Understanding complex dynamic systems

Dr Michael Lim

Consultant Anaesthetist

Cardiff and Vale UHB

Aims

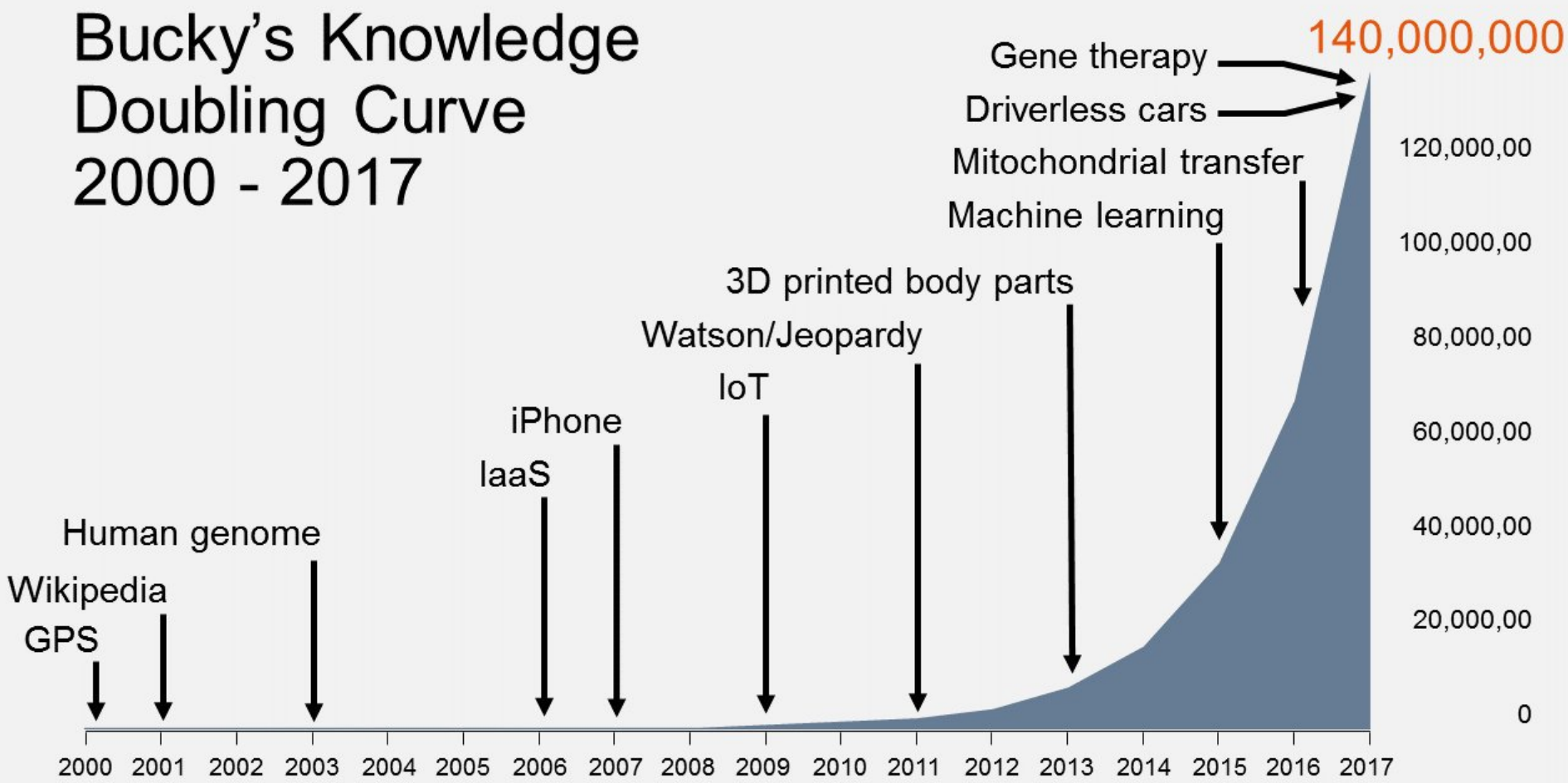
- Show how our understanding of the world is expanding
- Explain the different characteristics of dynamical systems
- Show how these characteristics help our understanding of real-life medical and health-care patterns

The pendulum swings

Traditional science

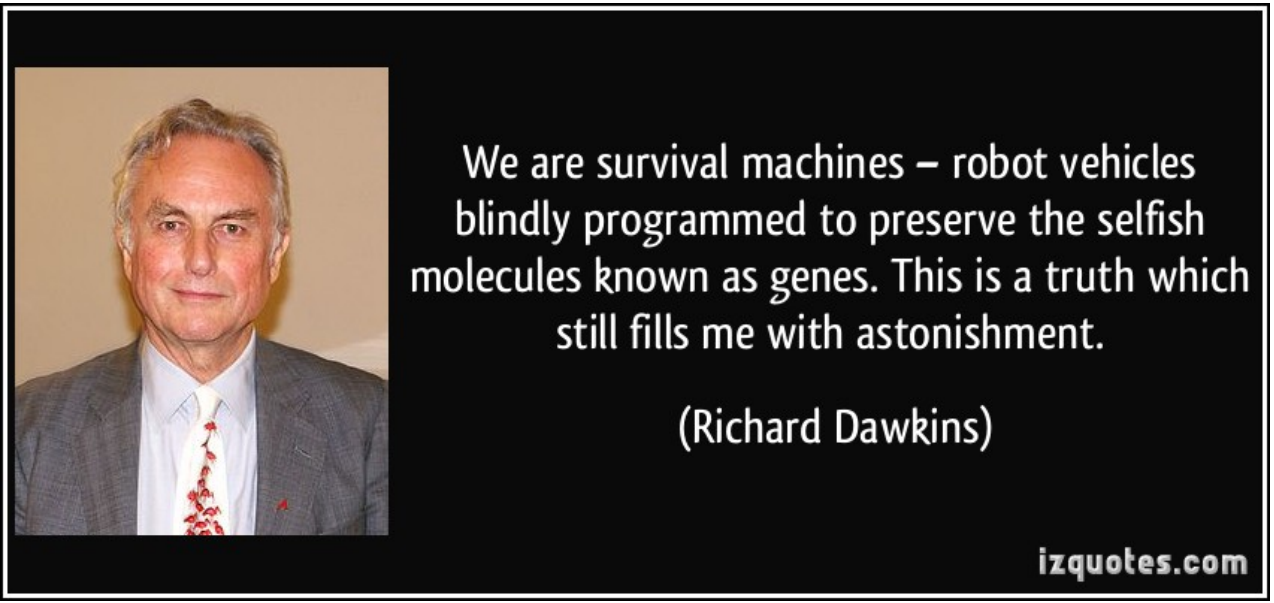
- Reduction
  - Rene Descartes (1596 – 1650)

