SYSTEMS, COMPLEX SYSTEMS & EMERGENCE

What is a System?

- A grouping of parts that operate together for a common purpose
  - *The elements and processes of a system affect one another, often in ways we cannot see*
- The relationship (spatial, functional or otherwise) between the parts matter
  - *If the relationship changes the system behaviour changes (it malfunctions)*
- The system is analysed in layers of abstraction
  - *The 'part' could very well be a 'system' on its own*
  - *Hence we sometime call it subsystems*
- A system may include people and physical parts
  - *A system could be biological, social, artificial, Algorithmic/computational….*

Example of Systems

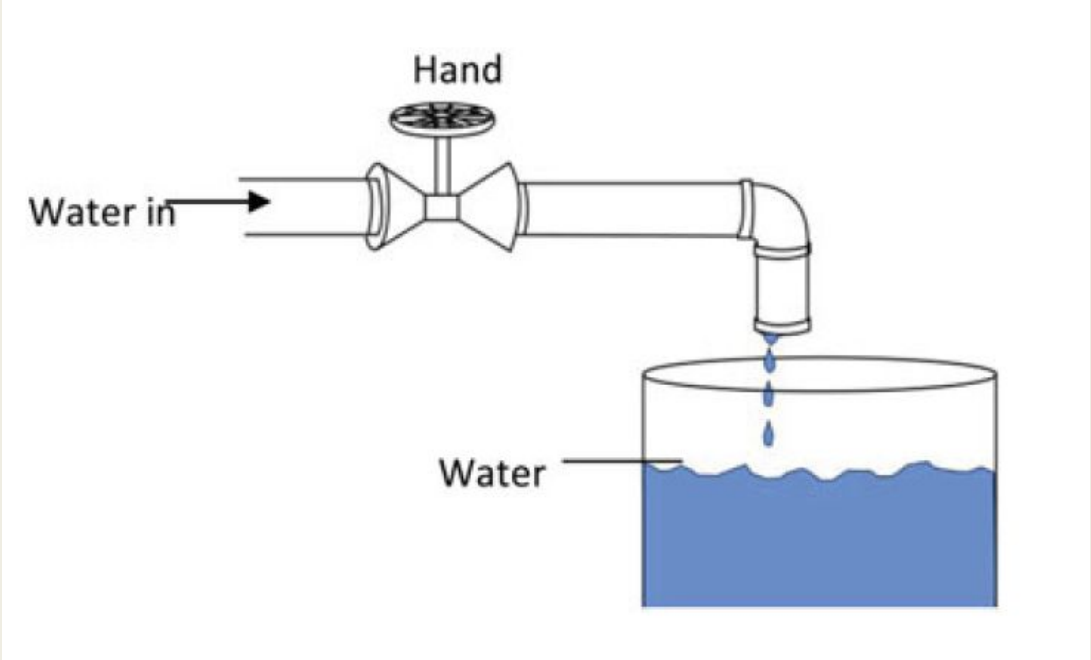
- A farm tractor is a system of components that work together for providing cultivation.
- A family is a system for living and raising children
  - *A system can be dynamic and adaptive*
- A computer System
  - *Processor, memory and peripherals work together to achieve something*
- A government is the system or group of people governing an organized community

One way to classify Systems

- There are many ways to classify systems
- A more interesting way is based on whether or not the output impacts the input
- Thus we classify the systems into two major types
  - *Open Systems*
  - *Closed Loop (Feedback) Systems*

