Modelling Complex Systems and Guided Self-Organisation

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The Fool's Cap Map of the World, 16th century

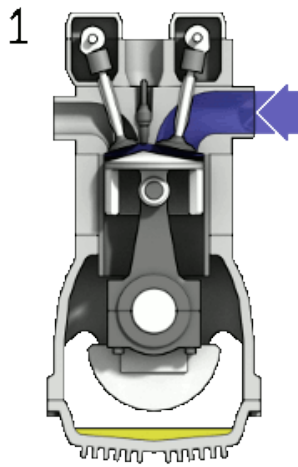
...one of the big mysteries in the history of cartography (1580 – 1590)

It is unknown why, when and by whom the map was made, but it is thought to be a kind of social criticism of its time...

Interdependent challenges

- Demographic & social
  - overpopulation & ageing population
  - epidemics and pandemics
  - surge in irregular migration
- Technological
  - infrastructure degradation
  - cascading power failures
  - transport and supply chain disruptions
- Environmental
  - climate change
  - natural disasters
  - animal & plant diseases

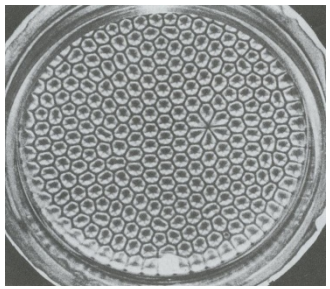
Complex (“weave”) vs Complicated (“fold”)

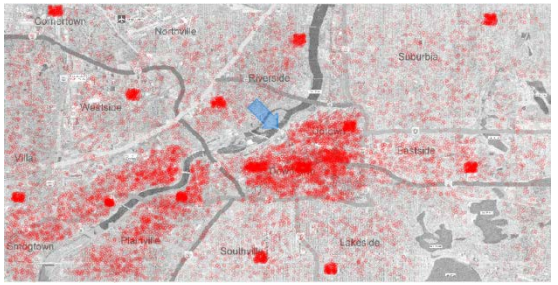
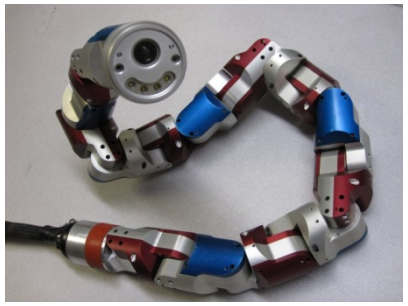


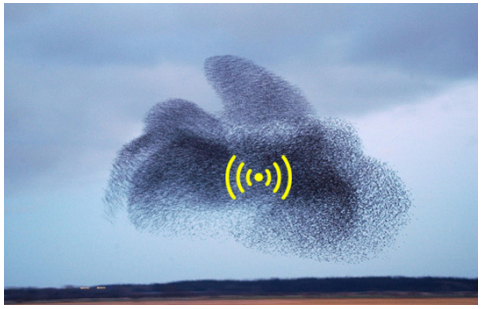
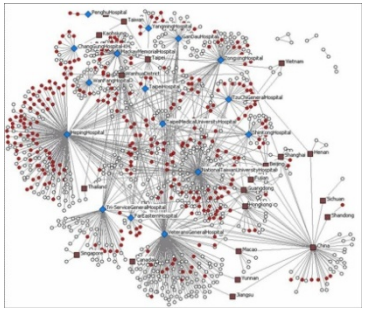
- Complex system
- Evolved adaptive response
- Emergent non-deterministic patterns
- Self-organisation: hard to predict
- Resilient to perturbations
- Interdependent networks
- Deals with information

- Complicated system
- Designed for performance
- Predictable deterministic regimes
- Blueprint: verification and testing
- Brittle to malfunctions
- Centralised management
- Deals with data

Self-organisation: a pervasive phenomenon



- . . . a set of dynamical mechanisms whereby structures appear at the global level of a system from interactions among its lower-level components
- The rules specifying the interactions among the system's constituent units are executed on the basis of purely local information, without reference to the global pattern, which is an emergent property of the system rather than a property imposed upon the system by an external ordering influence

  [Bonabeau et al., 1997]

Self-organisation

Examples of self-organisation in complex systems

- physics: avalanches
- technology: power grids
- techno-social: traffic
- eco-social: epidemics
- biology: animals groups (flocks, swarms, schools of fish)

https://www.youtube.com/watch?v=99j17GL3qlE

Lessons

- Microscopic particles ⟶ macroscopic effect
- Sensitivity to initial conditions
- Dynamics self-organise to a critical regime
- Can be triggered “on demand” (controlled release)