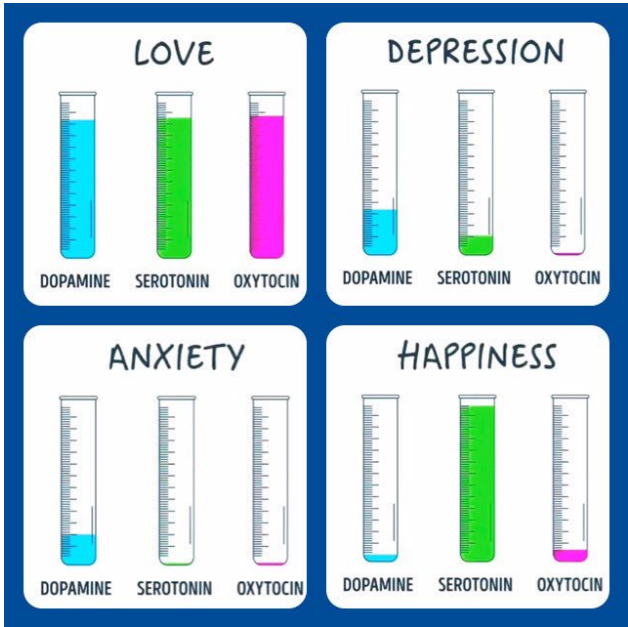
Worked really well!



Gone overboard?

- "… just as the classical field theory world of physics was overshadowed in the early 20th century by quantum theory and particle physics, the integrative systems-level physiology of the first half of the 20th century gave way to the reductionist molecular biology of the second half." [Hunter and Nielsen 2005]





Non-linearity

- "… the fraction of differential equations that can be solved exactly with a sane amount of effort is quite small ... once we stray too far from linearity ..." [Gershenfeld]

Emergent phenomena

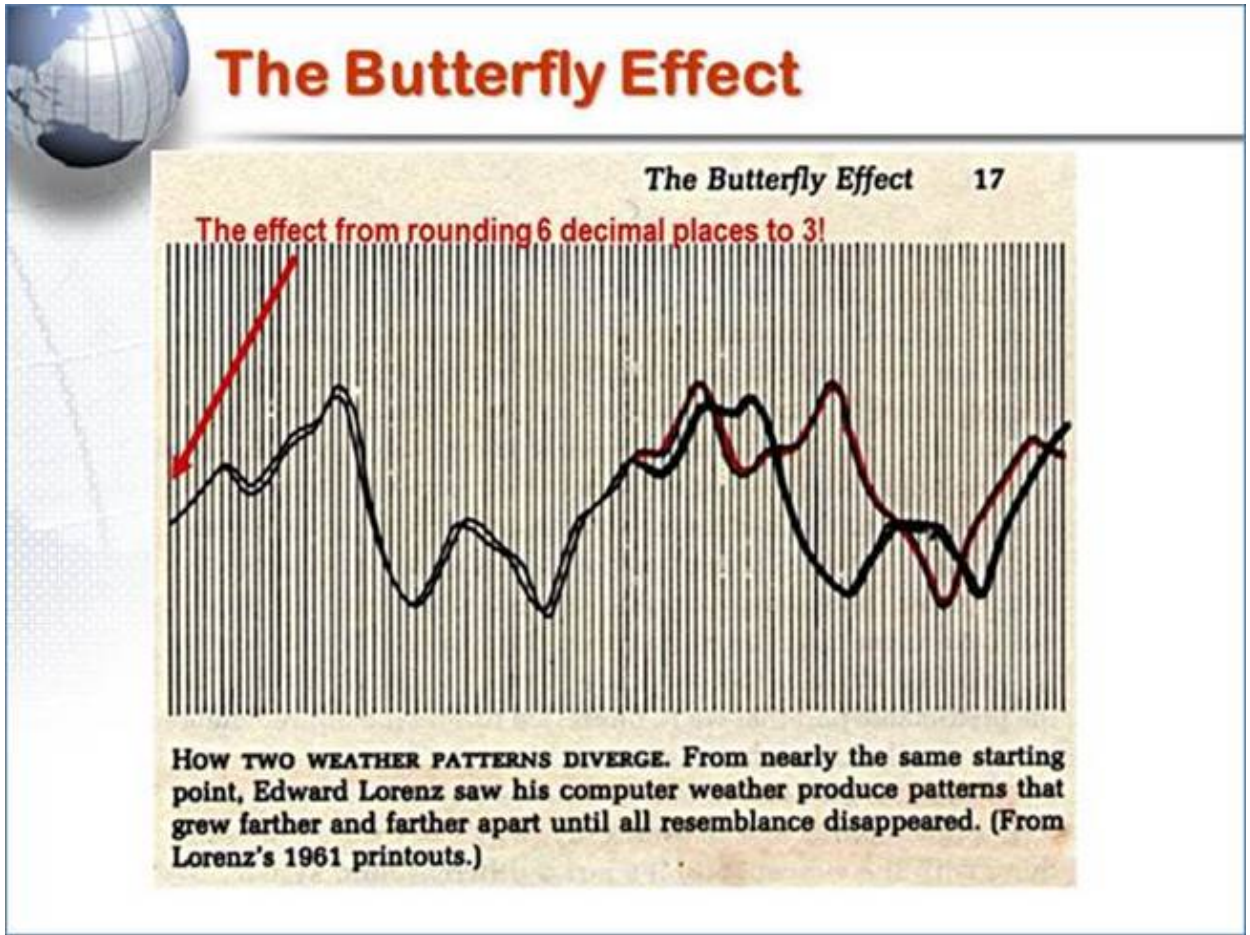
- "... unexpected behavioral properties of [complex] systems … cannot be predicted from the behavioral characteristics of individual system components" [Kannampallil et al]
- "The ability to reduce everything to simple fundamental laws does not imply the ability to start from those laws and reconstruct the universe ... At each level of complexity entirely new properties appear. Psychology is not applied biology, nor is biology applied chemistry. We can now see that the whole becomes not merely **more**, but very **different** from the sum of its parts." [Anderson]

