

# 01 Introduction to Complex Systems (Part I)

By NTU Complexity Institute



Stephen Hawking  
(1942–)

The 21st century will be the century of complexity.

# Heinz Pagels

(1939–1988)

“The great unexplored frontier is complexity... I am convinced that nations and people that master the new science of complexity will become the economic, cultural, and political superpowers of the next century.”

# Warren Weaver

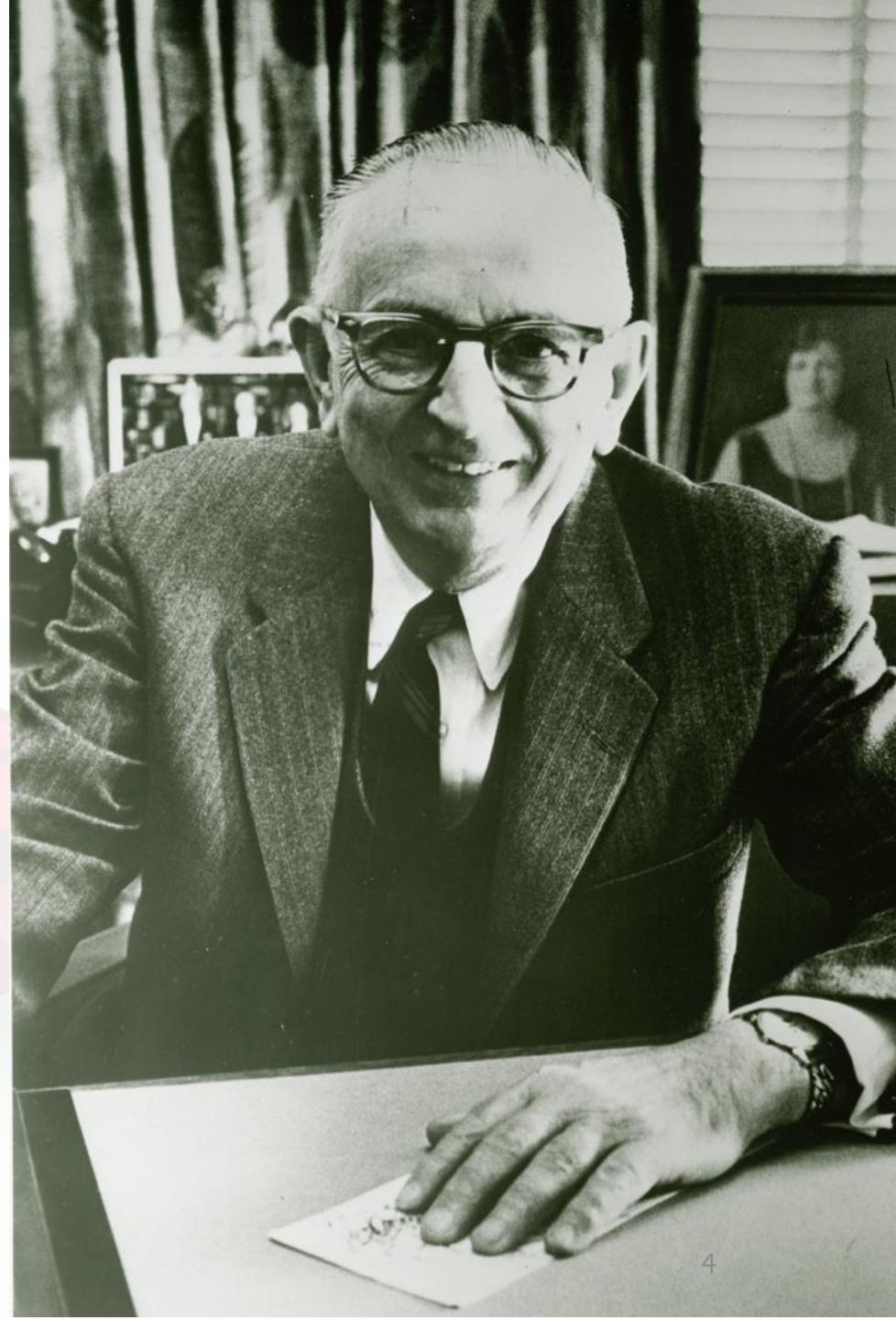
(1894–1978)

## Science and Complexity

*By Warren Weaver  
Rockefeller Foundation, New York City*

"Science and Complexity", American Scientist, 36: 536  
(1948)