Technology

https://www.youtube.com/watch?v=SGWDBsQNilU

Lessons

- Individual nodes ⟶ network effect
- Critical thresholds (tolerance margins)
- Harmful cascades of power failures
- Can be managed (safer margins, islanding)

Social dynamics + technology

https://www.youtube.com/watch?v=O3kL6nMap2s

Lessons

- Individual cars ⟶ traffic patterns
- Critical bottlenecks and capacity thresholds
- Harmful cascades of traffic jams
- Can be managed (larger capacities, re-routing)

Social dynamics + epidemics

https://www.youtube.com/watch?v=XHGLGAcMRu8

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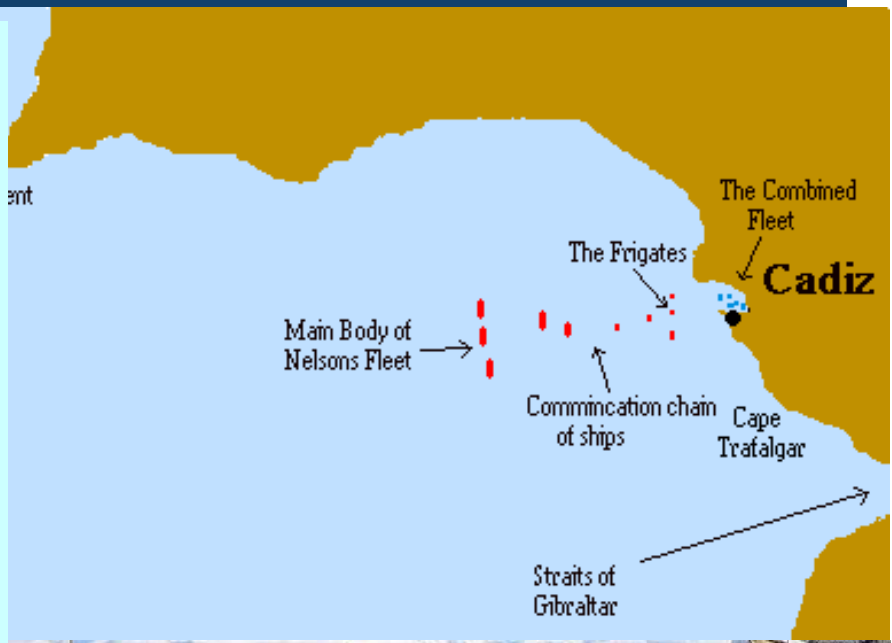
Lessons

- Individual people ⟶ pandemic
- Super-spreaders and critical thresholds (R_0)
- Harmful cascades of infection
- Can be mitigated (prophylaxis, vaccination, quarantine)

Biology

https://www.youtube.com/watch?v=D6HdoIsLMFg

“Trafalgar effect”



Lessons

- Individual animals ⟶ global effect
- Collective behaviour with survival benefits
- Useful cascades of information (“Trafalgar effect”)
- Can be guided (“herding”)

From simple interactions to complex patterns

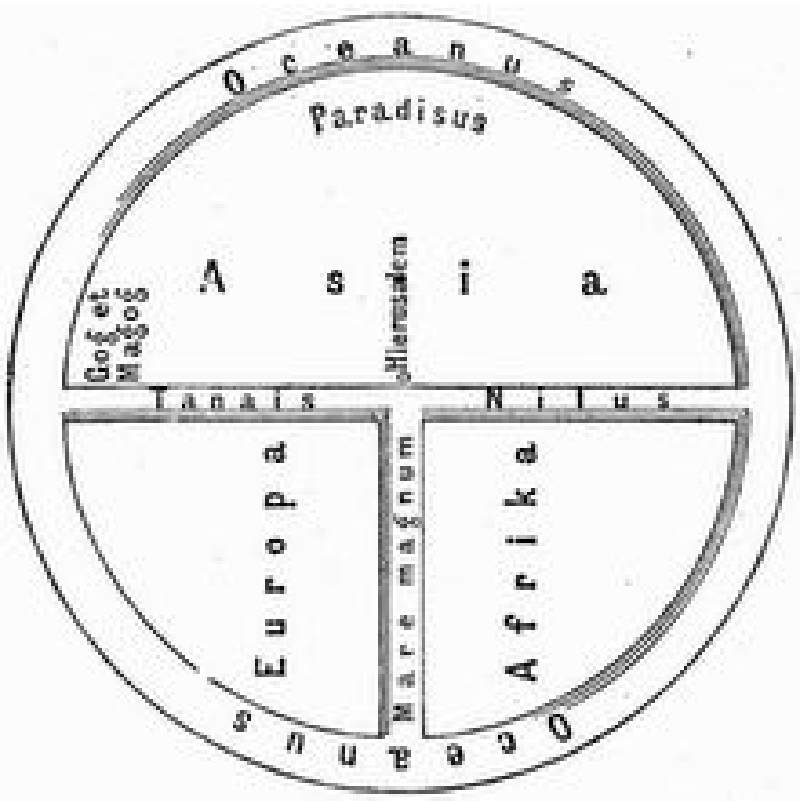
- Agents (particles, fish, cars) are independent but interacting