Dynamical systems

Definition: Models describing the time dependence of a point in geometric space

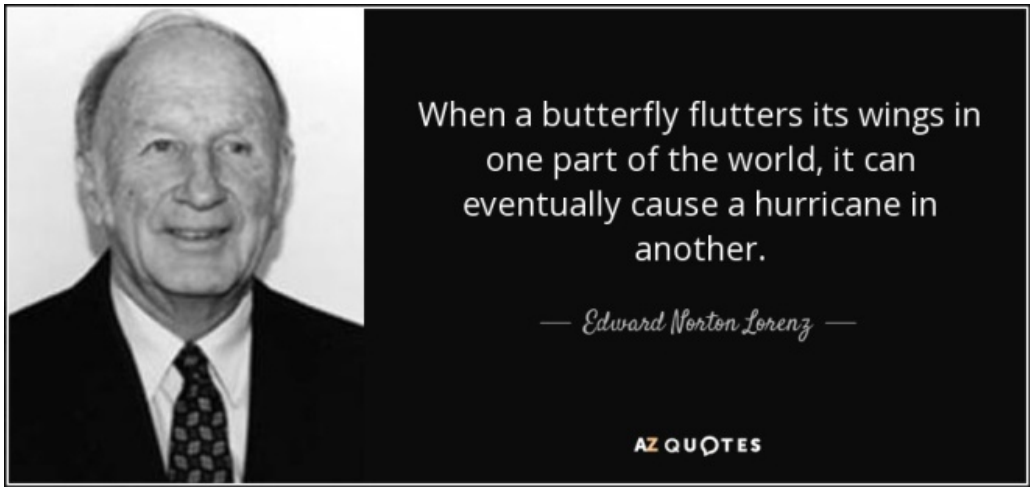
Chaos

- Edward Lorenz meterological simulation
  - printed *.506127 = *.506



Chaos

- Edward Lorenz meterological simulation
  - printed *.506127 = *.506
- Extreme sensitivity to initial conditions
  - Full name = Non-linear deterministic ***chaos***
  - Deterministic not unpredictable
  - Predictable therefore not emergent
  - But so sensitive to initial conditions as to be like chaos

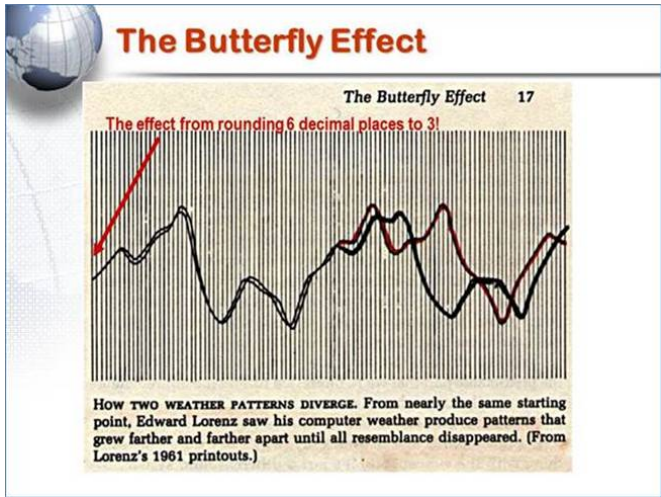


Chaos

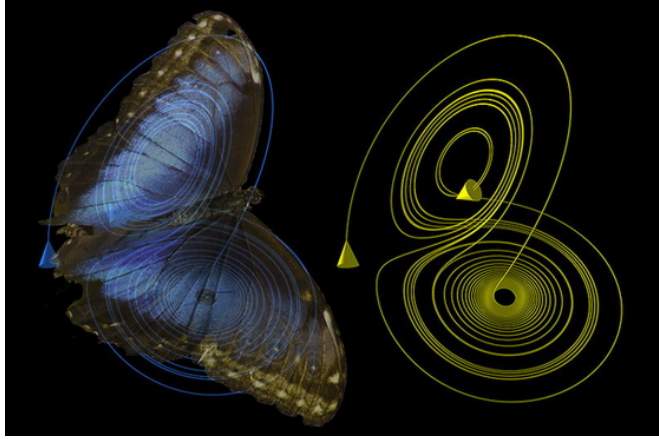
- Edward Lorenz meterological simulation
  - printed *.506127 = *.506
- Extreme sensitivity to initial conditions
  - Full name = Non-linear deterministic ***chaos***
  - Deterministic not unpredictable
  - Predictable therefore not emergent
  - But so sensitive to initial conditions as to be like chaos
- Not a new phenomenon
  - Henri Poincare's three body problem (1887)
  - Pendulum motion

How does Chaos affect us?