Open Systems

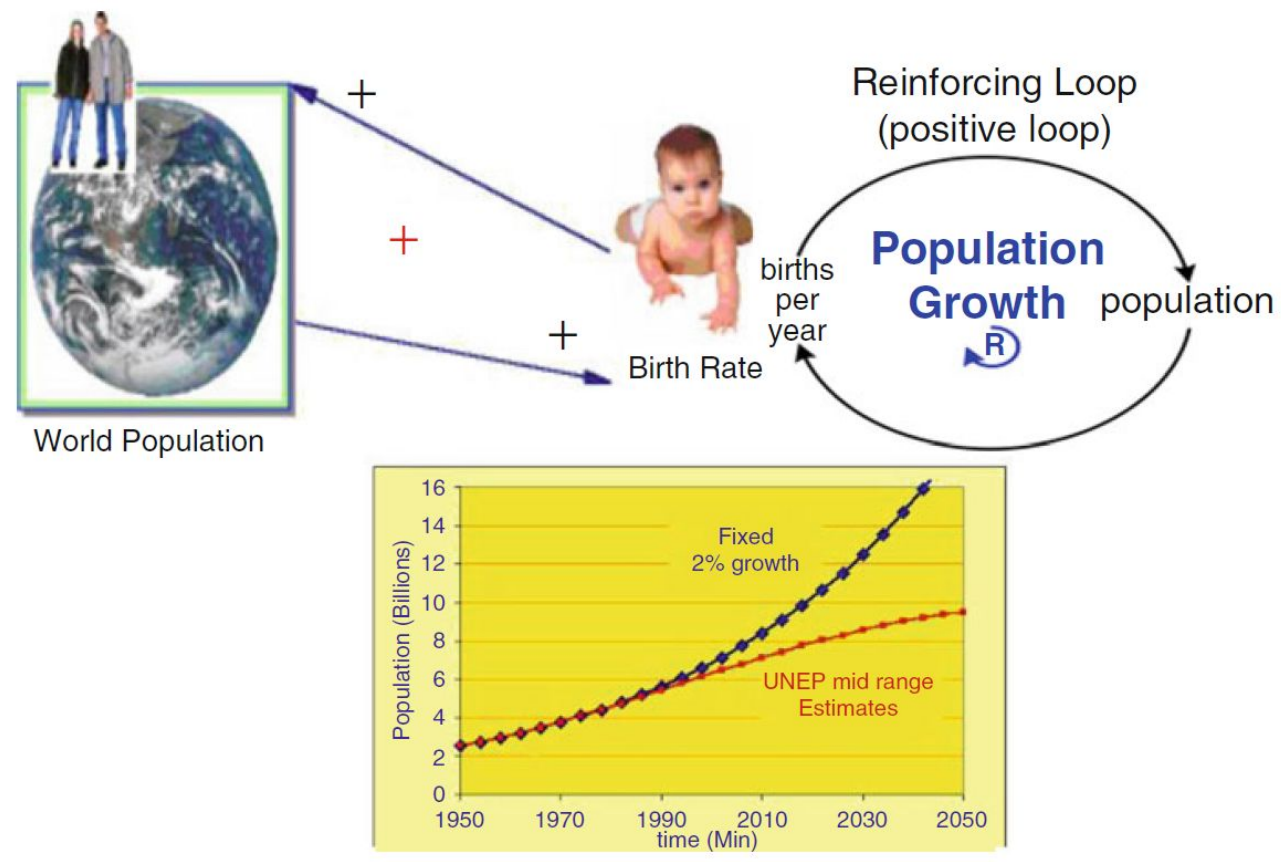
- The output responds to input, but **output has no influence on the input**.
- The input is not aware of its own performance.
- Past action does not affect the future action.
  - *For example, a watch is not aware of its inaccuracy and does not correct the time itself.*
- In an open system, the problem is perceived and action is taken, but the result does not influence the action