- As we move from physics to biology to social dynamics:
  - precise nature of the interactions is less defined
  - there are more hidden variables
  - it is harder to influence the desired outcome, to “guide” the system
  - there are fewer theories of the systemic behaviour / risk

- What can we learn from physics and biology?

World map, 8th century

T-O map (*orbis terrae*, orb or circle of the earth; East side is up)



The earliest known representation of T-O maps is attributed to Beatur of Liébana, an 8th century Spanish monk

World map, 12th century (regional connectivity)

al-Idrisi map (North side is up)

World map made by the Arab cartographer and geographer Abu Abd Allah Muhammad al-Idrisi in 1154 at the court of King Roger II of Sicily

World map, 16th century (continental connectivity)

Orbis Typus Universalis (North side is up)

World map created by the German cartographer Martin Waldseemüller in 1506, first published in 1513

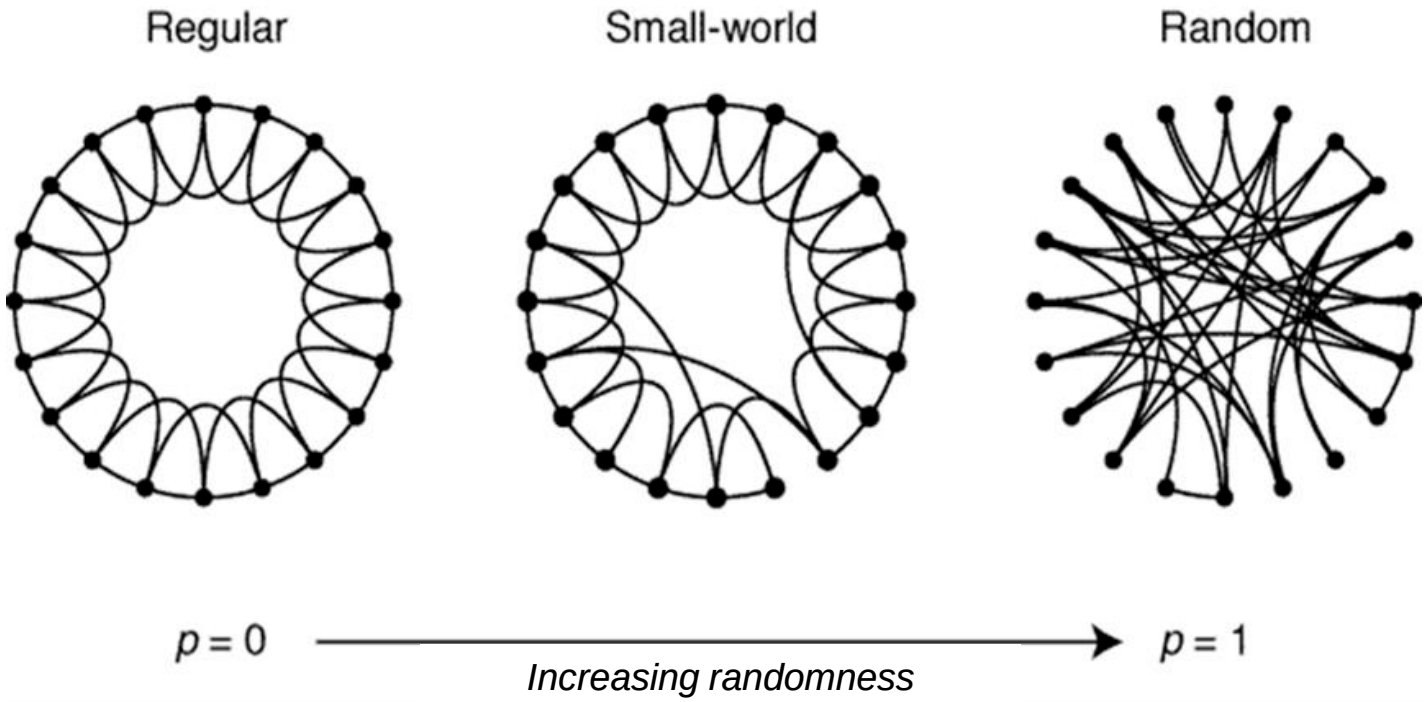
Earth view, 21st century (global connectivity)

