Emergence

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Learning objectives

- Explain what emergence is
- Explain what self-organizing system is
- Give examples of systems that exhibit emergent behaviour
- Explain the emergent mechanisms:
  - Neighbour interaction
  - Patter match
  - Feedback
  - Control

Emergence

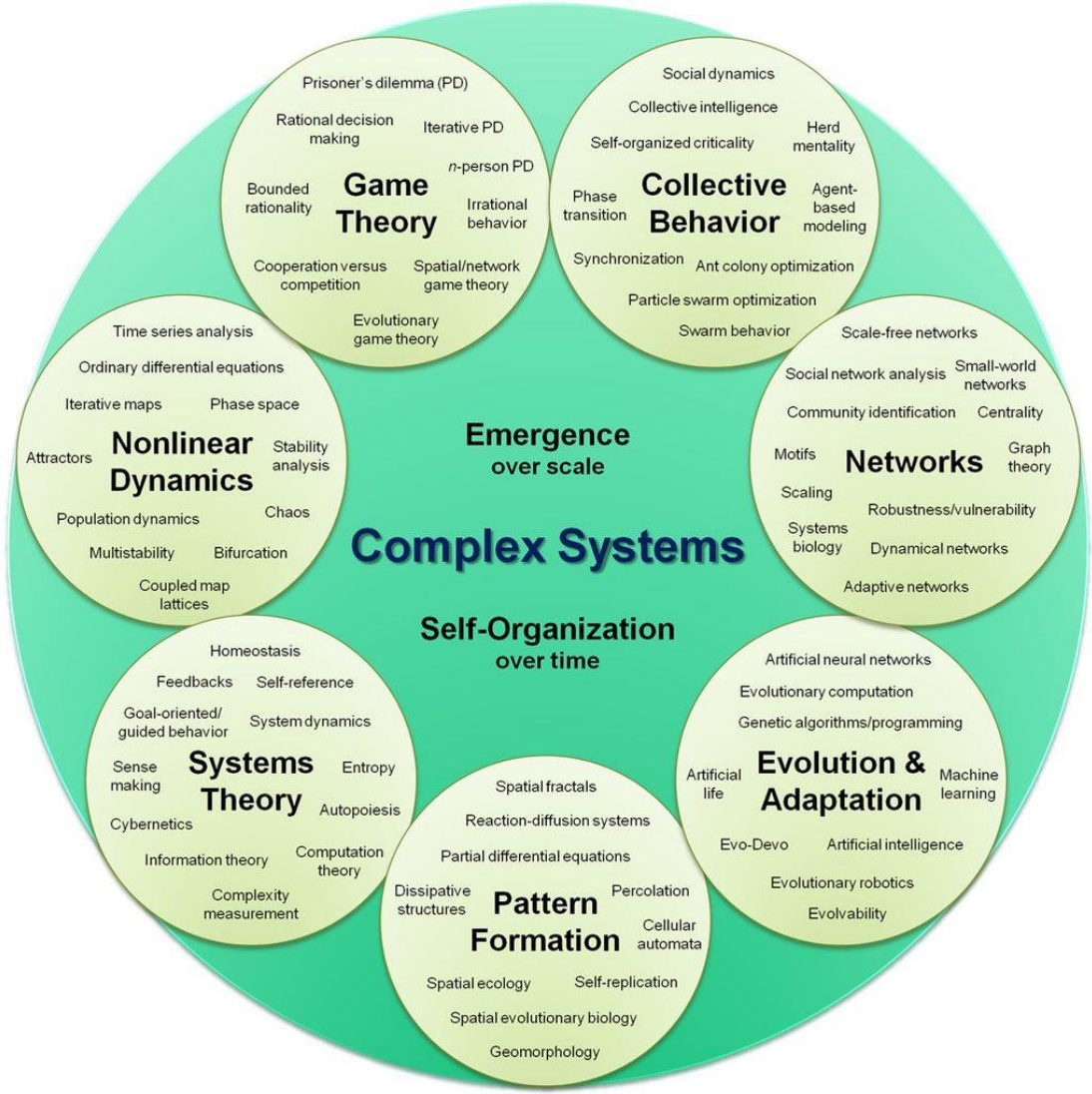
- Occurs when a system has properties that the individual parts of the system do not exhibit
  - Occurs when the parts of the system interact or work together to form a whole
- Emergence is the appearance of new phenomena on higher levels of a system
  - The appearance of new qualitative features on the level of an entire system that can not be observed at the level of its components
- Emergence is about the system's properties at different scales/volume/size
- Emergence solves problems by drawing on the intelligence of the system as a whole instead of the intelligence of individual parts of the system
- Emergence results from self-organizing systems
  - It refers to the ability of a class of systems (self-organizing systems (SOS)) to change their internal structure and/or their function in response to external circumstances
  - As a system grows, the system self-organizes (with time) and emergent behaviours emerge
- Self-organization and emergence are characteristics of scale-free networks

Emergence

Systems with emergent behaviour

- Show an increase in order as the system grows without external control
- Show new behaviour on a higher level of description which could not have been easily predicted from interactions of components at the lower level
- Are a result of a self-organization process
- Respond to specific and changing needs of their environment
- Form patterns in time
- Follow simple rules rather than a single, intelligent “executive” to create collectively efficient structures which are better than any conscious design
- Adapt to external conditions (environmental feedback)
- Are bottom-up systems; from low-level to higher level sophistication

How it all fits together



Source: Hiroki Sayama, D.Sc. - Created by Hiroki Sayama, D.Sc., Collective Dynamics of Complex Systems (CoCo) Research Group at Binghamton University, State University of New York