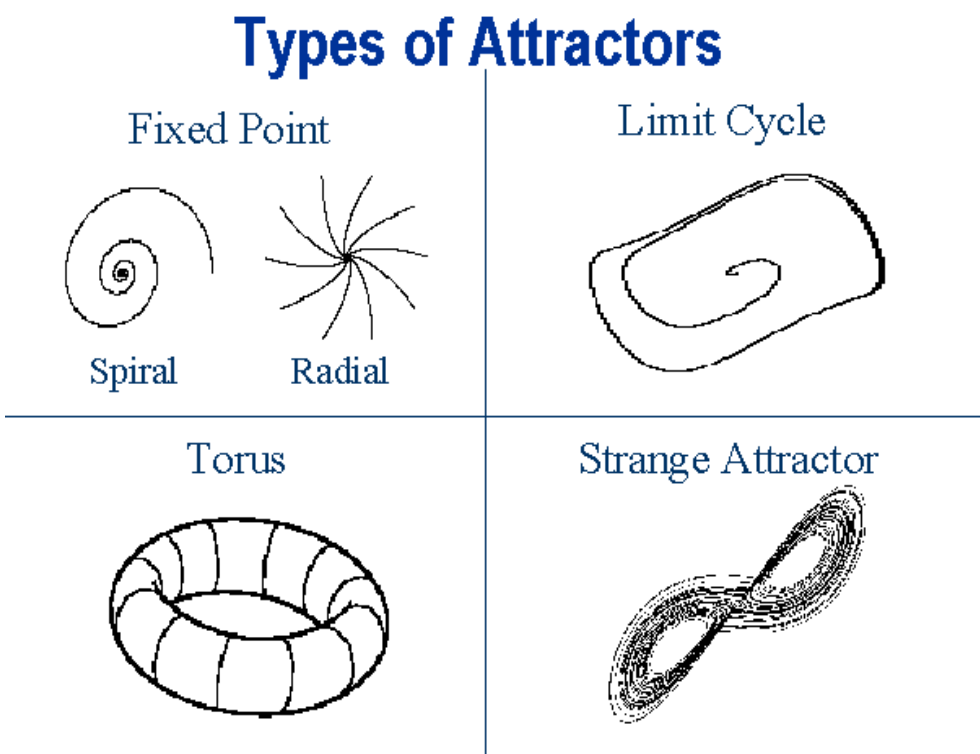
- Excitable tissues
  - ECG variability correlates with autonomic health
  - BIS EEG variability correlates with consciousness
- Physical features
  - Variability erodes with disease progression – diagnosis!
- Similar trajectories early on before spiralling
  - Sepsis, public health?



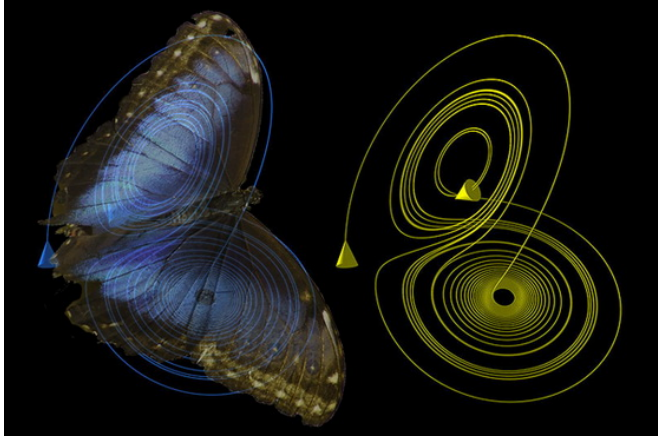
Attractors



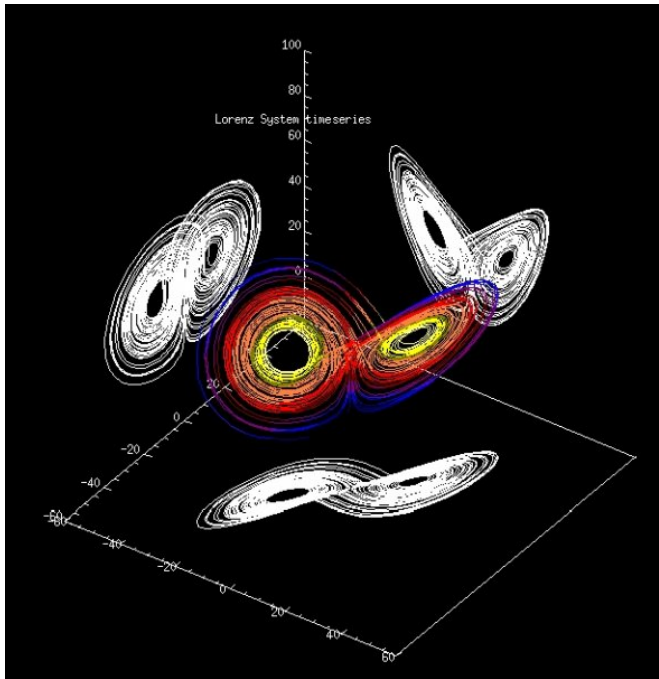
- Hurricane butterfly
- Lorenz attractor
  - Graphical representation of dynamic stability
- Attractors
  - Simple geometries