Google Earth (28 October 2014; 14:35 Australian Eastern Daylight Time)

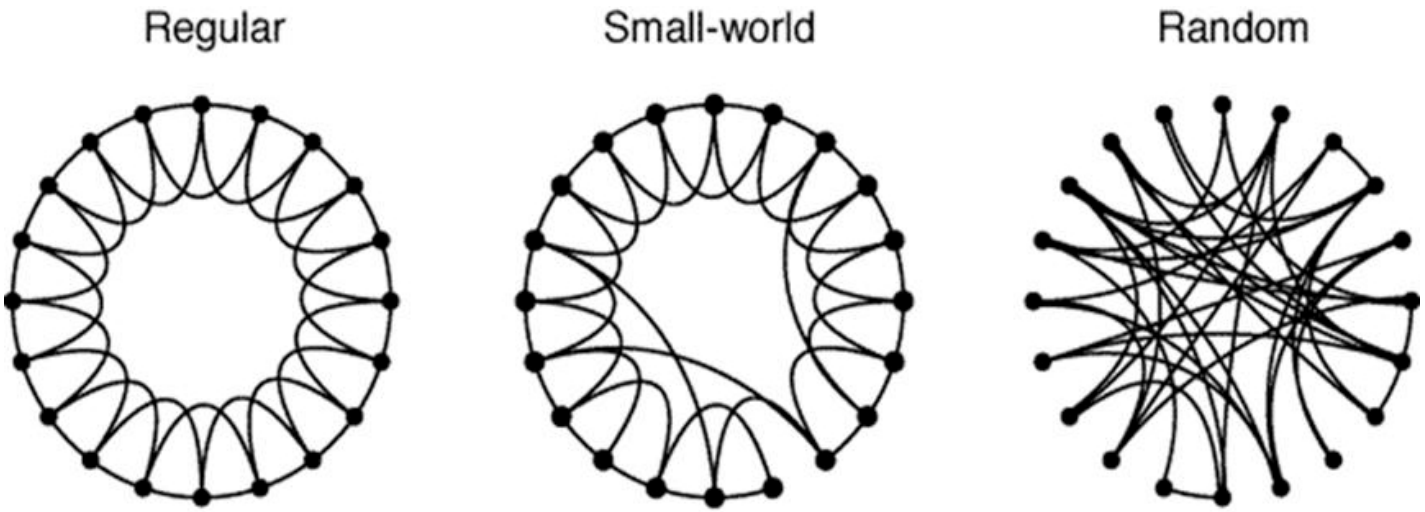
Still a small-world ...860 years ago

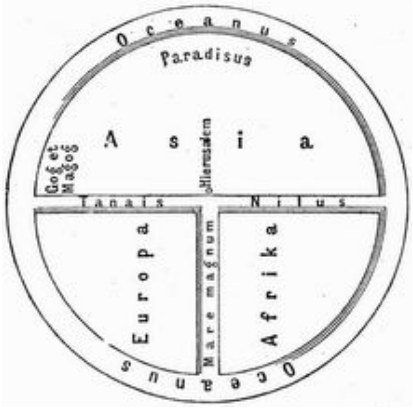
Google Earth (2014) vs al-Idrisi map (1154)