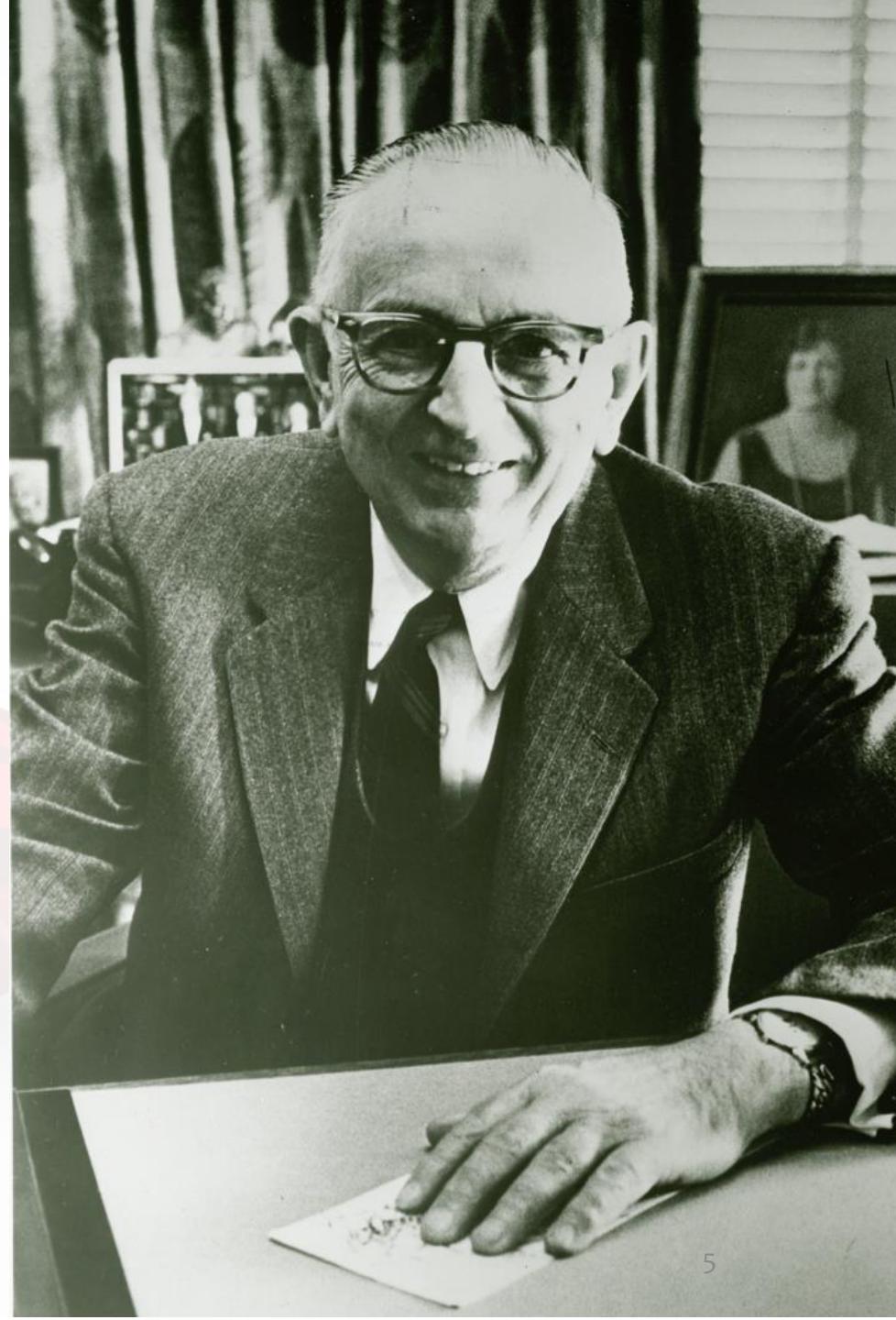
*Based upon material presented in Chapter 1 "The Scientists Speak,"  
Boni & Gaer Inc., 1947. All rights reserved.*



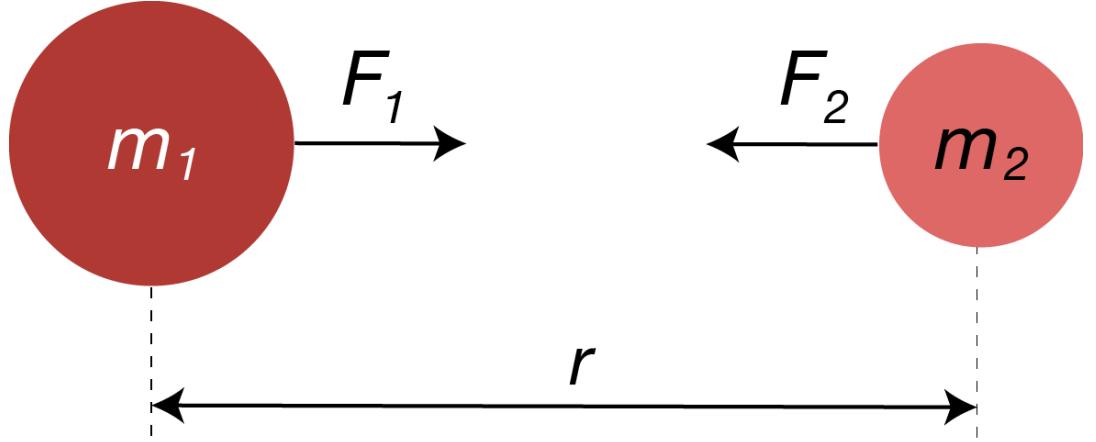
# Scientific Progress

Progress in Science:

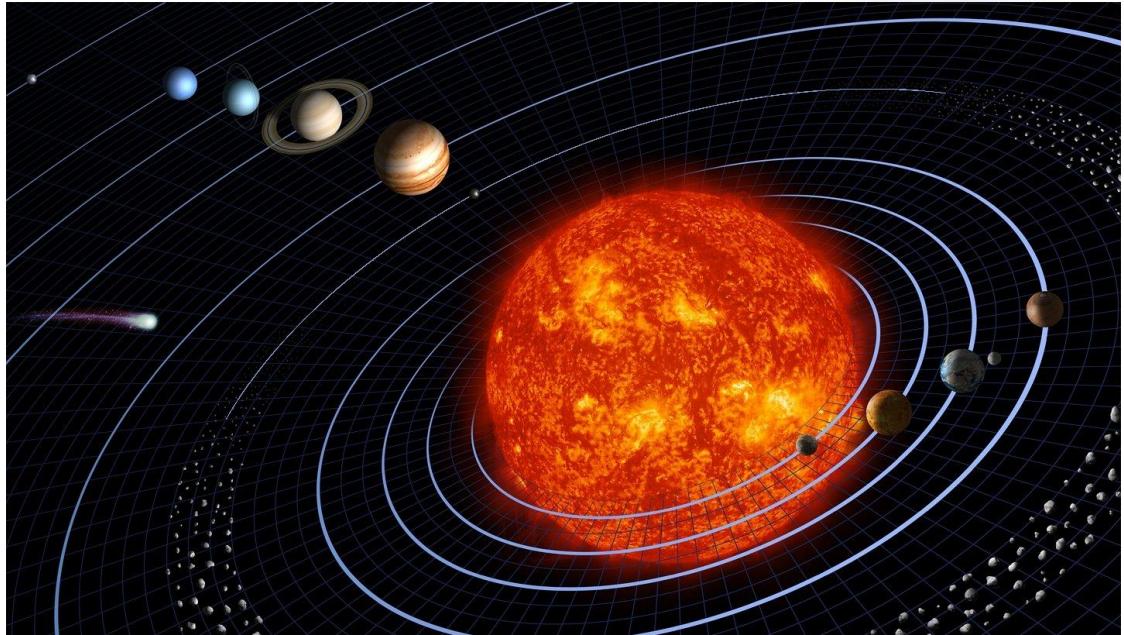
- Problems of simplicity
- Problems of disorganised complexity
- Problems of organised complexity