Feedback Systems

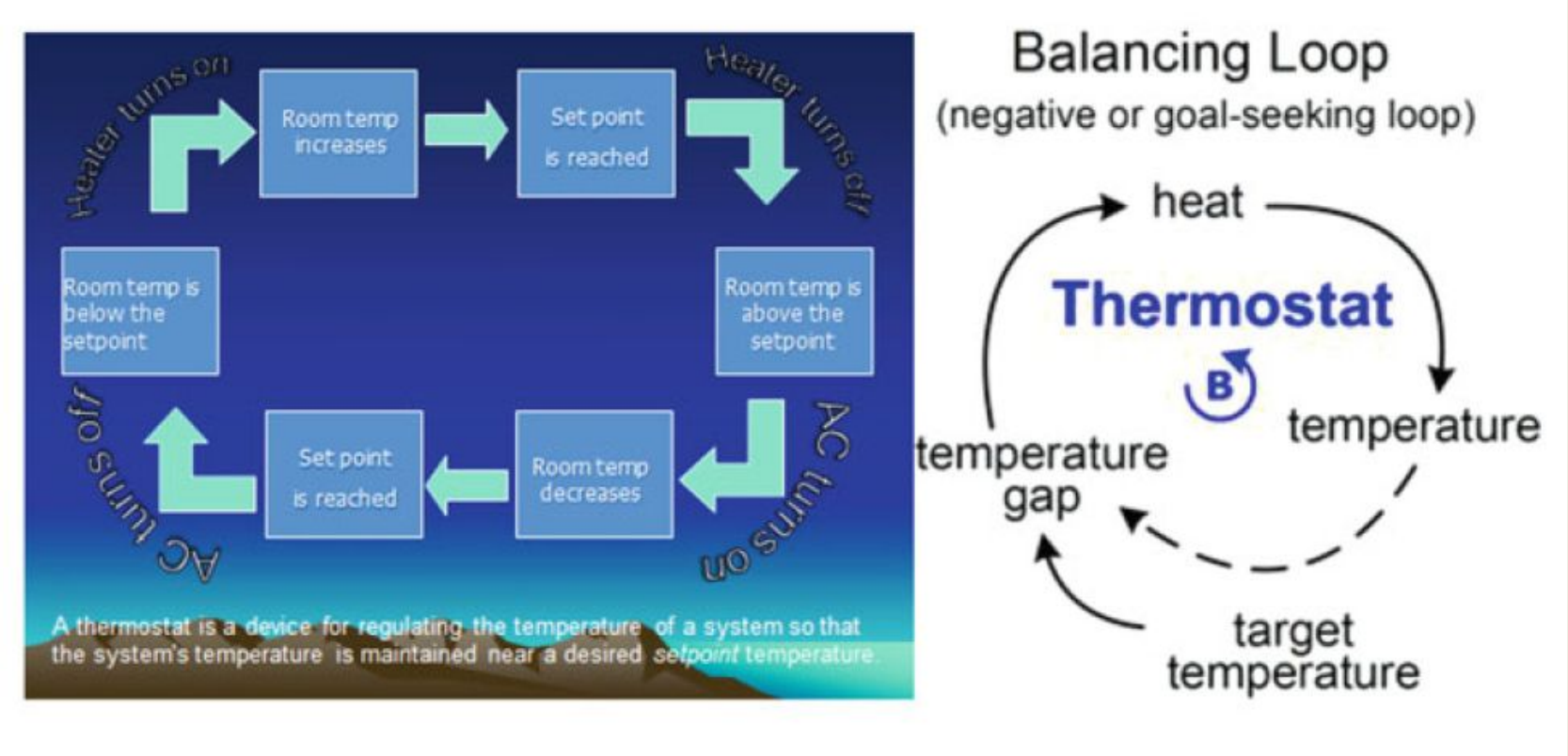
- Feedback systems are closed loop systems
- The inputs are changed on the basis of output.
- The results of the past action controls the future action.
- The problem is perceived, action is taken and the result influences the further action.
- Feedback system can be further classified as
  - *positive feedback systems: Generates growth*
  - *negative feedback systems: Goal seeking*

Positive Feedback System example



Population growth system is an example of positive feedback systems. Population multiply to produce more population which increases the growth rate at which the population is increased.

Negative Feedback System example



When the room temperature is controlled by a thermostat or temperature controller, the system tries to maintain the set temperature. When the heater is turned on, the temperature increases to set point and then heater is turned off.

A modern example

Complex Systems

What is Complexity?

Plexus means braided or **entwined**, from which is derived complexus meaning braided together, and the English word “complex” is derived from the Latin.

What is Complexity?

Complexity results from the **inter-relationship, inter-action and inter-connectivity** of elements within a system and between a system and its environment

Complexity is therefore associated with the **intricate inter-twining or inter-connectivity** of elements within a system and between a system and its environment.