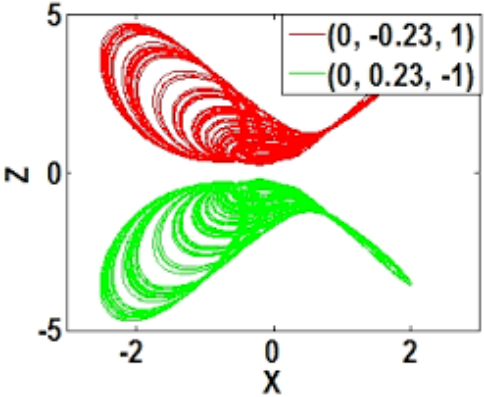
Attractors



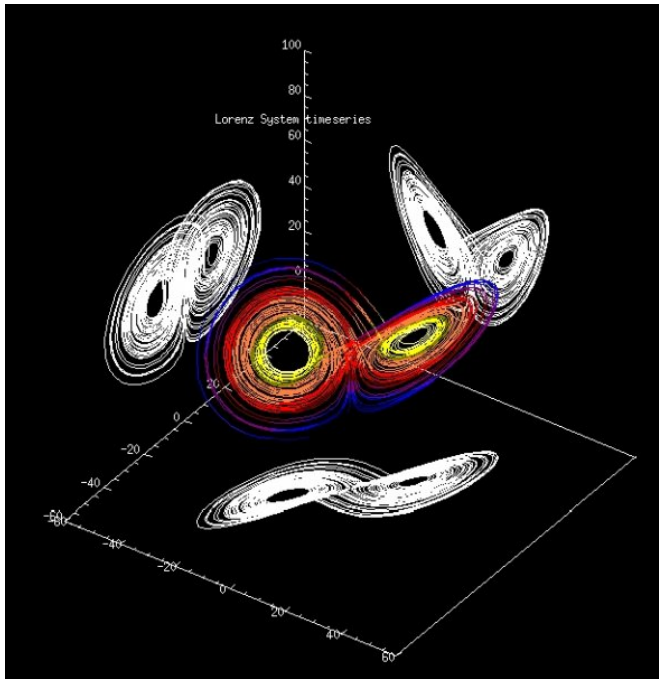
- Hurricane butterfly
- Lorenz attractor
  - Graphical representation of dynamic stability
- Attractors
  - Simple geometries
  - Chaotic strange attractors
    - Never traces the same path
    - Never settles into equilibrium
    - Fractal!