# Problems of Simplicity

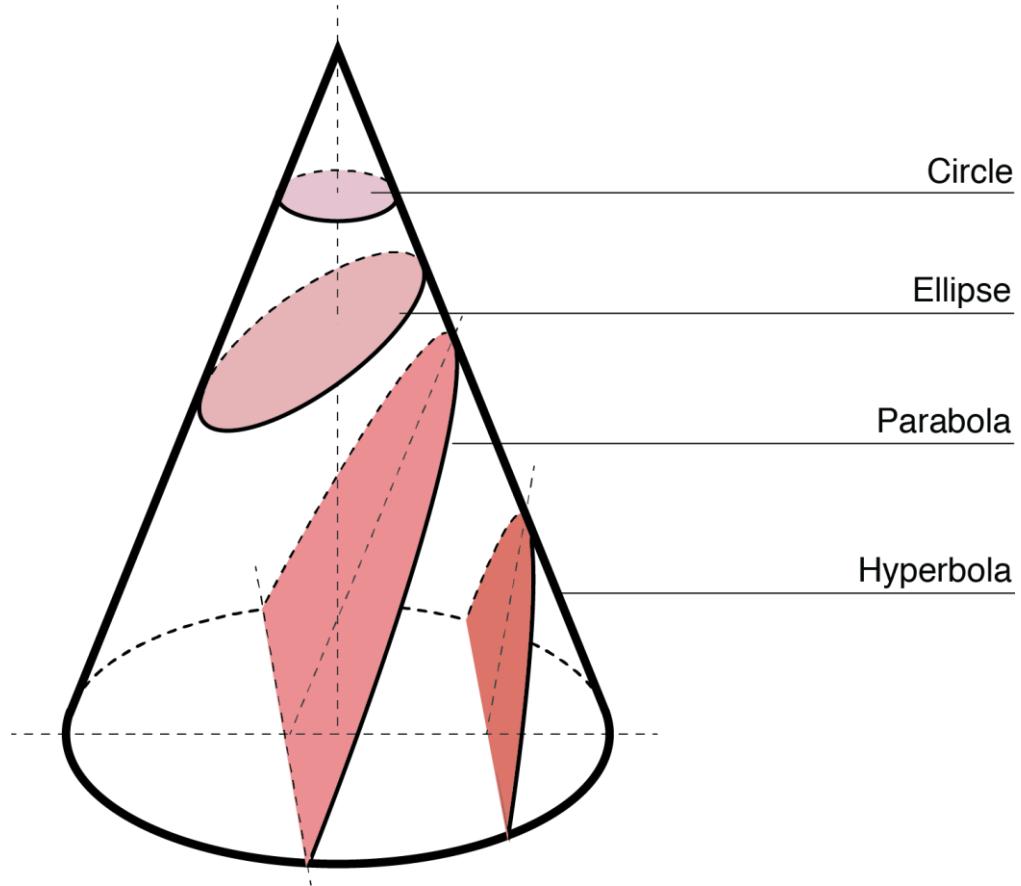


$$F_1 = F_2 = G \frac{m_1 \times m_2}{r^2}$$

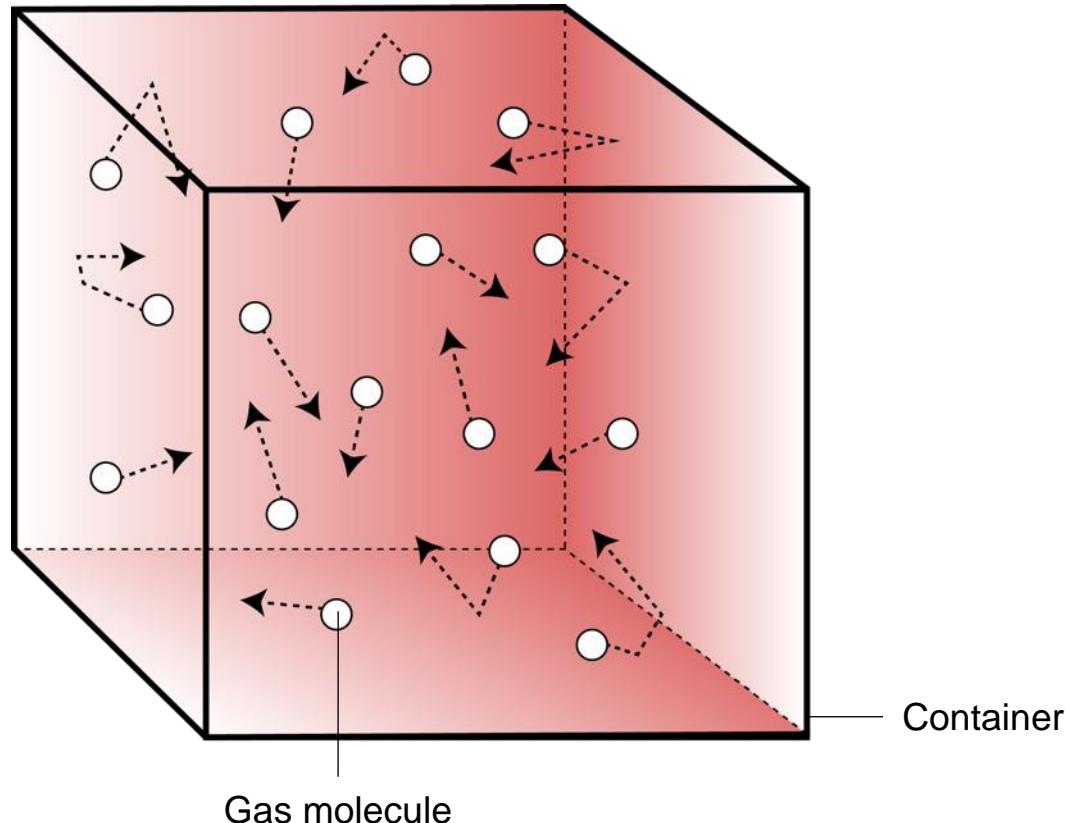