Complex Systems

- Systems that don’t yield to compact forms or representation or description
  - *In contrast to systems physicists study : a huge amount of empirical data can be described using elegant equations*
  - *No such descriptions for system like human brain, human genome*
- A system which has sophisticated internal causal architecture for storing and processing information *(I am not sure I buy this)*

Complex Systems (A more structured definition)

- Complex system consists of **many interacting parts**
  - *Have a hierarchy of subsystems*
- ***No centralized control****: coherence/organization emerges from just local interactions alone*
- ***Non linear*** *(the whole is greater than the some of the parts)*
  - *The output is far greater than what individuals can accomplish in isolation*
  - *Has feedback loops which causes large effects even for minor changes*
  - *Dense or high level of interconnectivity making it somewhat irreducible*
  - *Aggregate properties or behaviour is not predictable (at least not easily!)*
- ***Autonomy and adaptation***

But remember there is no single acceptable definition and the boundary between the definition of simple-system<-> complex system is somewhat grey

Complex? Systems

What are Complex Adaptive Systems?

- Natural Systems characterized by apparently complex behaviors
  - *Emerging as a result of often nonlinear spatio-temporal interactions among a large number of component systems*
  - *The components have different levels of organization.*
- These systems have recently become known as Complex Adaptive Systems
- CAS are dynamic systems able to adapt in and evolve with a changing environment.

Attributes of CAS

- **Distributed Control**
  - *There is no single centralized control mechanism that governs system behavior*
  - *overall behavior usually cannot be explained merely as the sum of individual parts*

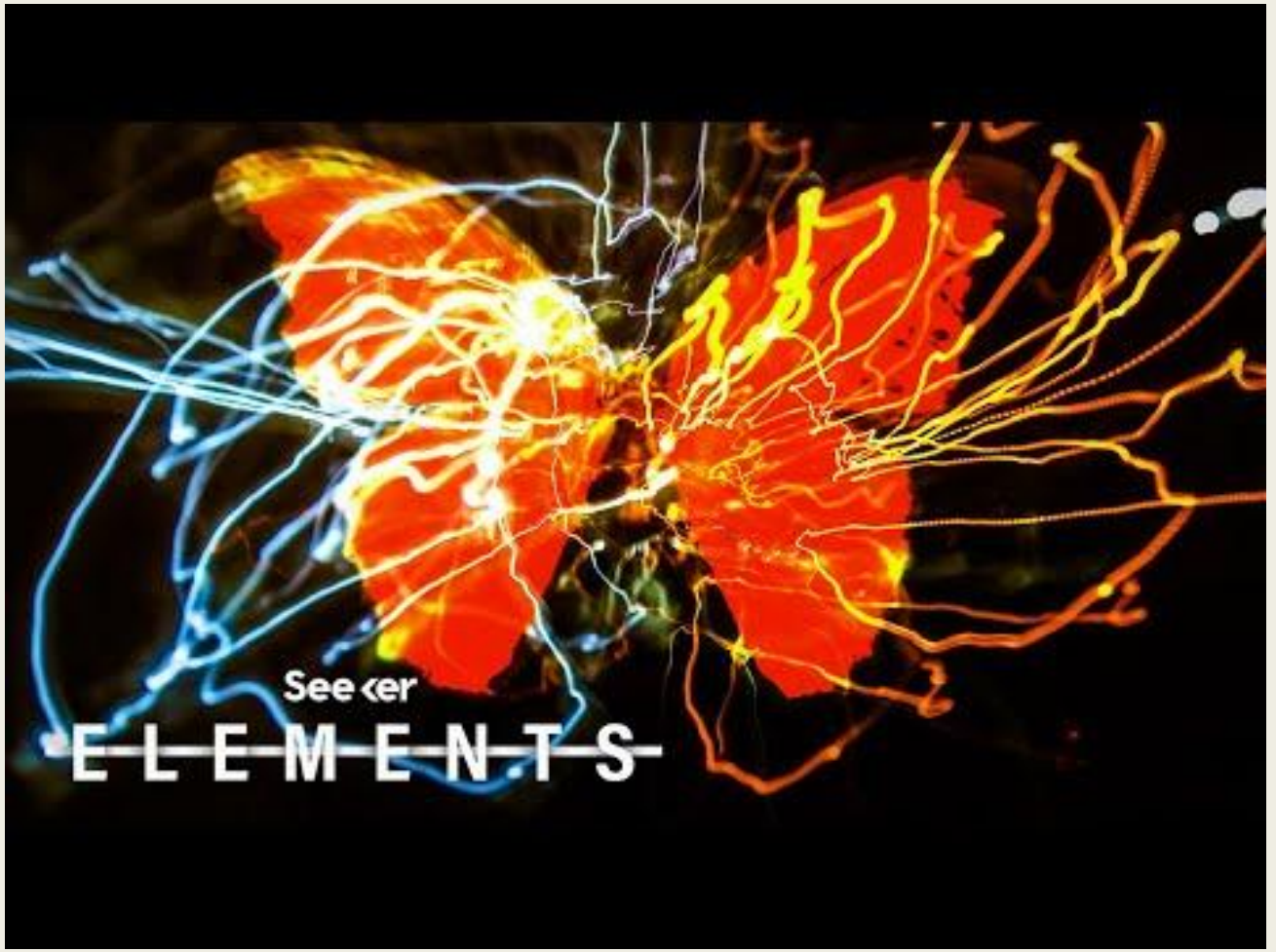
- **Connectivity**
  - *High inter-connectivity within a system and between a system and its environment*
  - *decision or action by one part will influence all other related parts but not necessarily any uniform manner*