Early examples of emergence

- Ant colonies
- City Neighbourhoods
- Brain neurons
- Markets

Ants

- Queen is not an authoritative figure but plays a major role in colonies
  - She lays eggs and is fed/cared for by the workers
  - She doesn’t decide which worker does what
  - She is responsible for giving birth to all members of the colony; in the best interest of colony to keep her safe
- One queen and many workers taking flexible roles
- Communication through pheromone trails for food finding
- Gestures to express emotions
- Ants create a midden – garbage dump and a cemetery
  - These are created as far away as possible from the colony and from each other

Manchester in 1842

- Became a hub for wool trade in 1600s. Was exporting goods to other parts of the world
- Grew rapidly between 1700 and 1850 when it then officially became a city (1853)
- Was a busy place which attracted workers and merchants but was not recognized as a city until much later
  - There was no government structure in place
- Despite the seemingly chaotic industrial part of town, there was a strange type of order that was noticed by Friedrich Engels
  - “I have never elsewhere seen a concealment of such fine sensibility of everything that might offend the eyes and nerves of the middle class. And yet it is precisely Manchester that has been built less according to a plan and less within the limitations of official regulations –and indeed more through accident –than any other town”.

New York neighbourhood, 1961

- To understand how a city works, one has to approach it as a problem from the street level up
- Jane Jacobs:
  - “Vital cities have marvelous innate abilities for understanding, communicating, contriving and inventing what is required to combat their difficulties. They get their order from below; they are learning machines, pattern recognizers”

Fundamental principles of design of systems that learn from the ground level up

- More is different. There should be a critical mass of individuals/subjects in the system
  - We learn more from 10 ants vs 1000 ants
  - The global behaviour only becomes apparent by studying the entire system and not individuals
  - If we studied one ant in isolation, we won't know that pheromone secretion was part of an overall effort to create a distribution line
- Ignorance is useful.
  - Make it simple; build an interconnected system of simple elements
  - If parts are complicated, the system easily gets complicated.

Fundamental principles of design of systems that learn from the ground level up

- Encourage random encounters.
  - While connections are not random, provide ways that random encounters can occur
  - This allows new discovery
- Look for patterns in the signs
  - To allow for a flow of information
  - The pattern creates a gradient, providing (environmental) feedback
    - Ants rely heavily on patterns. A gradient in the pheromone trail leads them towards a food source
- Pay attention to neighbours
  - Local information can lead to global wisdom
  - Individuals who can't assess the global situation still *work together* in a coordinated way
  - They think locally and act locally but their collective action produces global behaviour
  - More individuals in the system = more neighbours
  - Without ants stumbling on one another, colonies will exist without logic

Emergence mechanisms

- Neighbour interaction
- Pattern match
- Feedback
- Control

Neighbour interaction

- Ant-colonies: ants interacting through pheromones and observing their neighbours
- Cells in the embryo–all cells reading different sections of the same DNA, taking cues from their neighbours about what section to ”read”
- SimCity – city-building video game
- Sidewalks as providers of interactions that change people’s behavior

Pattern match

- Patterns emerge as optimal points (equilibriums) in interactions and their driving forces
  - What is equilibrium? A balance of forces , e.g. a point of mutual convenience for everyone involved.
  - Example: Trading streets in old cities, e.g. Florence
- Complex systems “learn” patterns
  - Learning is not contingent on consciousness
  - Our immune systems learn throughout our lifetime building antibodies
  - Social networks/social media learn from our activities and behaviours and make recommendations

Florence XI –XXI Century

- Do cities learn?
  - Silk weavers and goldsmiths settled on Por Santa Maria street north of Ponte Vecchio in the XI-th century, they are still there now
  - The pattern is “learned” by the city, but not consciously; it persists due to individual conscious decisions, but at a lower level (self-interest, max. utility)
  - If a time traveler from the past visits Florence, they will still locate where the silk weavers and gold smiths are
- Certain elements of cities get passed on from generation to generation because they are associated with a physical structure that has its own durability
  - Cathedrals and universities
- City can also learn about the *specialization of the city* which could also make structures stay in place over time
  - Florence

Feedback

- Self organizing systems rely extensively on feedback for growth and self-regulation
- Positive feedback and negative feedback
  - Positive feedback propels one onward
  - Positive feedback boosts a particular action
  - Negative feedback steers towards a target (e.g. a thermostat)
  - Negative feedback is a way of reaching an equilibrium point despite unpredictable and changing external conditions
- Examples
  - Pheromone trails of ants when finding food
  - Online communities like Netflix; watching or not watching their recommendations
  - Systems with user ratings: Amazon and eBay

Control

- Emergent system “is a little chaos machine, unexpected things happen and you only control it from the edges” -Eric Zimmerman, scientist, artist, game designer
- “The rules make the game”, emergent systems are rule-governed as well (low level rules)… if an agent stops following the rules, anarchy or chaos results
- Group behaviour can evolve in unpredictable ways
  - e.g. Online games - SimCity has no pre-defined objectives
  - The more autonomous the system, the more irrelevant the player is
  - Game designers wonder how far off the edge should a player be, to keep him/her interested in the game?
- For online emergent systems, find some middle ground between too much order and too little
  - Social networks do this well

Summary

- Emergence is a result of a self-organization process
- Self-organization and emergence are characteristics of scale-free networks
- Emergence existed before technology, e.g. ant colony, cities etc.
- Emergence mechanisms include neighbour interaction, pattern match, feedback, and control

References

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