# Problems of Simplicity

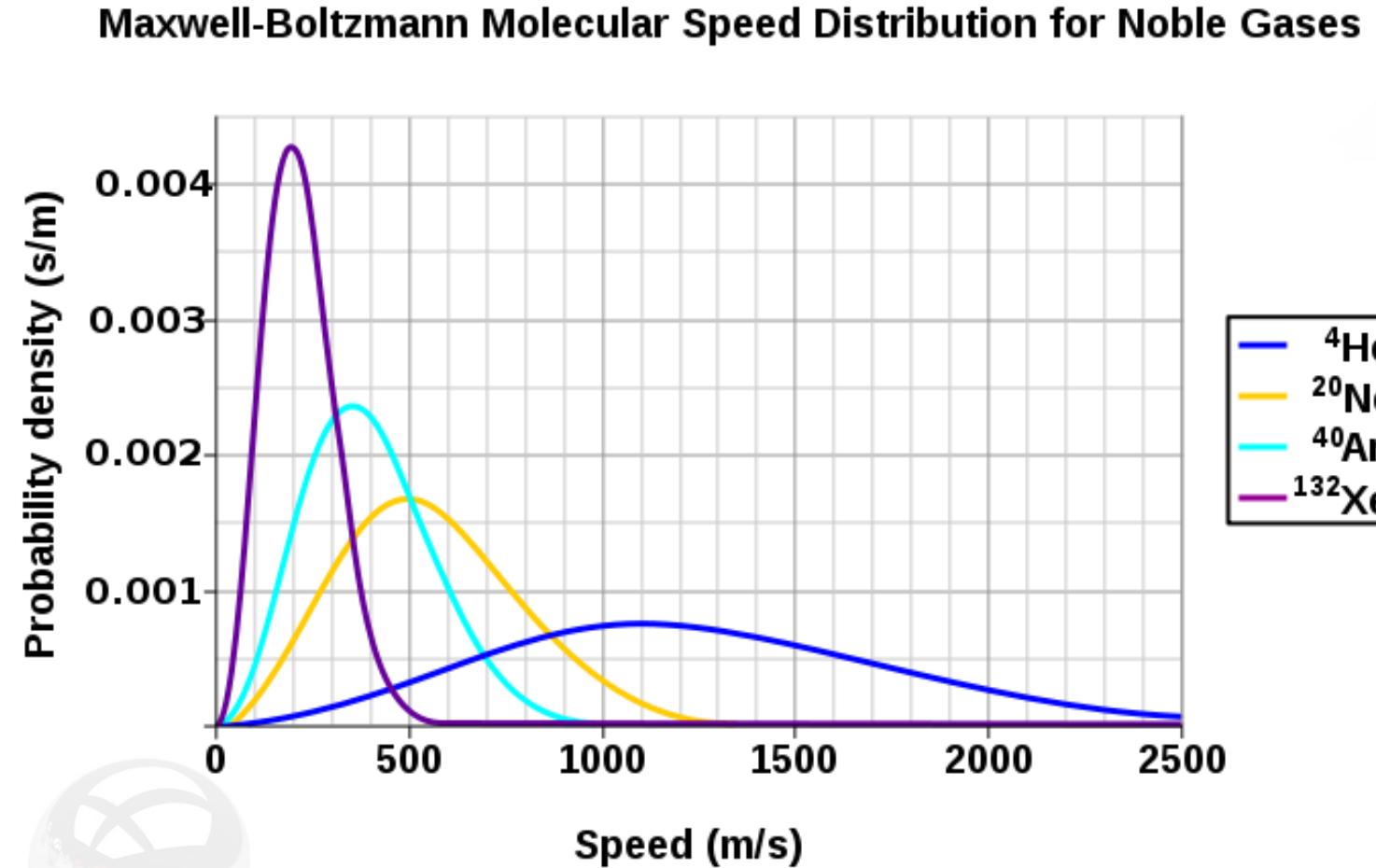
$$r = \frac{a(1 - \epsilon^2)}{1 - \epsilon \cos \theta}$$