Small Worlds



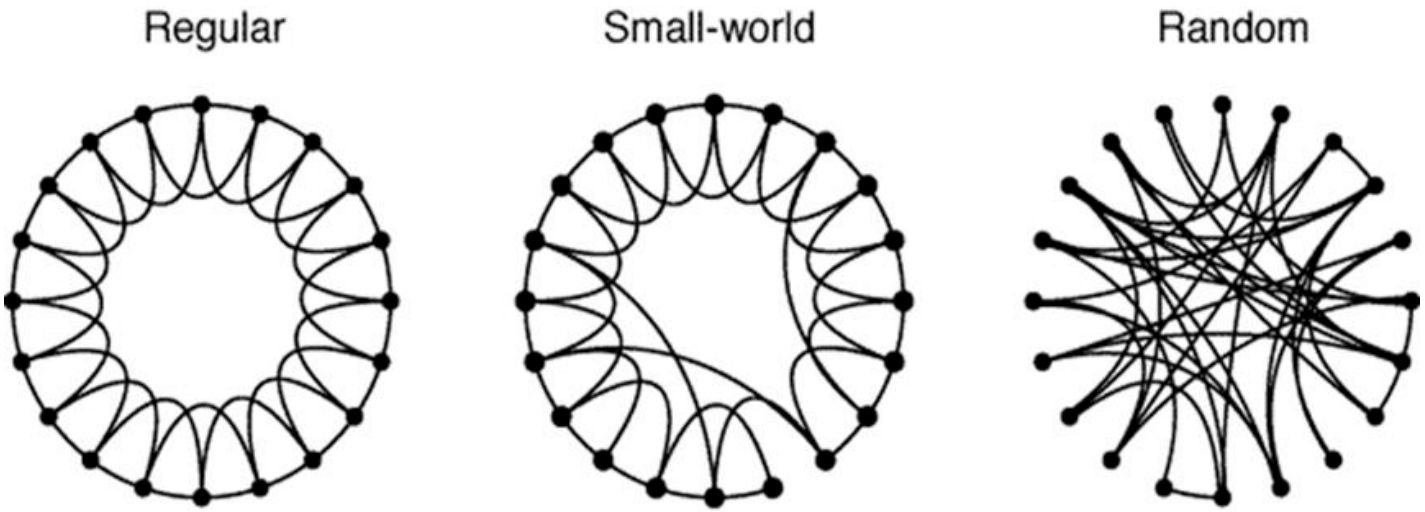
Small Worlds and complex systems

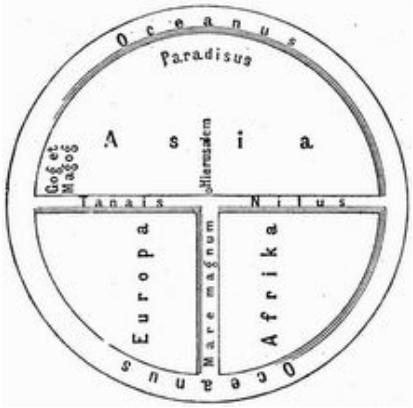




Ordered system

Small Worlds and complex systems

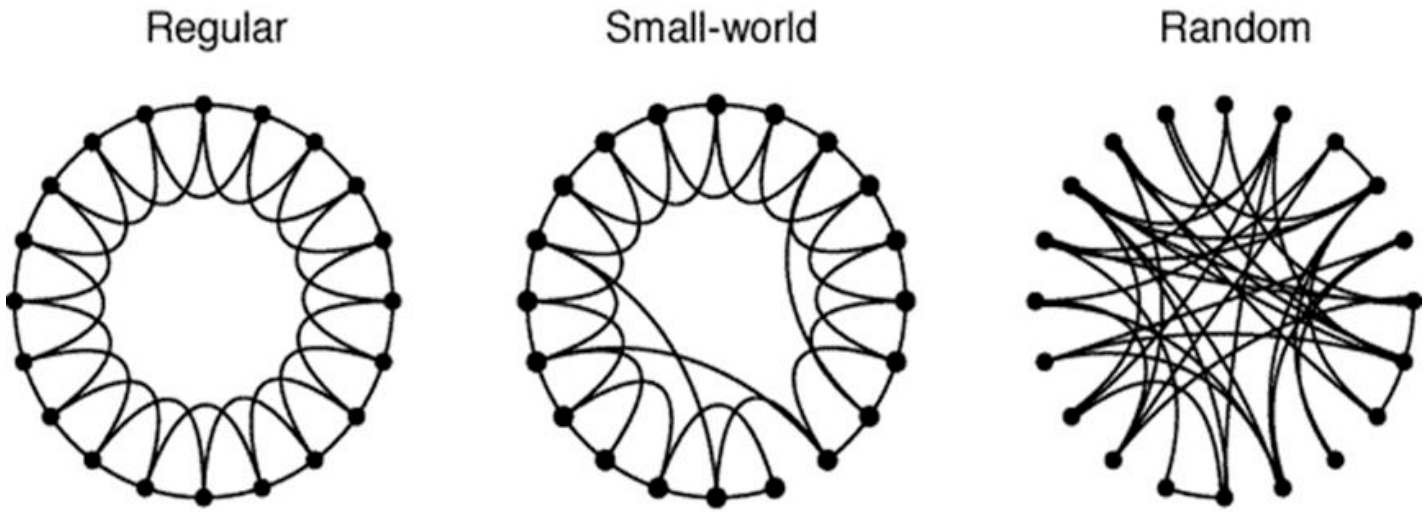




Ordered system

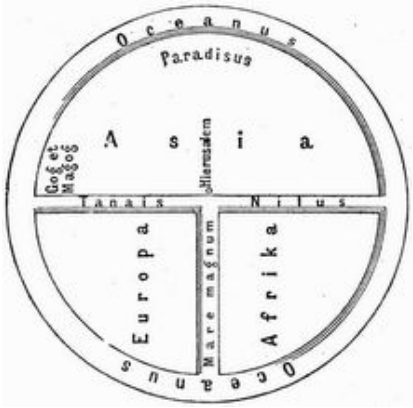
Complex system

Small Worlds and complex systems



$p = 0$ ⟶ $p = 1$

Increasing randomness

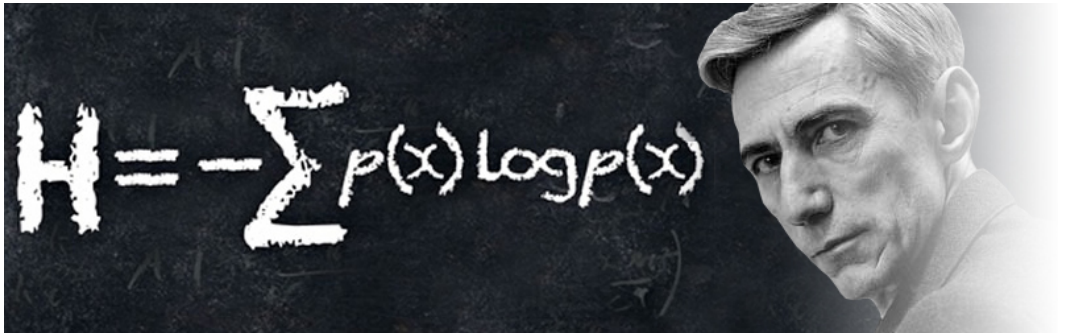


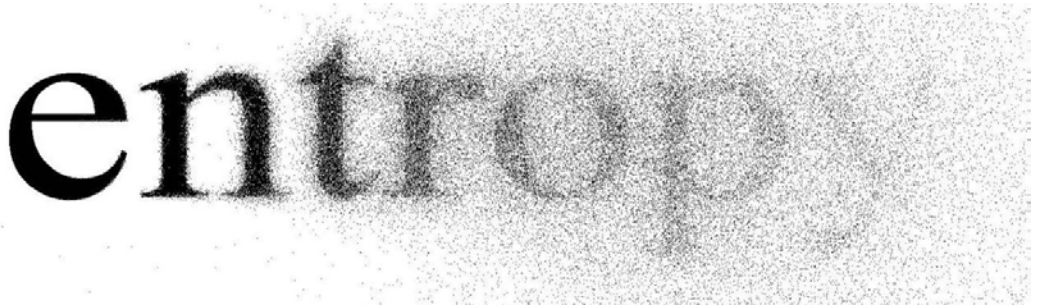
Ordered system

Complex system

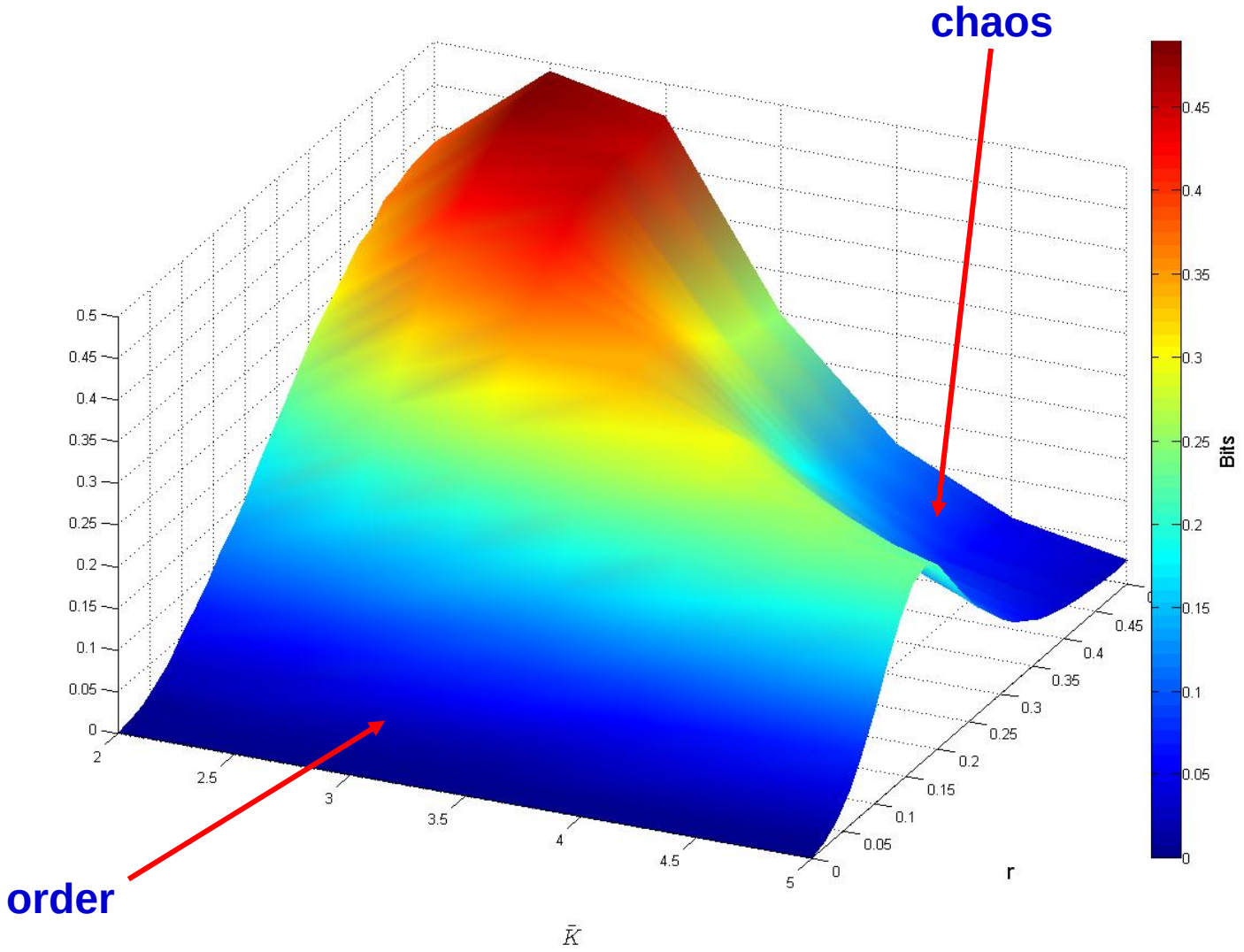
Chaotic system

