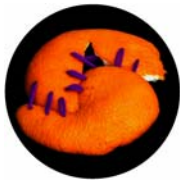


Entropy, Order Parameters, and Complexity

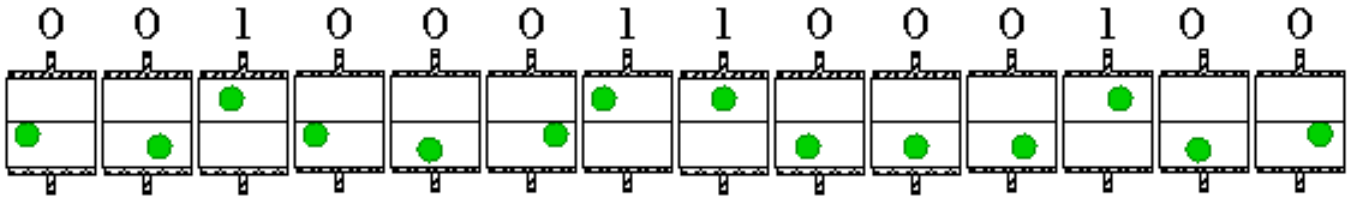
Incorporating the last 50 years into the statistical mechanics curriculum

James P. Sethna, Cornell University, 2007
http://www.physics.cornell.edu/sethna/StatMech/

The purview of science grows rapidly with time. It is the responsibility of each generation to join new insights to old wisdom, and to distill the key ideas for the next generation.

Computation and Entropy

Bennett & Feynman's Information Engine

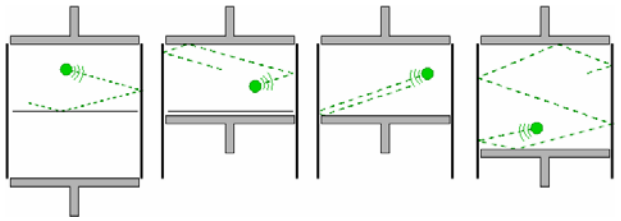


Minimalist magnetic tape

Deep relation:

Thermo Entropy: $\Delta S = Q/T$

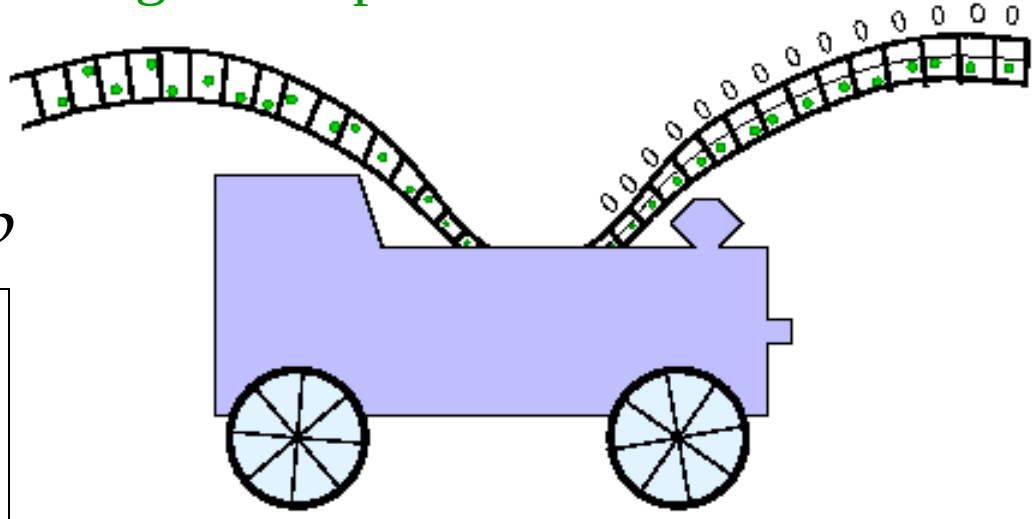
Info Entropy: $S = -k_B \sum \rho \log \rho$



Extract k_BT from each bit *if* atom position known: information into work!

