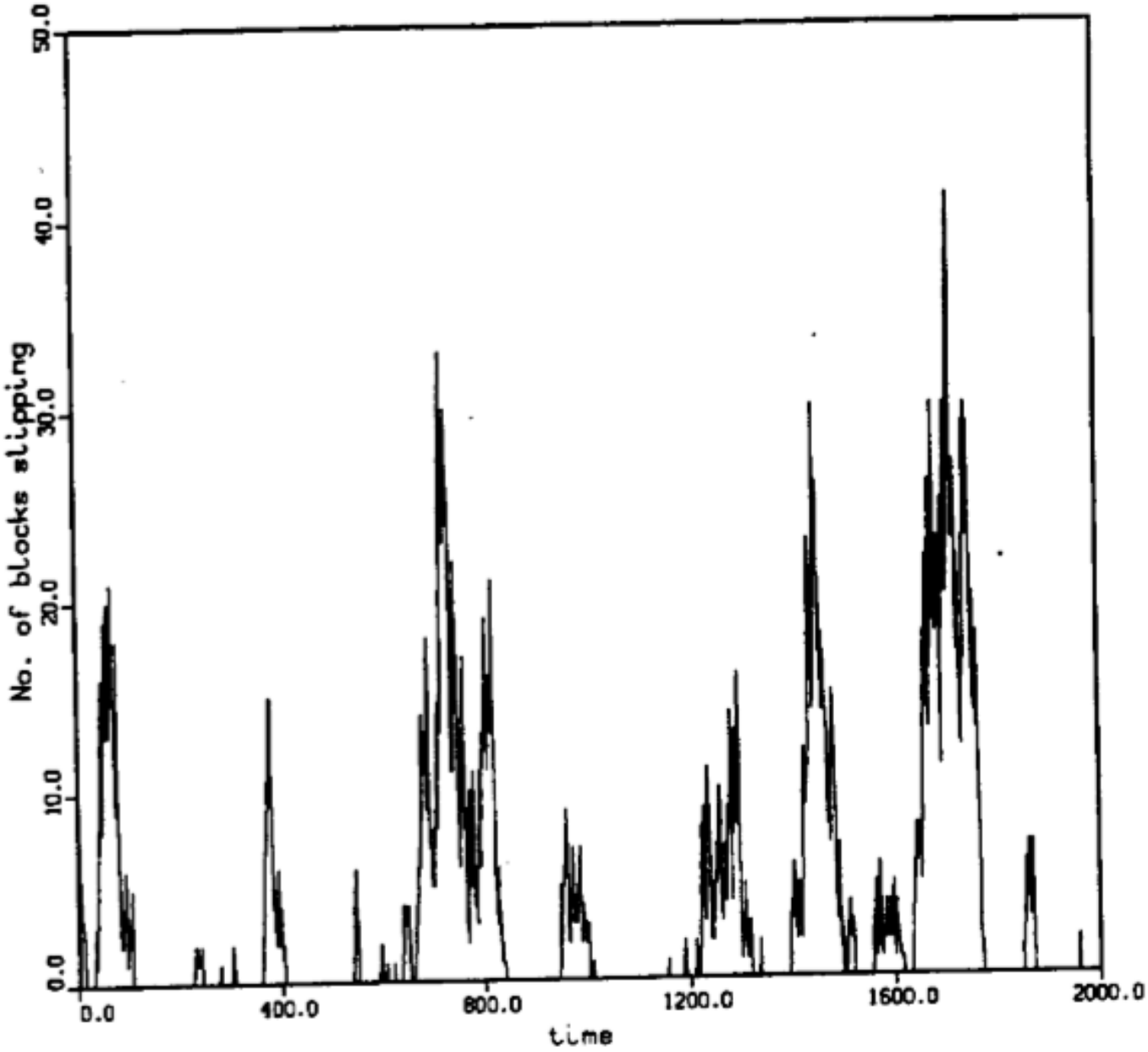
xsand.c  and xfires.c 

- Simple 1-d sandpile automaton Java applet

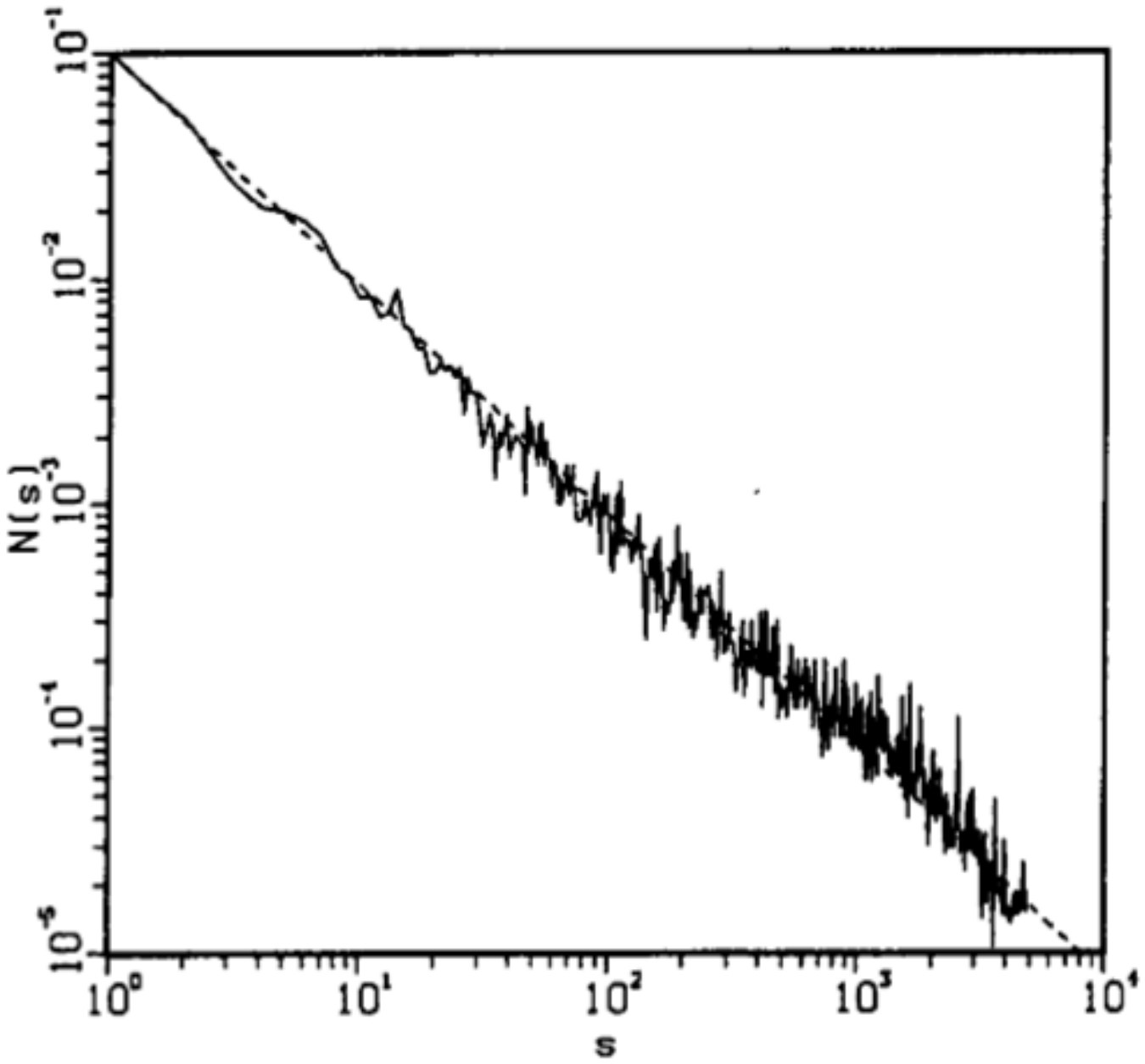
Bak-Tang Earthquake Fault Model

- Physical picture
  - ◇ Earth's crust is periodic 2-D lattice
    - ○ Blocks at each site
    - ○ Connected by springs
    - ○ Static and dynamic friction (stick-slip motion)
  - ◇ Blocks are pulled in a fixed direction by force due to tectonic plate motion
- The model
  - ◇ 2-D square lattice of side L with $N = L^2$ sites
  - ◇ Real variable $z(i, j)$ represents force on block at site (i, j)
    - ○ Slip occurs at a critical threshold force $z_{\rm cr}$, e.g., $z_{\rm cr} = 4$
  - ◇ Initialize at time $t = 0$
    - ○ Assign small random values to $z(i, j)$

