What affects the order observed in physical systems?

Second Law of Thermodynamics

The maximum entropy principle: For a closed system with fixed internal energy (i.e., an isolated system), the **entropy** is maximised at equilibrium.

The minimum energy principle: For a closed system with fixed entropy, the total energy is minimized at equilibrium.

Nature is irreversible.

Who is Belousov?
- 1893 – 1970
- 1951: Discovered an oscillating chemical reaction
  - Over 6 years, editors rejected his work as “impossible”
  - Published in an obscure, non-reviewed journal
  - Quit science

Who is Zhabotinsky?
- 1960’s: Rediscovered Belousov’s reaction sequence
- Graduate student of Moscow State University
- Careful experiments persuaded others that it was real
- 1980: Belousov & Zhabotinsky awarded the Lenin prize for BZ reaction

Belousov-Zhabotinsky Reaction

Body Art
Who’s Fibonacci?

• Leonardo of Pisa (c. 1170 – c. 1250)
• His father was nicknamed Bonaccio – “good natured” or “simple”
• Leonardo nicknamed Fibonacci – “son of Bonaccio”
• 1202: Introduced a sequence of numbers to Western Europe in the book Liber Abaci
• Fibonacci sequence actually described in Indian mathematics
• Golden ratio – approximately 1 : 1.618 or 0.618 : 1

Why is the Fibonacci Sequence Interesting?

Logarithmic Spiral
Phyllotaxis
Petal Number

Golden Ratio 1 : 1.618 or 0.618 : 1

Bubbles
Who’s Per Bak?

- Born in Brønderslev, Denmark (1948)
- Worked at Brookhaven National Laboratory: Upton, NY
- 1987: ‘Self-Organized Criticality’
- “He was the most American of Danes. Danes eschew confrontation, but he was arrogant and loved to fight with his colleagues in academia. We all have stories of how we first met him, usually remembered by some outrageous statement or insult.” - Predrag Cvitanović

“Perhaps I’m the only crazy person in here, but I understand zero - I mean ZERO - of what you said!”

“Excuse me, but what is actually non-trivial about what you did?”

Can we apply principles of self-organization in physical systems to biological groups?

- Traffic
- Spatial arrangement of individuals in the group

Can we apply 1/f noise in biological systems?

- Forest Fires
- Network theory

Self-Organized Criticality

Large interactive systems naturally evolve toward a critical state in which a minor event can lead to a catastrophe. Self-organized criticality may explain the dynamics of earthquakes, economic markets and ecosystems.

by Per Bak and Kan Chen

AVALANCHE DYNAMICS may be explained by the theory of self-organized criticality, which states that some self-similar events create statistically critical events in a critical way in which rare events cause significant changes of small sizes. If the theory holds true, then one may begin to understand the dynamics of catastrophes.

Bak & Chen 1991

The 5 Major Transitions in Evolution

1. The origin of chromosomes
2. The origin of eukaryotes
3. The origin of sex
4. The origin of multicellularity
5. The origin of social groups

Maynard Smith & Szathmáry 1995