No minimum measurement energy

Information transformed into work

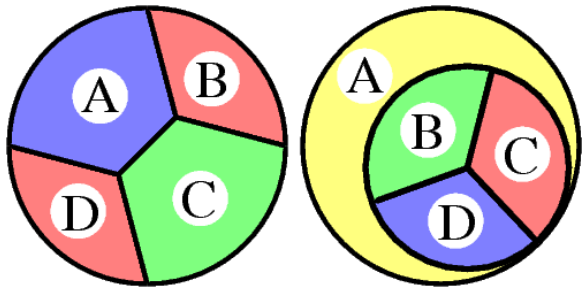


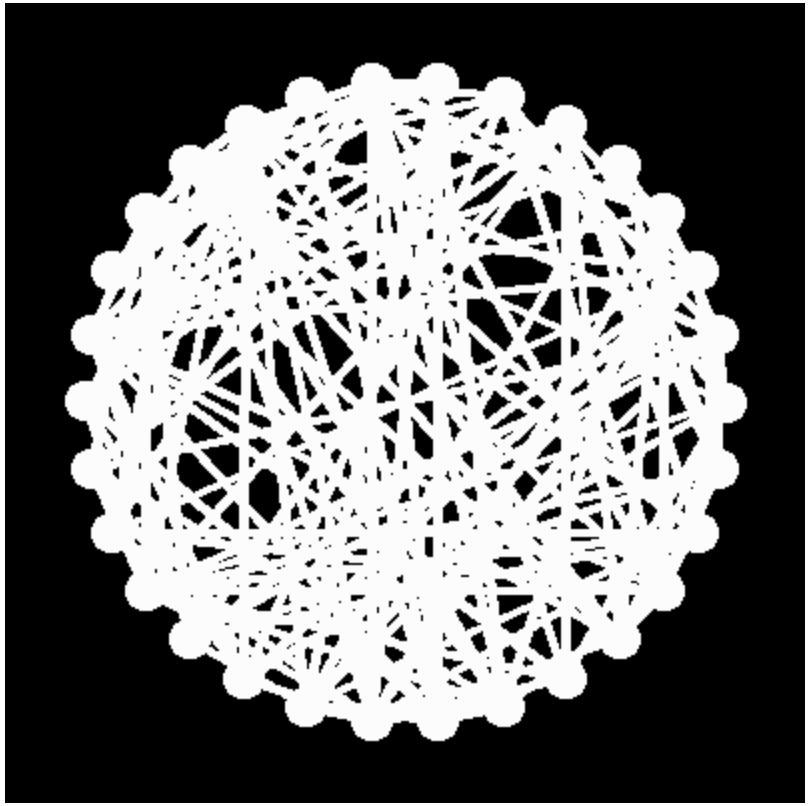
- Reversible computation
- Entropy of glasses
- Card shuffling & entropy

Computational Complexity

Statistical mechanics of NP-complete problems

NP-complete problems
- Traveling salesman
- 3-colorability
- Number partitioning
- Logical satisfiability (SAT)
- Worst case: exponential time





Random instances may not be hard…

Ensembles; statistical mechanics; phase transitions; spin glass methods.