Attractors

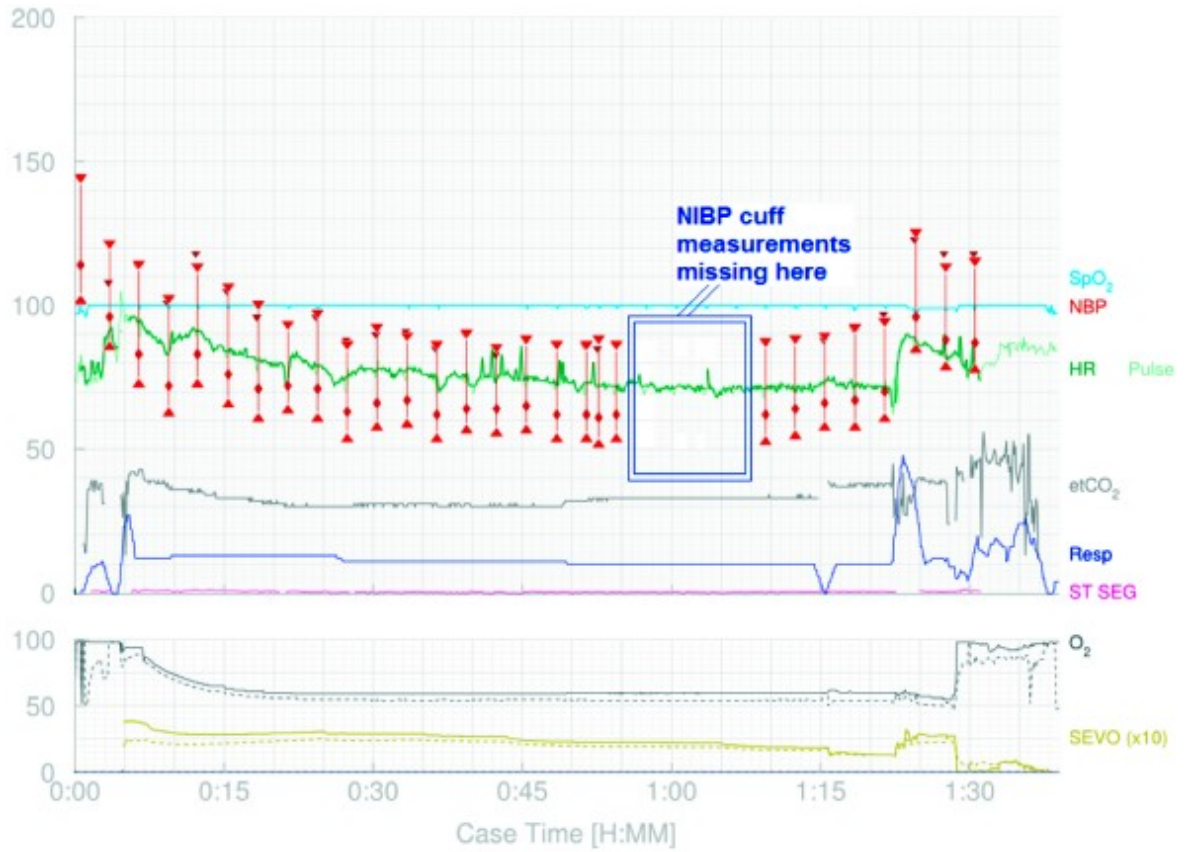


- Hurricane butterfly
- Lorenz attractor
  - Graphical representation of dynamic stability
- Attractors
  - Simple geometries
  - Chaotic strange attractors
    - Never traces the same path
    - Never settles into equilibrium
    - Fractal!
  - Deterministic never intersects



How do attractors affect us?

- Dynamic stability is all around us
  - BW set points
  - BP

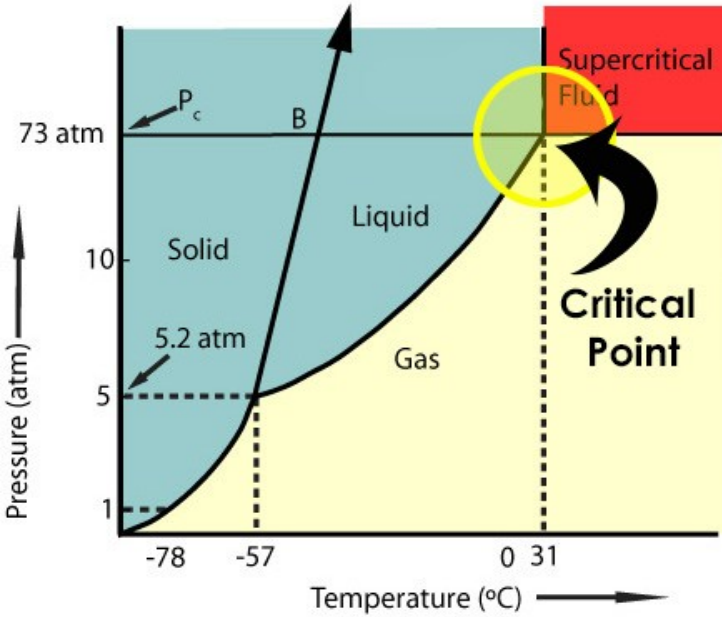


How do attractors affect us?

- Dynamic stability is all around us
  - BW set points
  - BP
- Move from one attractor to the next
  - Need significant perturbation
    - Personal emotional incidents
  - Smarter therapeutics if we understand physiological attractors
    - BP
    - AF

Criticality

- Critical point
  - Across scales
  - Boundaries are removed (usually)
    - Local/global, solid/liquid/gas
- Self-organised criticality
  - Critical point as attractor

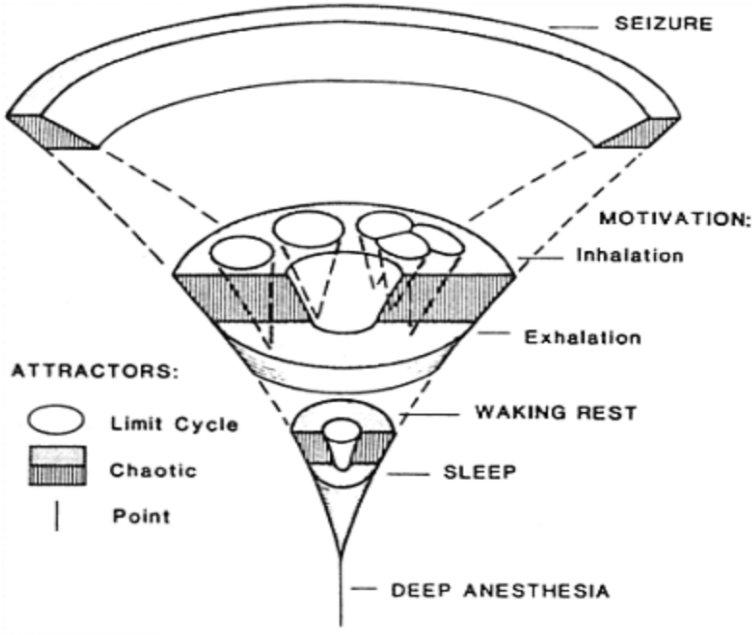


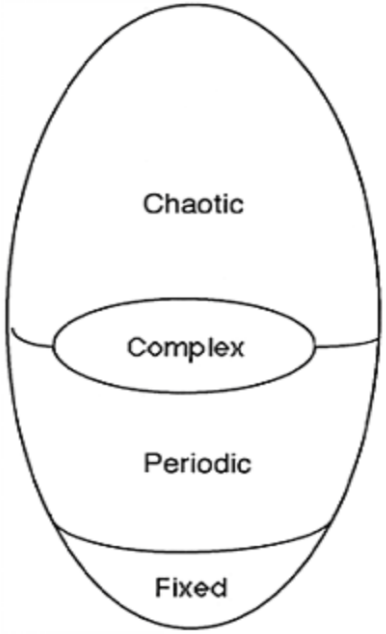
How does Criticality affect us?