Attributes of CAS

- **Coevolution**
  - *Elements in a system can change based on their interactions with one another and with the environment*
  - *Patterns of behavior change over time*

- **Dependence on Initial Conditions**
  - *Changes in the input characteristics or rules are not correlated in a linear fashion with outcomes*
  - *Small changes can have a surprisingly profound impact on overall behavior, or vice-versa, a huge upset to the system may not affect it*

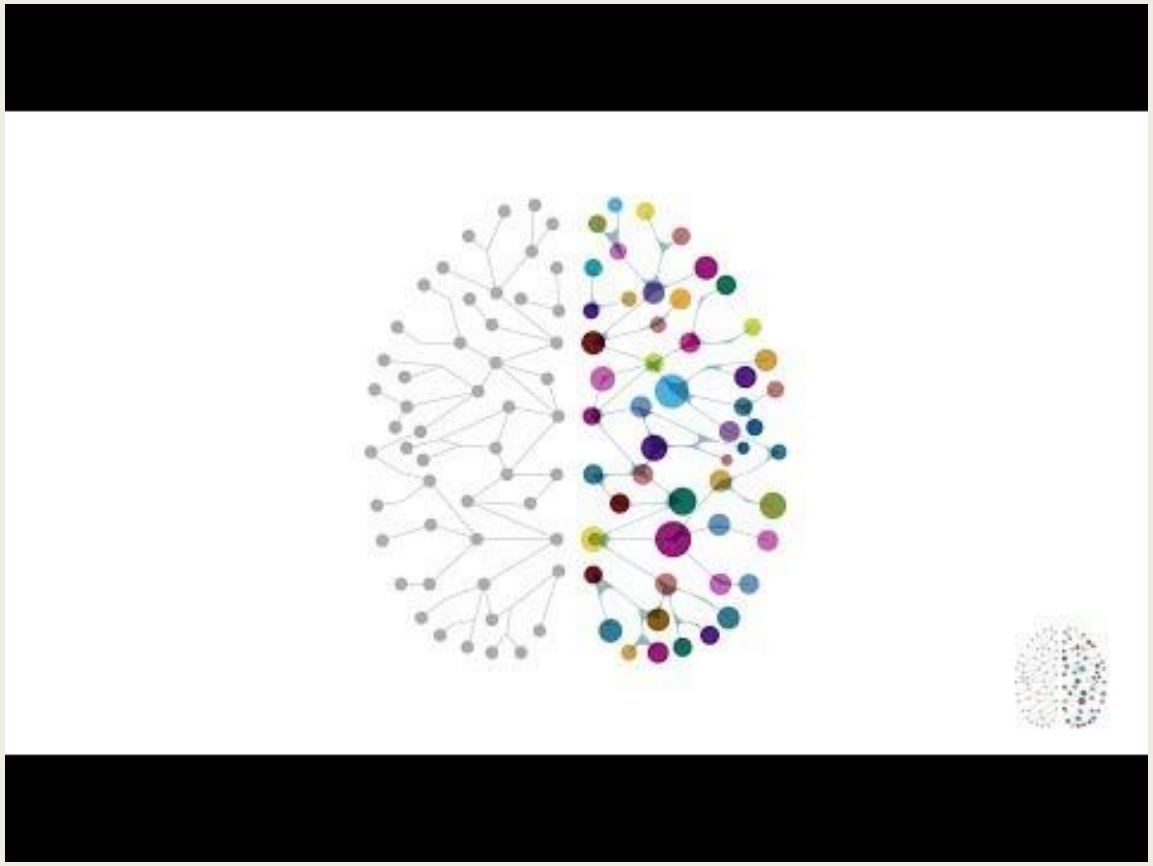
Complexity and Chaos (Sensitivity to initial conditions)