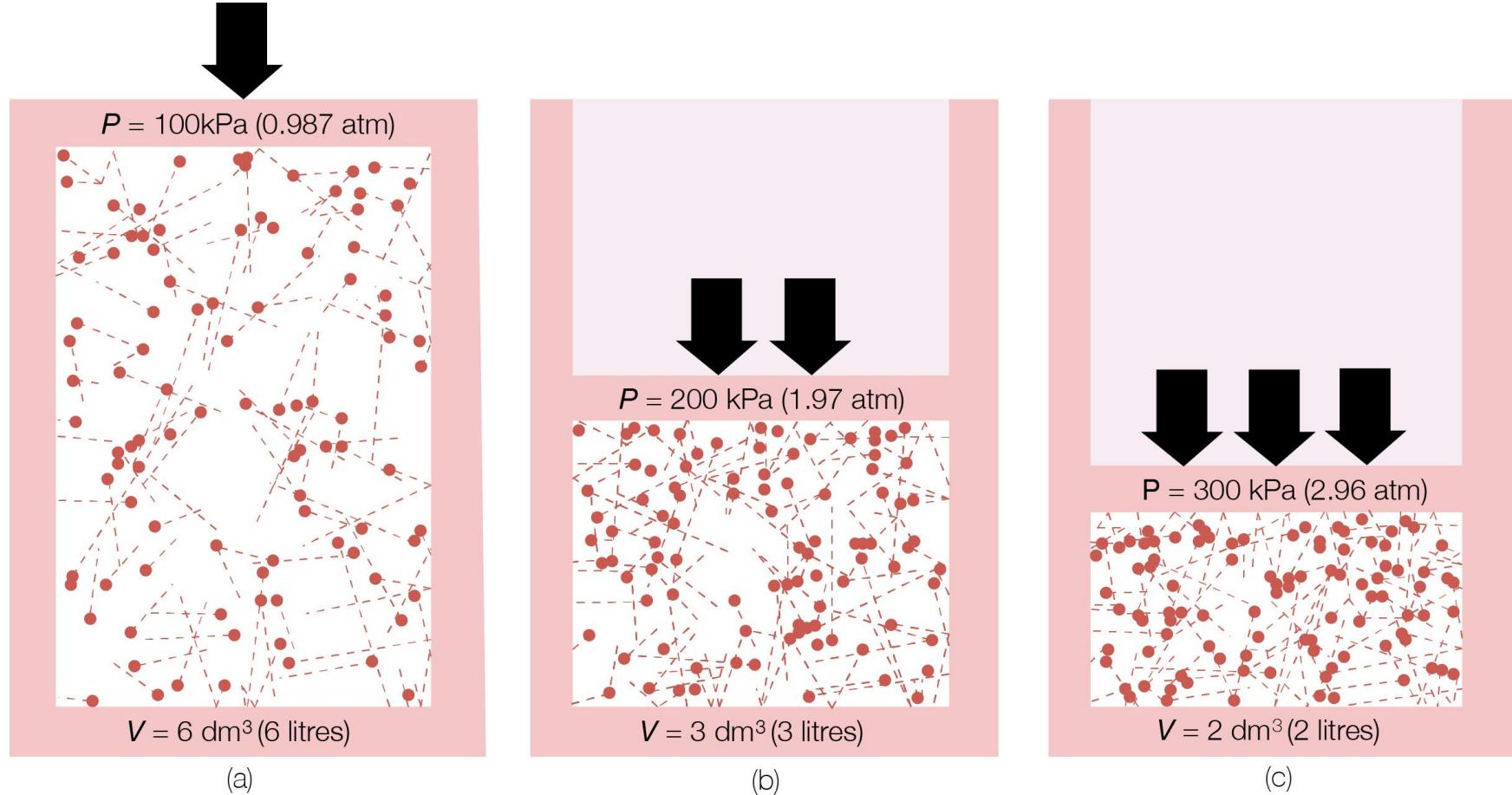
# Problems of Disorganised Complexity



# Problems of Disorganised Complexity



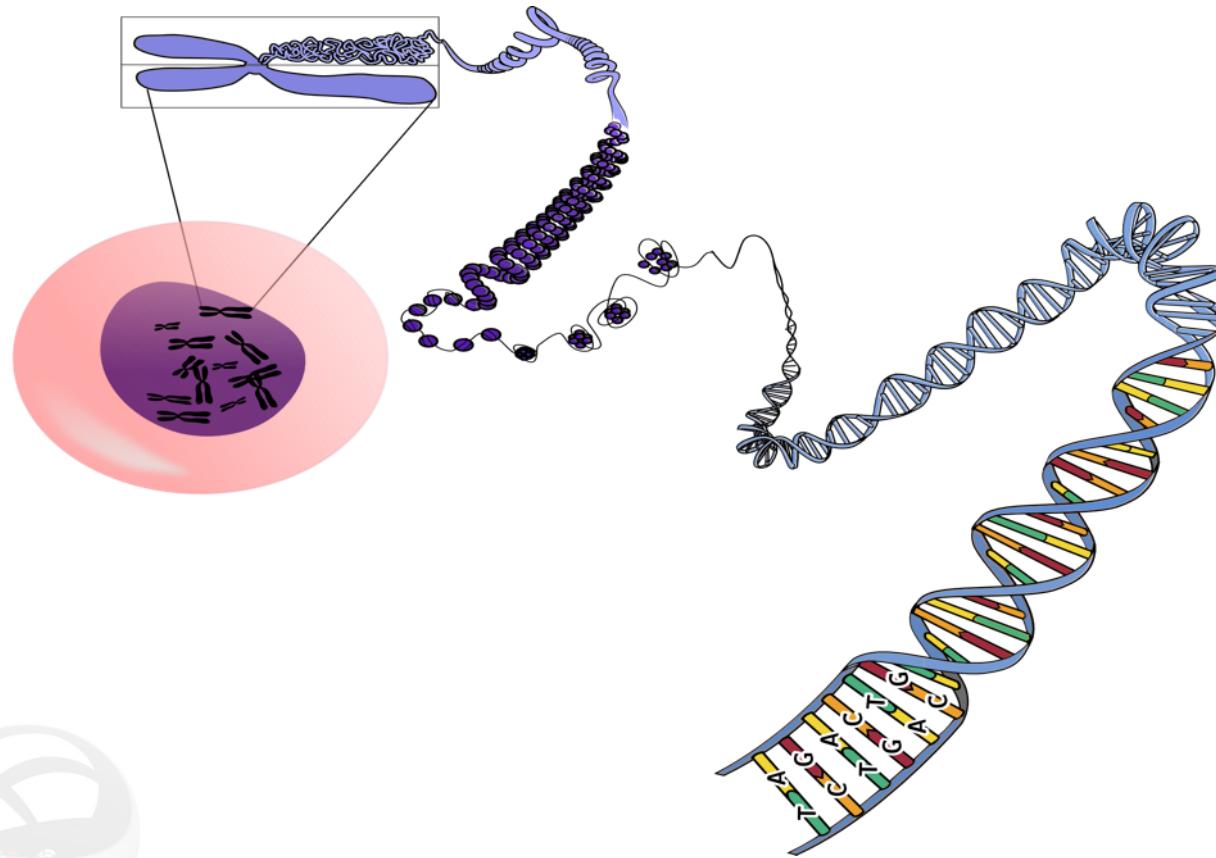
# Problems of Disorganised Complexity



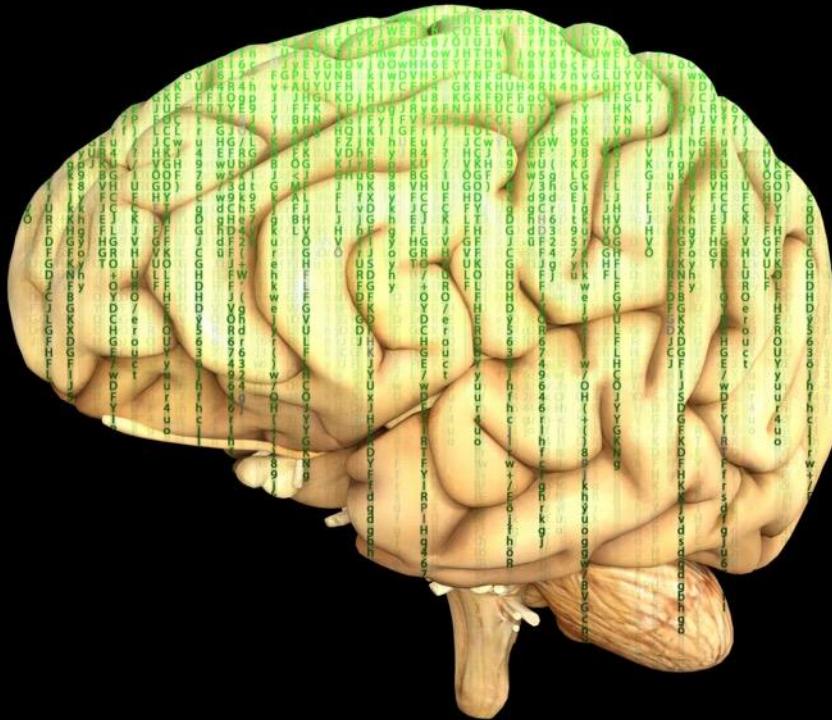
# Problems of Disorganised Complexity



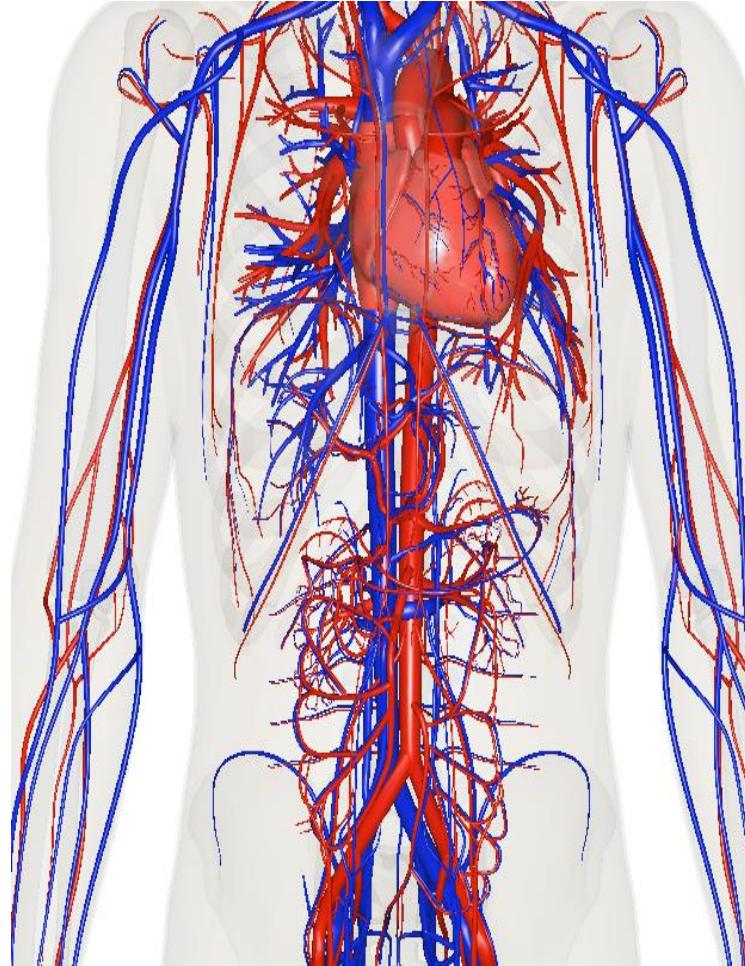