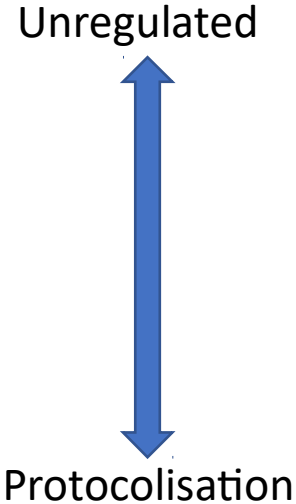
- Avalanching behaviour
  - Epilepsy
  - Morale
  - Critical incidents
- Adaptive
  - Non-arithmetic response, resistance to change
  - Quick low-cost fixes uncommon
- Communication
  - Flat hierarchy
  - Role for physical scientists

Complexity

- Greek “complexus” = Intertwined
- Not well defined: + many heterogenous
- Edge of chaos: between order and disorder







Chaos versus complexity

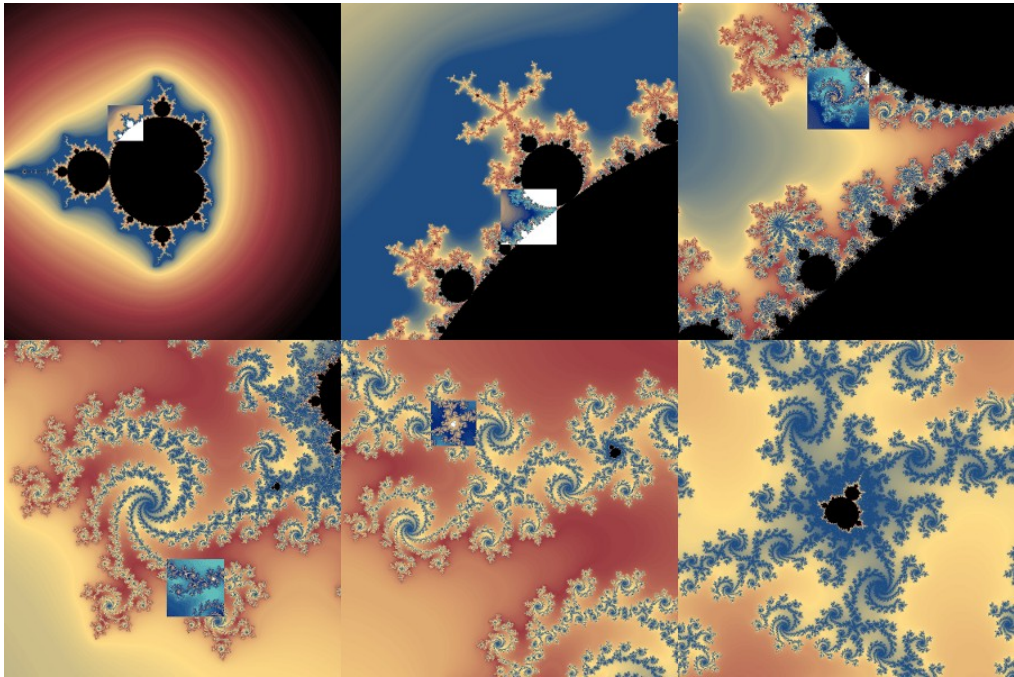
	Chaos	Complexity
Nature	Deterministic	Probabilistic
Evolution	Predictable	Emergent
Trajectory	Cannot intersect	Can merge and intersect
Initial conditions	Extreme sensitivity	Adapts therefore robust
Feedback	Local	Across scales (criticality)
Attractors	Exclusive and strange	Inclusive and multiple
Method of study	Reduction to basic laws	Non-fragmentable

How does Complexity affect us?

- Emergent
  - Unintended consequences
- Unexpected behaviours
  - Development of allergies?
- Robustness
  - Protocolisation of care is not optimal global strategy

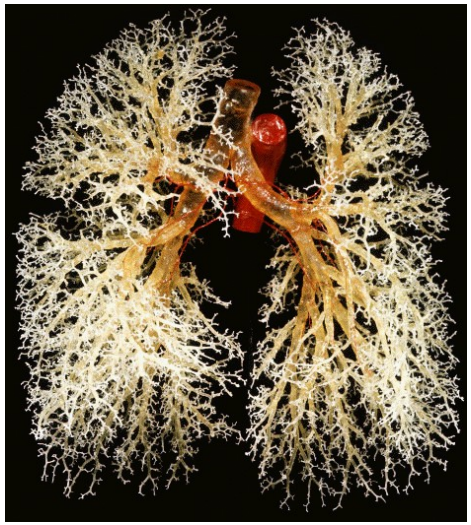
Fractals = “fractional dimension”

- Generated from a recursive equation or algorithm
  - Self-similar on zooming
  - Equally detailed
  - Length increases
    - Not Euclidean
    - D = log(N) / log(1/a)



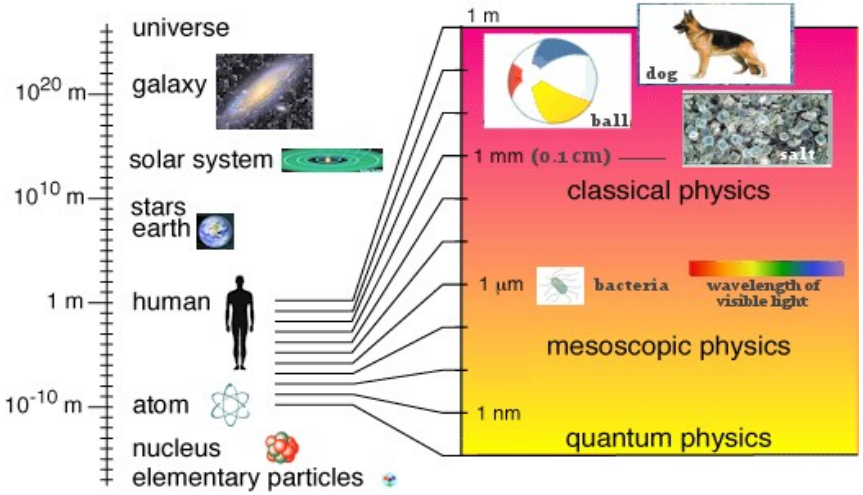
BIGGER ON THE INSIDE

How do fractals affect us?