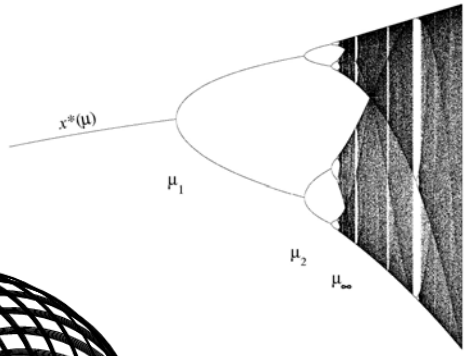
Dynamical Systems

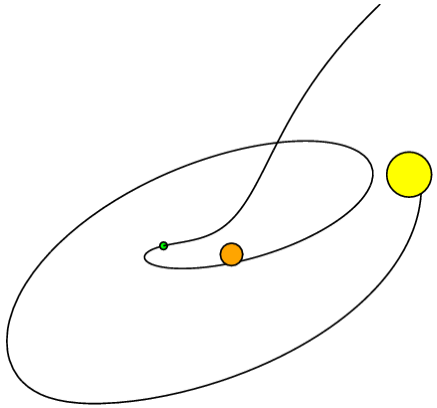
Chaos, Ergodicity, and KAM

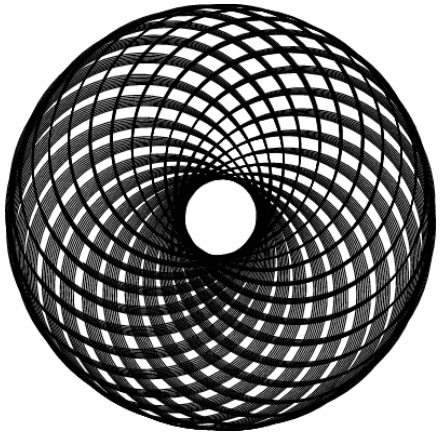
Why equilibrium?

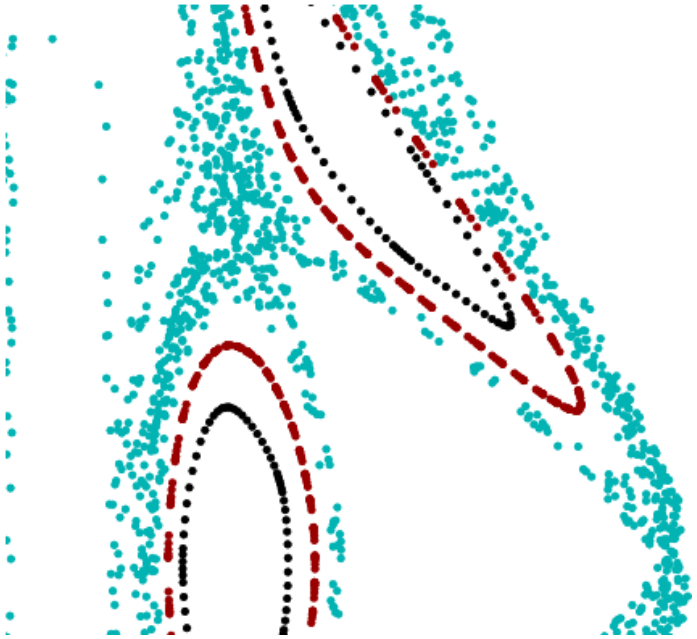
Chaos destroys initial state

Ergodicity







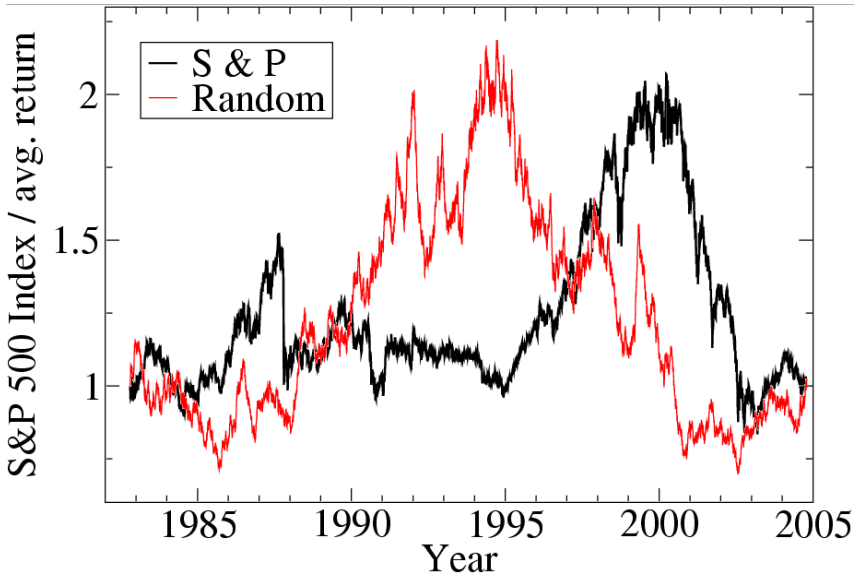


Why has the earth not left the solar system (equilibrium)?