Best example for a Complex Adaptive System?

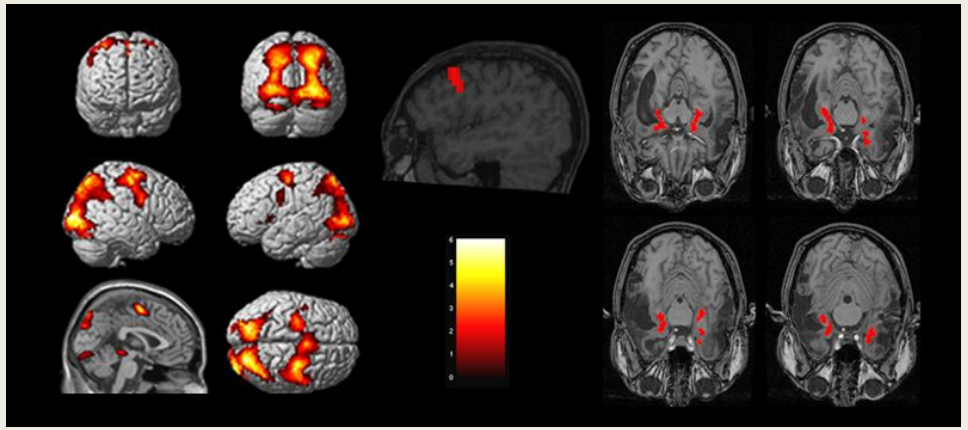
Our brain!

Best example for a Complex Adaptive System - *Neuroplasticity*



TBI & Recovery

- Su, Y. S., Veeravagu, A., & Grant, G. (2016). Neuroplasticity after traumatic brain injury. Translational research in traumatic brain injury.
- Jasey, N., & Ward, I. (2019). Neuroplasticity in brain injury: maximizing recovery. Current Physical Medicine and Rehabilitation Reports, 7(4), 333-340.



fNCI (as in the example above) allows us to see the results of neuroplasticity treatment at Cognitive FX in action.

Another good but (fictional) example for a Complex Adaptive System?

T-1000


HD

Emergence

Emergence

- The outcome resulting as a product of interaction between parts/subsystems in a complex system
- ‘emergence’ is the arising of novel and coherent structures, patterns, and properties through the interactions of multiple distributed elements

  - Wilensky, Uri. An Introduction to Agent-Based Modeling (The MIT Press) (p. 6).

Emergence

"*Every resultant is **either a sum or a difference** of the co-operant forces; their sum, when their directions are the same—their difference, when their directions are contrary. Further, every resultant is clearly traceable in its components, because these are homogeneous and commensurable. It is otherwise with **emergents**, when, instead of adding measurable motion to measurable motion, or things of one kind to other individuals of their kind, there is a co-operation of things of unlike kinds. The emergent is unlike its components insofar as these are incommensurable, and it cannot be reduced to their sum or their difference*"