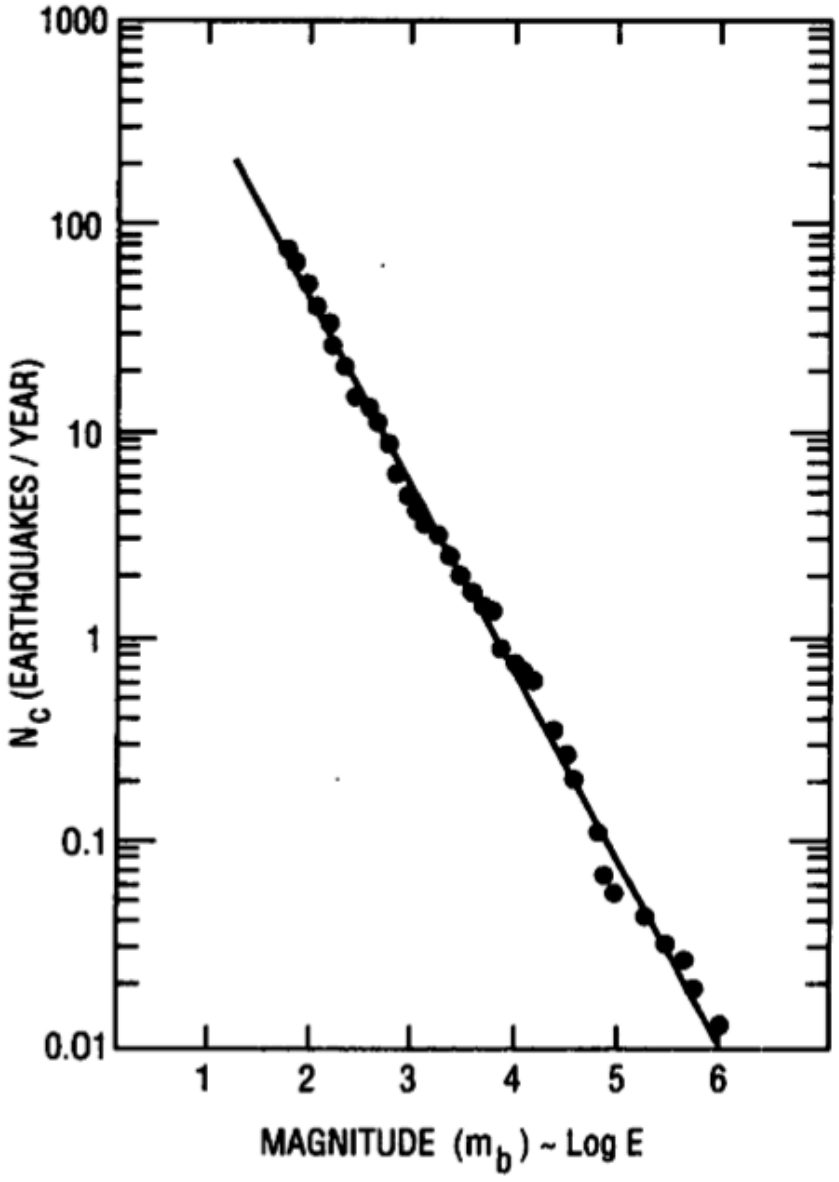
- ◇ Repeat
  - ○ Increase each $z(i,j)$ by small p, e.g., $p = 0.00001$ – (synchronous update), and let $t \longrightarrow t+1$
  - ○ If *all* $z(i,j) \leq z_{\rm cr}$, fault is stable, go to Repeat
  - ○ While any site (i,j) is unstable, decrease force by $z_{\rm cr} = 4$ at (i,j) and increase force at each neighbor by $z_{\rm cr}/4 = 1$
- ◇ The size of the event s is the total number of blocks that become unstable and slide
- ◇ Note that an instability can trigger a very large event!



Slip event sizes s as a function of time t



Distribution of sizes $N(s)$ versus s



Earthquake statistics for the New Madrid zone from Johnson and Nava, J. Geophys. Res. B**90**, 6737 (1985).