- KAM theorem: invariant tori
- Breakdown of ergodicity

Social Sciences

Econophysics, social networks

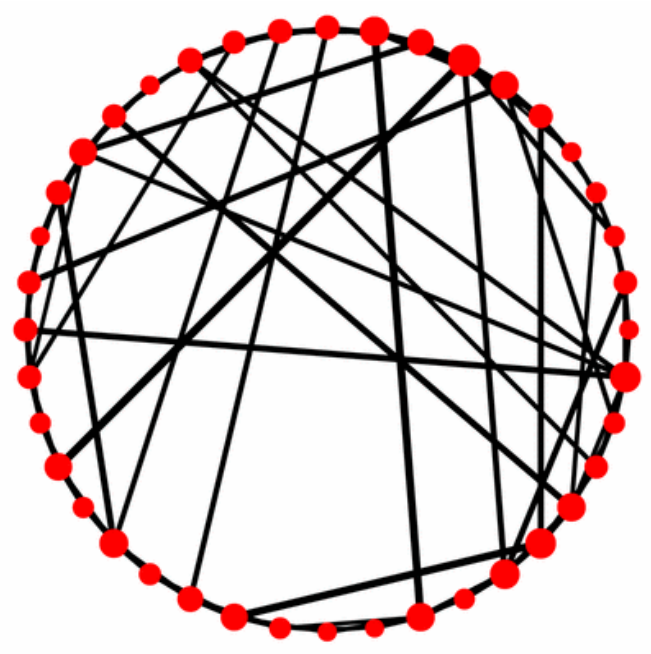


Stock prices and random walks

- Volatility, diversification
- Heavy tails
- Derivatives, Black-Scholes …

Six degrees of separation

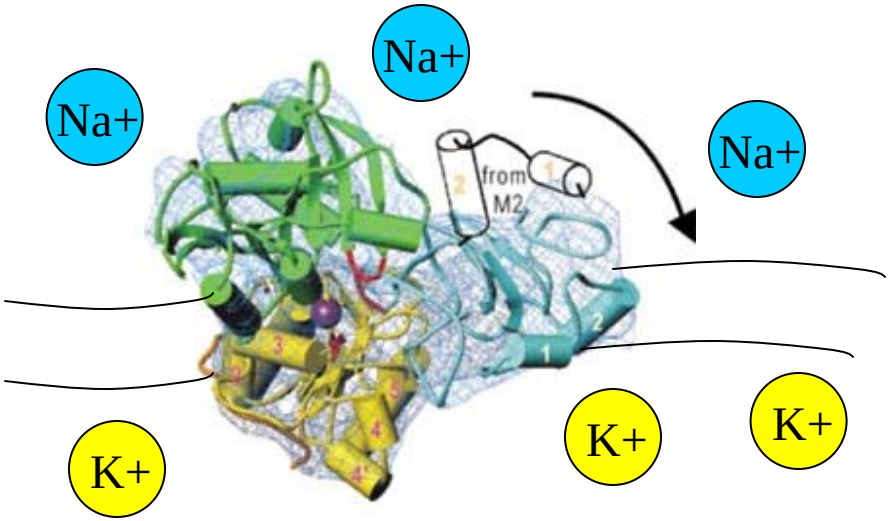
- Small world networks
- Betweenness algorithms



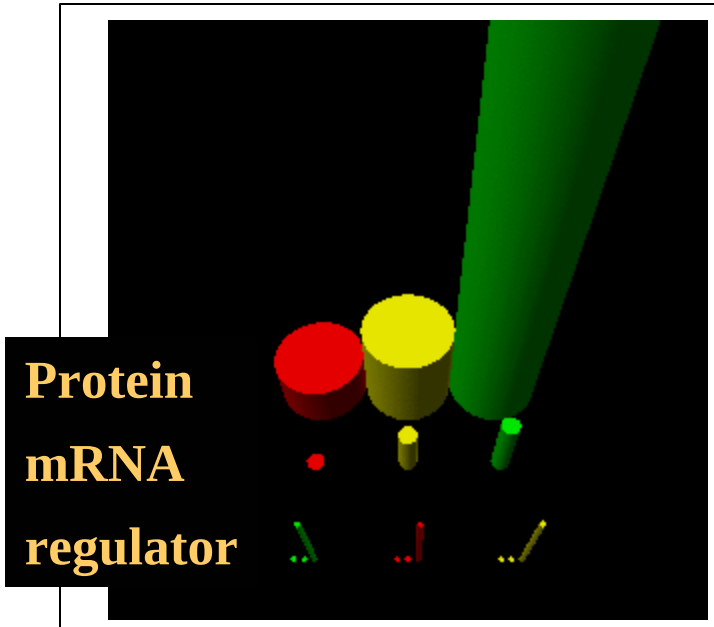
Watts and Strogatz

Biology

(Chris Myers, Michelle Wang)