# Problems of Disorganised Complexity



# Problems of Disorganised Complexity



# Problems of Disorganised Complexity





# Properties of Complex Systems

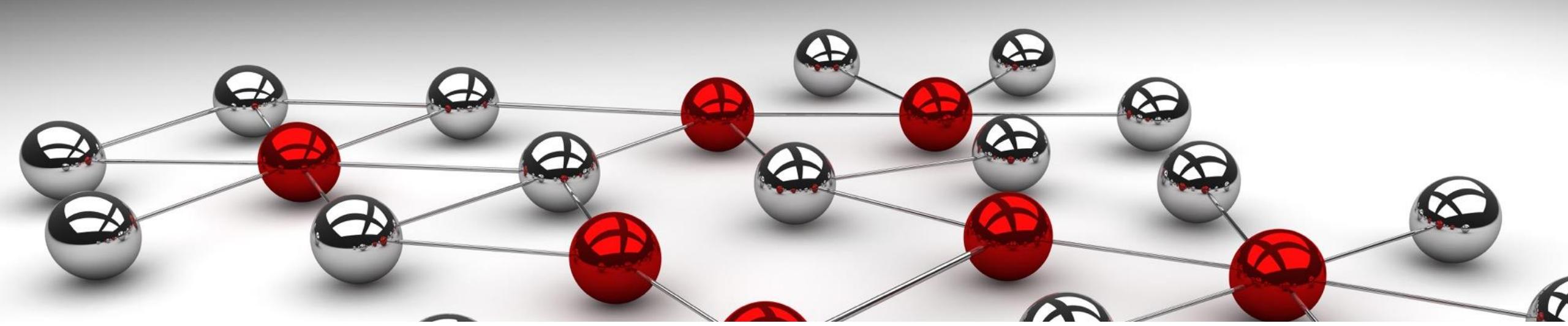
## Complex Systems

- Many heterogeneous components
- Strong, nonlinear interactions
- Self-organisation
- Emergence
- Irreducible
- Adaptation
- History dependence

# Why Should We Care About Complex Systems?

- Common in nature and human societies