Information and entropy



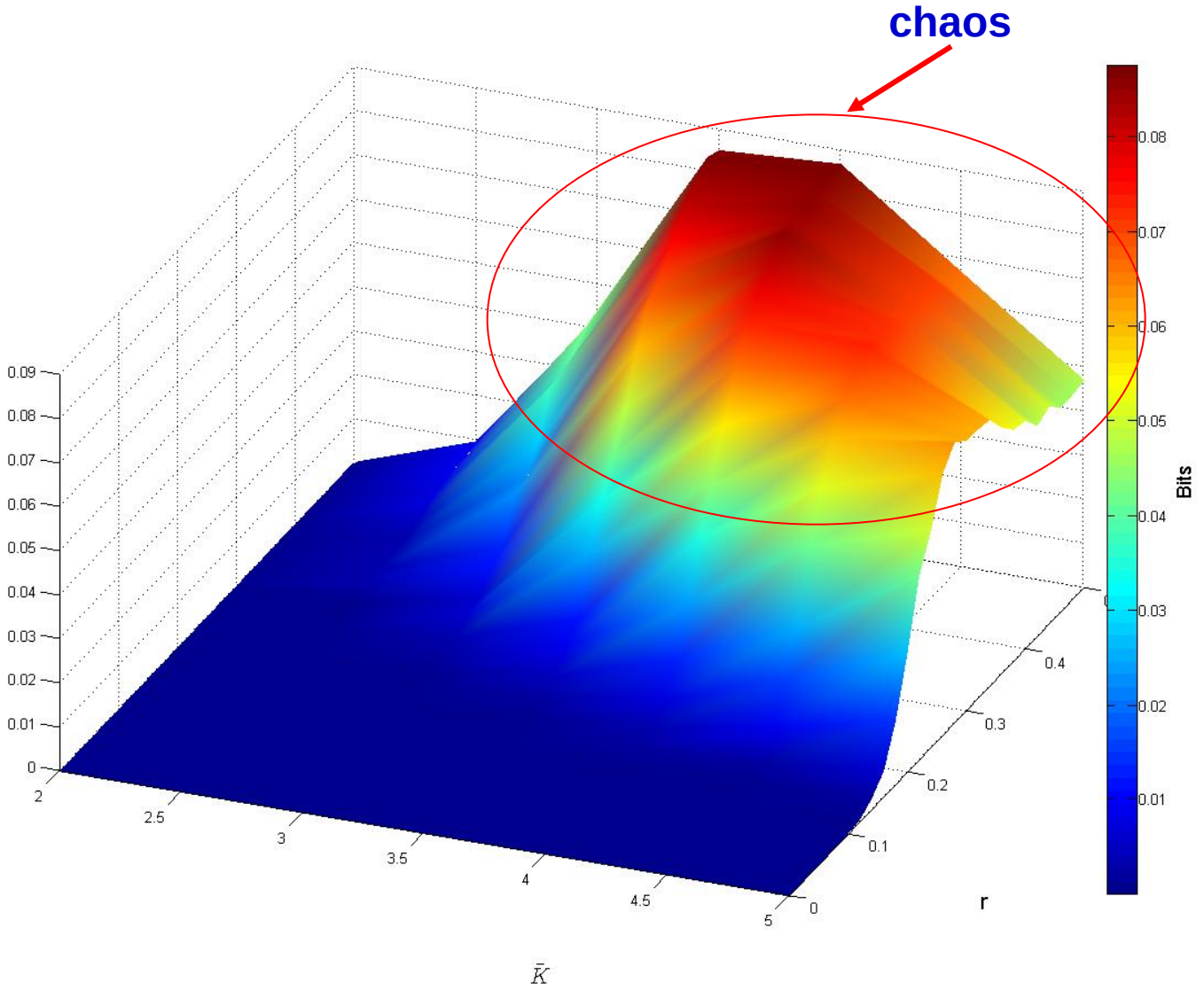


Active information for small-world network



J. T. Lizier, S. Pritam, M. Prokopenko, Information dynamics in small-world Boolean networks, *Artificial Life*, 17(4), 293-314, 2011.

Transfer entropy for small-world network



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Lessons for Guided Self-Organisation

- "social thermodynamics" – interactions in social groups are less predictable, but may produce quantifiable aggregation patterns
  - critical thresholds (critical "temperature")