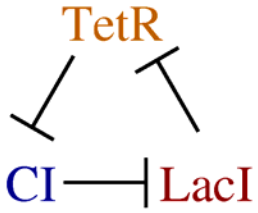


Ion pump as Maxwell's demon



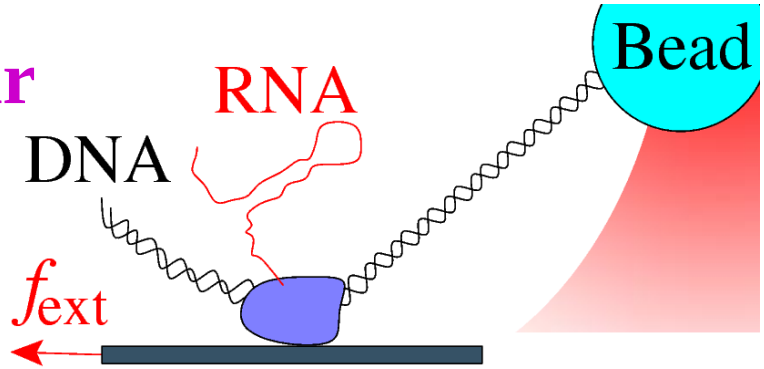
Genetic Networks

- Stochastic evolution
- Monte Carlo
- Shot noise
- Telegraph noise



Elowitz and Leibler

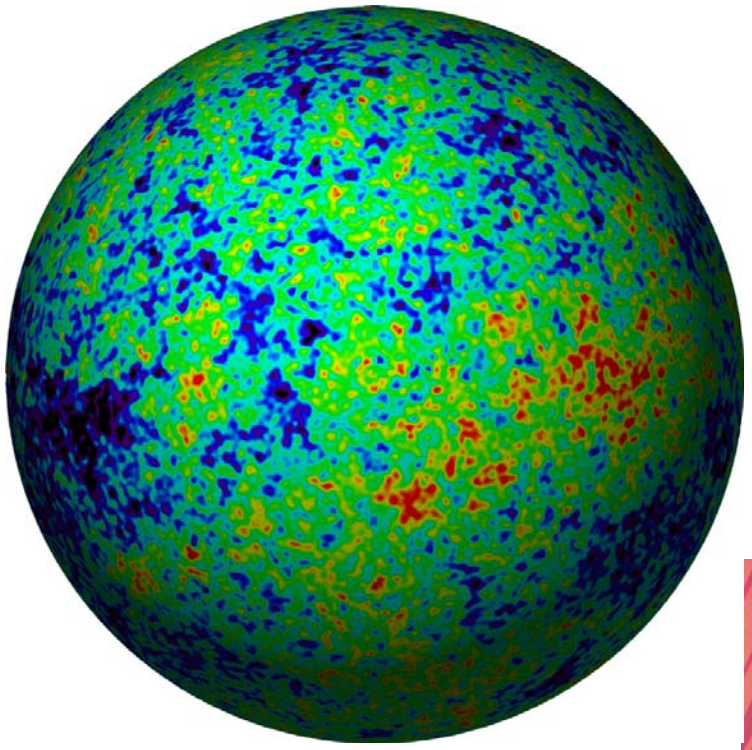
Molecular motors



Random walks; Ratchet and pawl; 'Force' free energy

Growth and evolution

Patterns and correlations

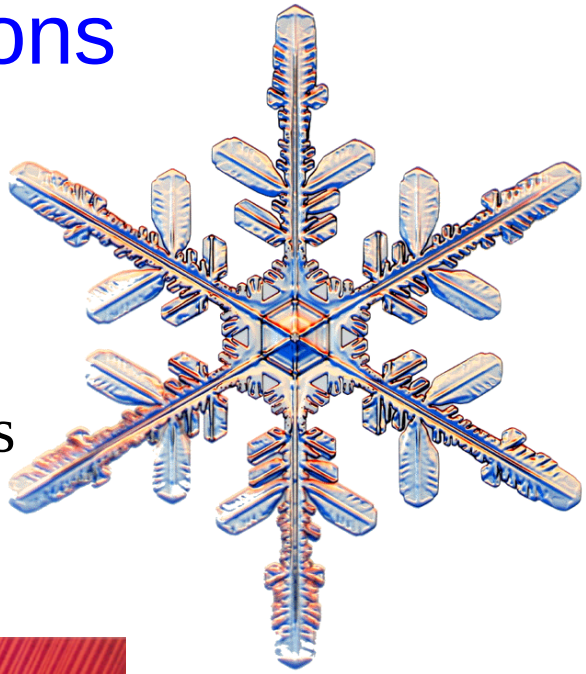


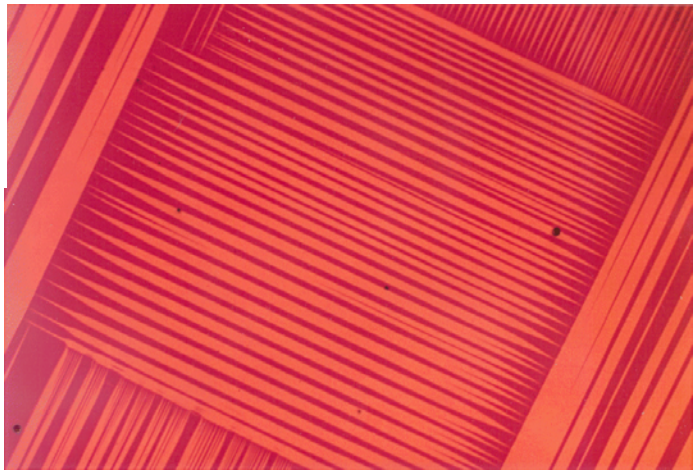
Microwave background