- Seemingly defy the Second Law of Thermodynamics
- Required in natural/man-made/social systems
- Understand, predict, control and integrate into policy



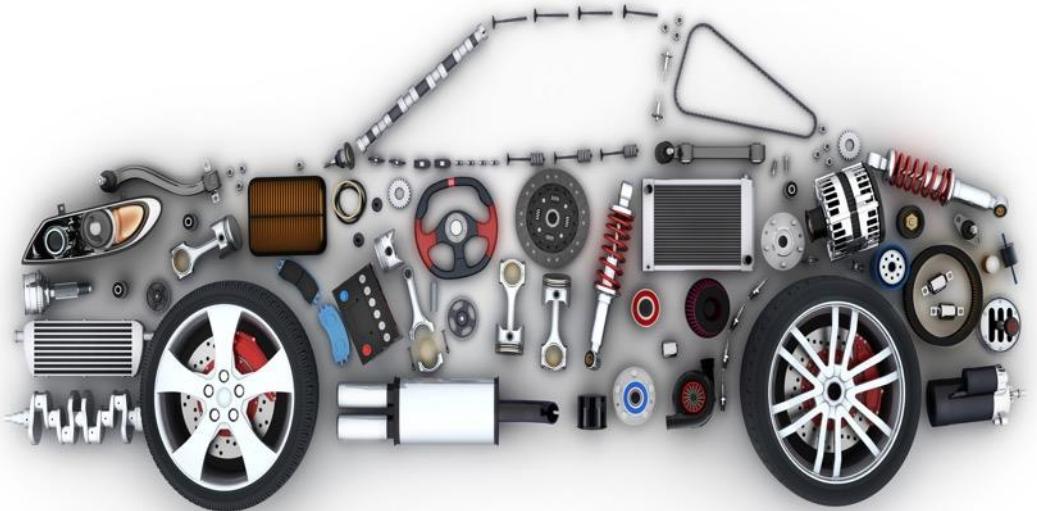


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# Complicated vs Complex



iStock.com/viadru



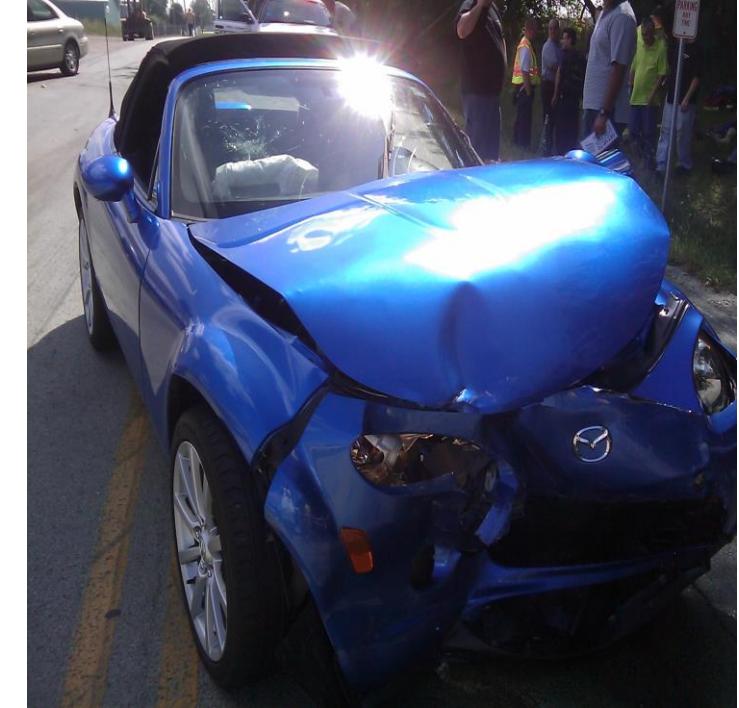
# Why is a Car Not Complex?