  - bottlenecks / "hot-spots"
- "collective intelligence" – hidden variables may change quickly, but collective behaviours can adapt to critical situations
  - agent-based simulation
  - optimal information flows
- "guided self-organisation" – the art of guiding collective behaviours towards desired outcomes is becoming a science
  - how to set constraints and network topology?
  - how to define interaction rules?

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The solution is not a formula: it is the mindset!

Master of Complex Systems (MCXS): starting in 2017

Anticipate, Control and Manage Complexity of the Unexpected

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Master of Complex Systems

Anticipate, control and manage the complexity of the unexpected

http://sydney.edu.au/courses/master-of-complex-systems

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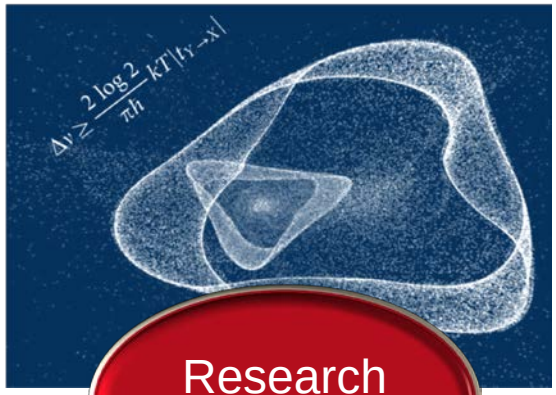
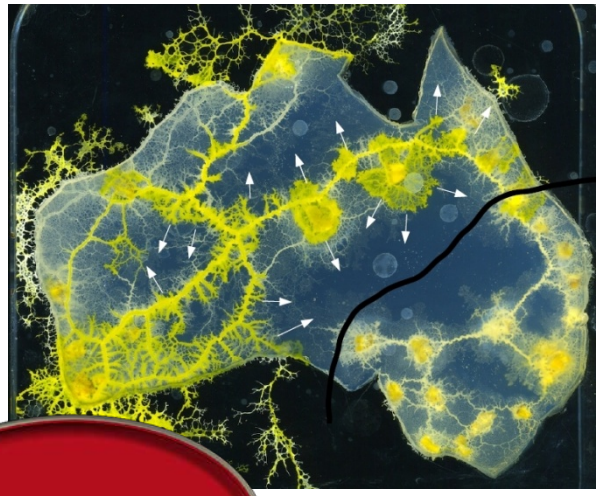




Research methods

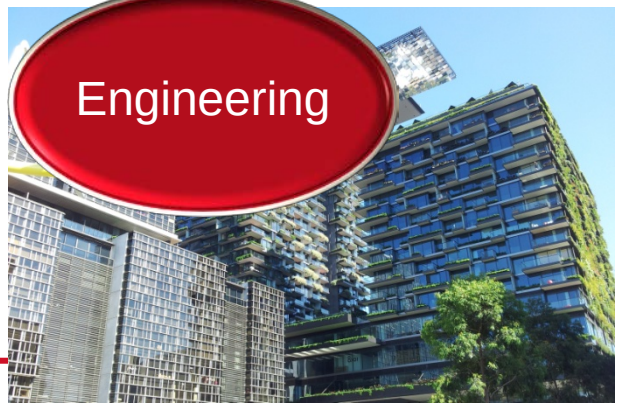
Ecology

Biosecurity

MCXS

Transport

Engineering



bit.ly/MCXS-USYD