- Wave equations
- Correlation functions

Snowflakes and dendrites

- Growth dynamics
- Linear stability





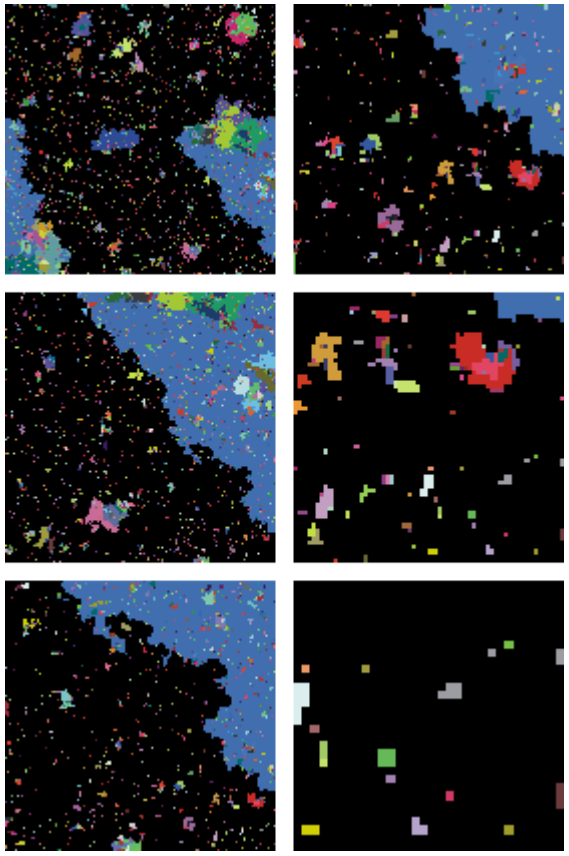
Martensites

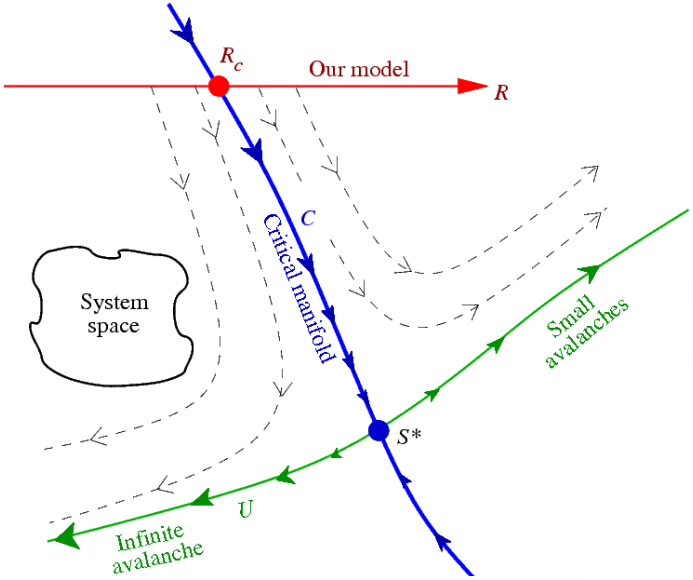
- Non-convexity
- Microstructure

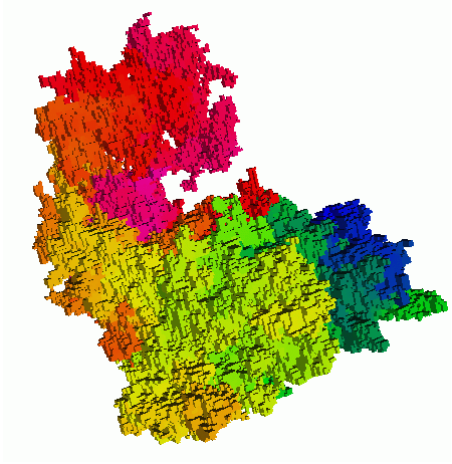
Complexity, scaling

and the Renormalization Group

Scale invariance

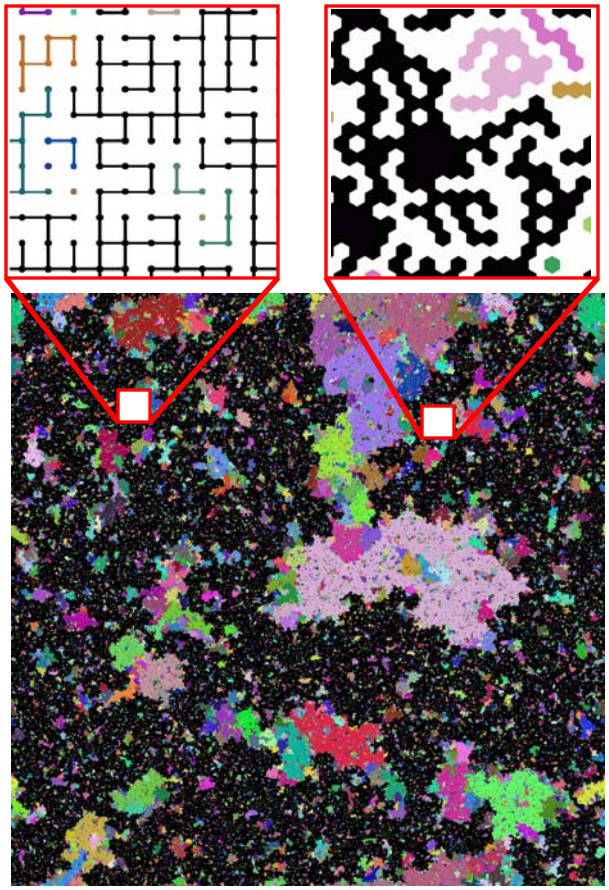






Fractal Structures

Universality



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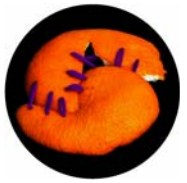

Incorporating the last 50 years into the statistical mechanics curriculum

Statistical mechanics is important to students and researchers in mathematics, biology, engineering, computer science and the social sciences. It will be taught in all of these fields of science in the next generation, either in physics departments or piecemeal in each field. By teaching statistical mechanics to a variety of fields, we enrich the subject for those with backgrounds in physics.