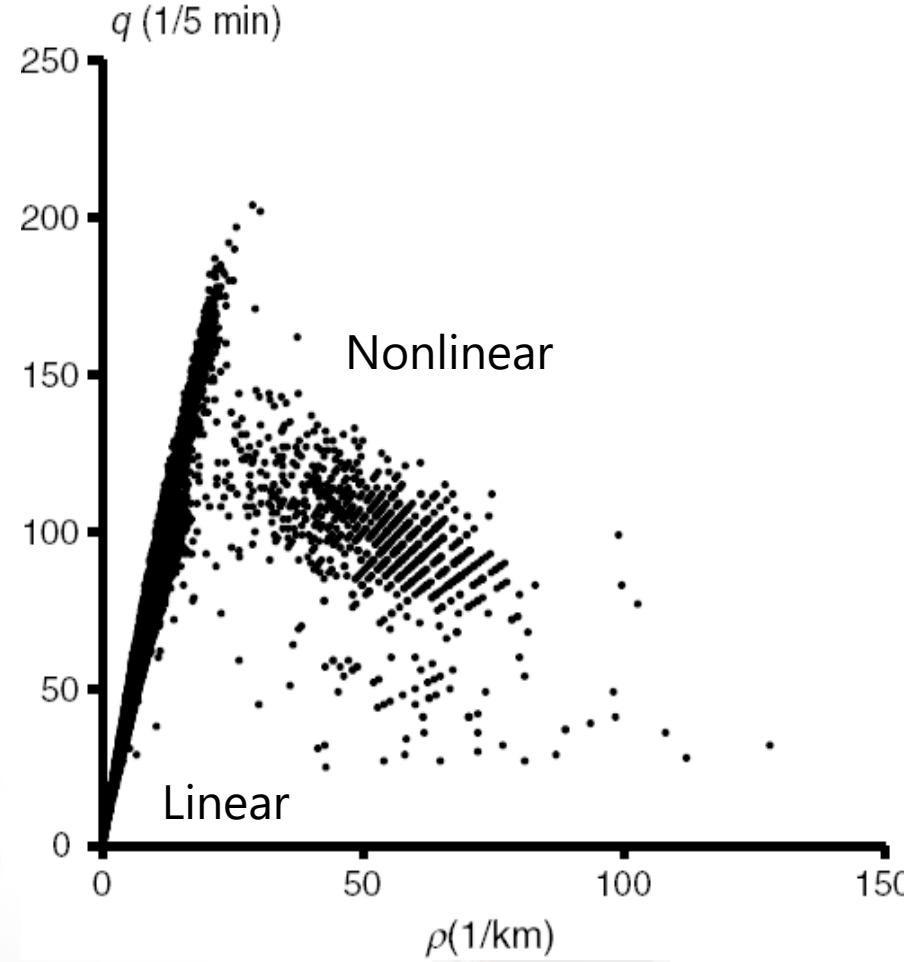
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# Why is Traffic Complex?



# Why is Traffic Complex?



Free-flowing



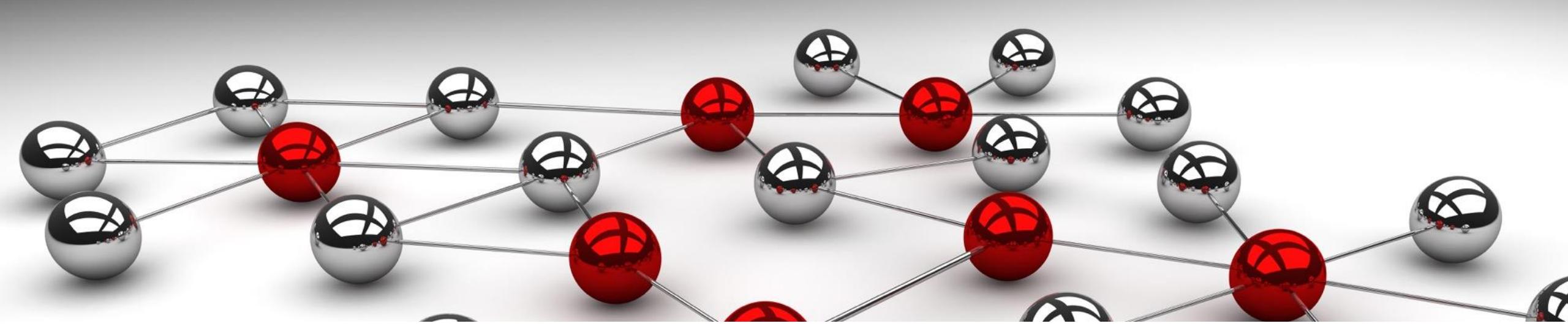
Congestion



# Other Examples of Complex Systems

- Nervous systems
- Immune systems
- Living organisms
- Pandemics
- Insect colonies
- Ecosystems
- Cities
- Markets
- Economies
- Human societies
- The World Wide Web





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# Wicked Problems

- Socially complex
- No clear solution
- Interdependent and multi-causal
- Involves changing behaviours
- Unforeseen outcomes

# Pandemics

- People are highly connected to each other
- Understanding the dynamics of pandemics
- Transmission of pandemic: Combination of genetic and social network
- Case study — HIV: Predicting the spread through heterosexual and homosexual networks
  - Simulate the resurgence of HIV
- Mitigation: Introduce behavioural changes

# Crime

- Criminal networks: Cannabis production
- Understand the value chain of crime nets



- Combine and analyse various types of data
- Map the data into dynamical networks and replay the situation to understand the case

## **Acknowledgements**

- Slide 4-5: Rockefeller Foundation, "Portrait of Warren Weaver," 100 Years: The Rockefeller Foundation, accessed March 28, 2017, <http://www.rockefeller100.org/items/show/1760>
- Slide 6: Photo of planetary system, extracted from Pixabay: <https://pixabay.com/en/solar-system-planet-planetary-system-11111/> by Wikimages: <https://pixabay.com/en/users/Wikilmages-1897/> (Public Domain)
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- Slides 19-20: Vladru (Photographer). (2016). *Abstract car and many vehicles parts* [Photograph]. Retrieved March 13, 2017, from [http://www.istockphoto.com/sg/photo/abstract-car-and-many-vehicles-parts-qm596780762-102274195?st=\\_p\\_car%20parts](http://www.istockphoto.com/sg/photo/abstract-car-and-many-vehicles-parts-qm596780762-102274195?st=_p_car%20parts).
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- Slide 22: Sugiyama, Y., Fukui, M., Kikuchi, M., Hasebe, K., Nakayama, A., Nishinari, K., Tadaki, S. and Yukawa, S. (2008). Traffic jams without bottlenecks—experimental evidence for the physical mechanism of the formation of a jam. *New Journal of Physics*, 10. doi: <https://doi.org/10.1088/1367-2630/10/3/033001>
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