In the second half of the 20th century, developments in mathematical modeling were limited to basic paradigms, such as flow in morphologically simple regions (e.g., Poiseuille or Womersley solutions), or to models based on electric network analogies. Exact solutions are very difficult to obtain in more general situations, because of the strong nonlinear interactions among different parts of the system and the geometric complexities of individual vascular morphologies. [Quarteroni]

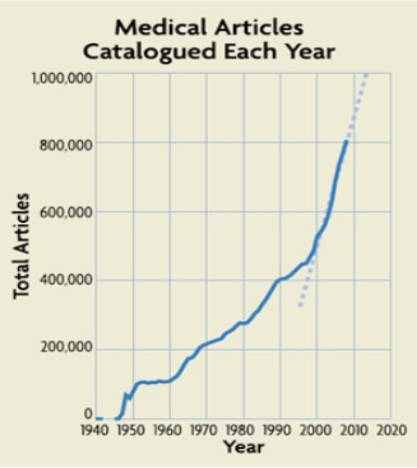
How do fractals affect us?



> I believe that scientific knowledge has fractal properties; that no matter how much we learn; whatever is left, however small it may seem, is just as infinitely complex as the whole was to start with. That, I think, is the secret of the Universe.

~Isaac Asimov, *I, Asimov: A Memoir*

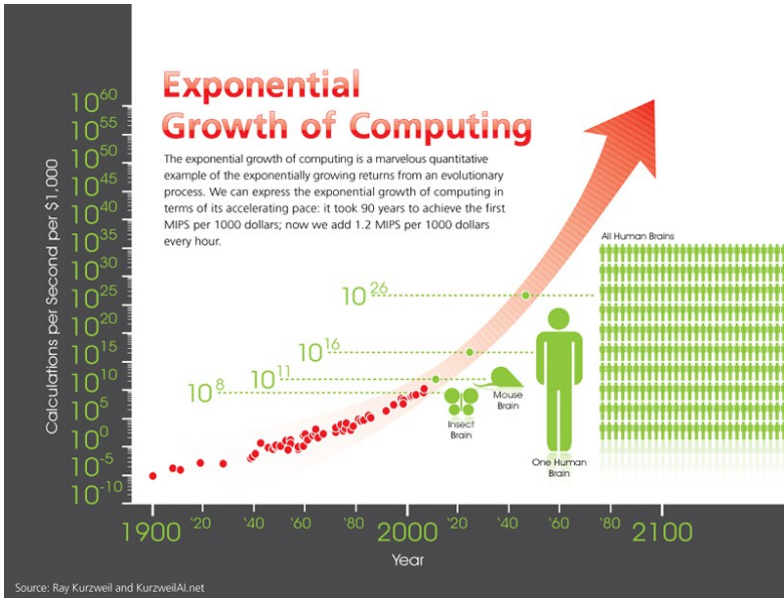
Growth of Medical Knowledge

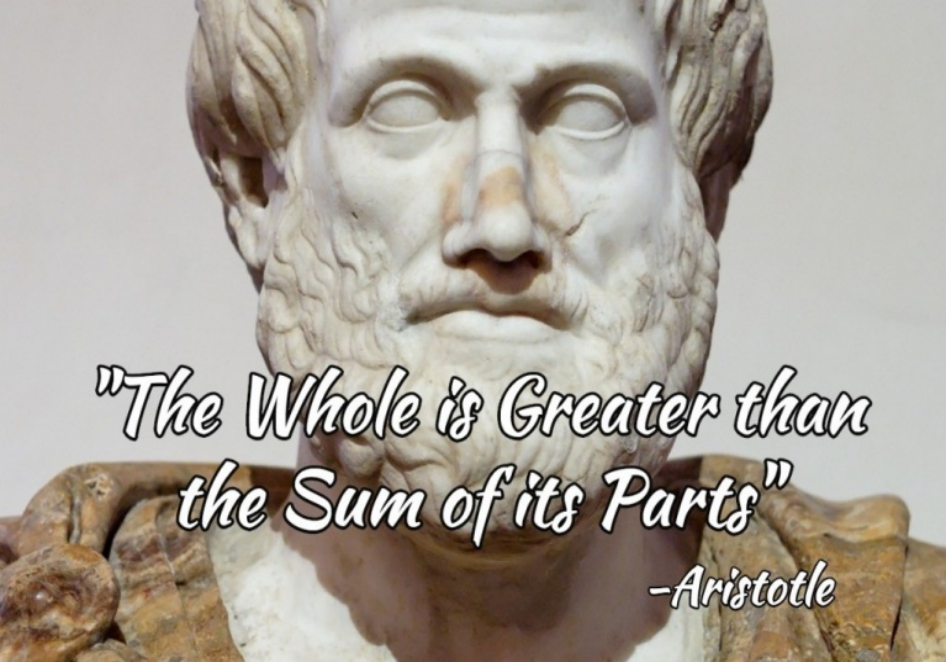


1 million articles per year expected in 2012

Medical specialists would need 21 hours of reading a day to stay current

Gillam M et al
http://research.microsoft.com/en-us/collaboration/fourthparadigm/4th_paradigm_book_part2_gillam.pdf





Conclusion

Thank you!

Questions?