



## Self-organization in Physical Systems

Jennifer Jandt  
Complex Systems  
April 9<sup>th</sup>, 2008




## Self-Organization in Biological Systems



Camazine et al. 2001

## What affects the order observed in physical systems?

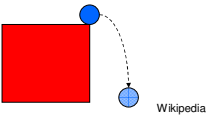


## Second Law of Thermodynamics

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.



Wikipedia

## Belousov-Zhabotinsky Reaction




- 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 Reaction1](#) [Belousov-Zhabotinsky Reaction2](#)

Ball 1999


## Body Art



Ball 1999

1  
1  
2  
3  
5  
8  
13  
21  
34  
55  
89  
144

## 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

Wikipedia


1 1 2 3 5 8 13 21 34 55 89 144...

## Why is the Fibonacci Sequence Interesting?


Logarithmic Spiral



Phyllotaxis





Petal Number



*Golden Ratio 1 : 1.618 or 0.618 : 1*


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## Bubbles

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## Bubbles








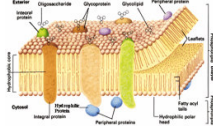

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## Bubbles

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## Bubbles

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## Sand Ripples

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## 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

Wikipedia

## 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

Bak & Chen 1991

AVALANCHE DYNAMICS may be explained by the theory of self-organized criticality, which states that snow piles and other large complex systems naturally evolve to a critical state in which minor events can cause chain reactions of many sizes. If the theory proves correct, analysts may improve predictions of catastrophes.

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

[www.scottcamazine.com](http://www.scottcamazine.com)

## 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