– G.H. Lewes, Philosopher

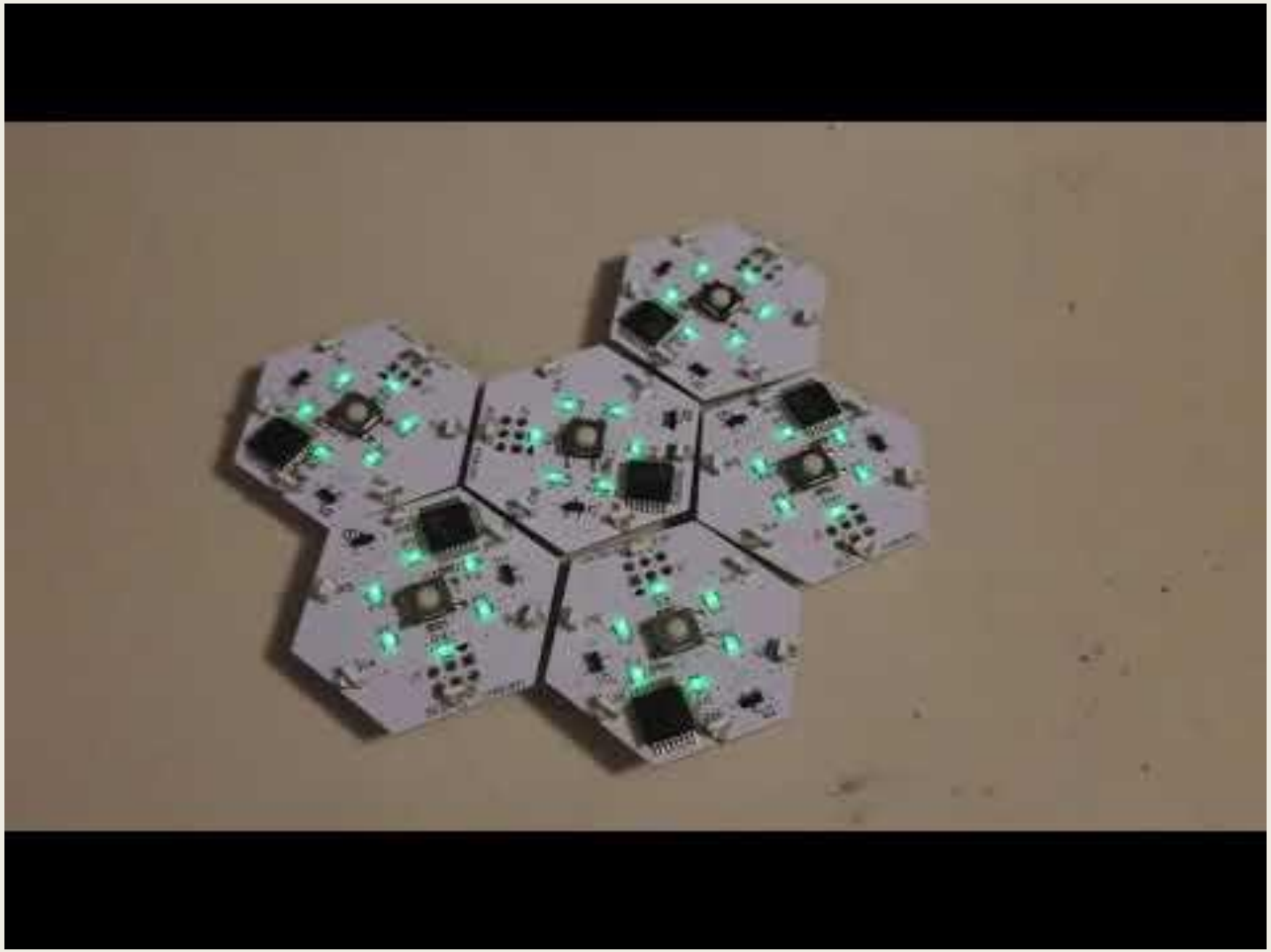
(from Wilensky, Uri. An Introduction to Agent-Based Modeling (The MIT Press) (p. 6). The MIT Press)

Emergence

Examples of Complex Systems and Emergence

- Nature: Bee hive, ant colonies, Termite mounds, flocking, Sand Dunes
- Artificial: Social Network, Cities, Botnets, Stock market
- More Interestingly
  - *Human intelligence could be an emergent phenomenon (Neural net)*
  - *Consciousness (emergent property of brain)*

Synthetic example



The Central question

How do large systems with

- Simple components
- Limited communication among components
- With NO central controller (Boss)

Give rise to Organized, Adaptive behavior?

The Central question

- Hypothesize the states/attributes of individual components
- Hypothesize behavior
  - *How they interact with other components/environment*
- Validate by simulation and data driven testing

Summary