Adaptive Systems

Lecture 2: Systems

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Canvas discussions

- Everyone can see my answers
- I will normally check these at least twice a week

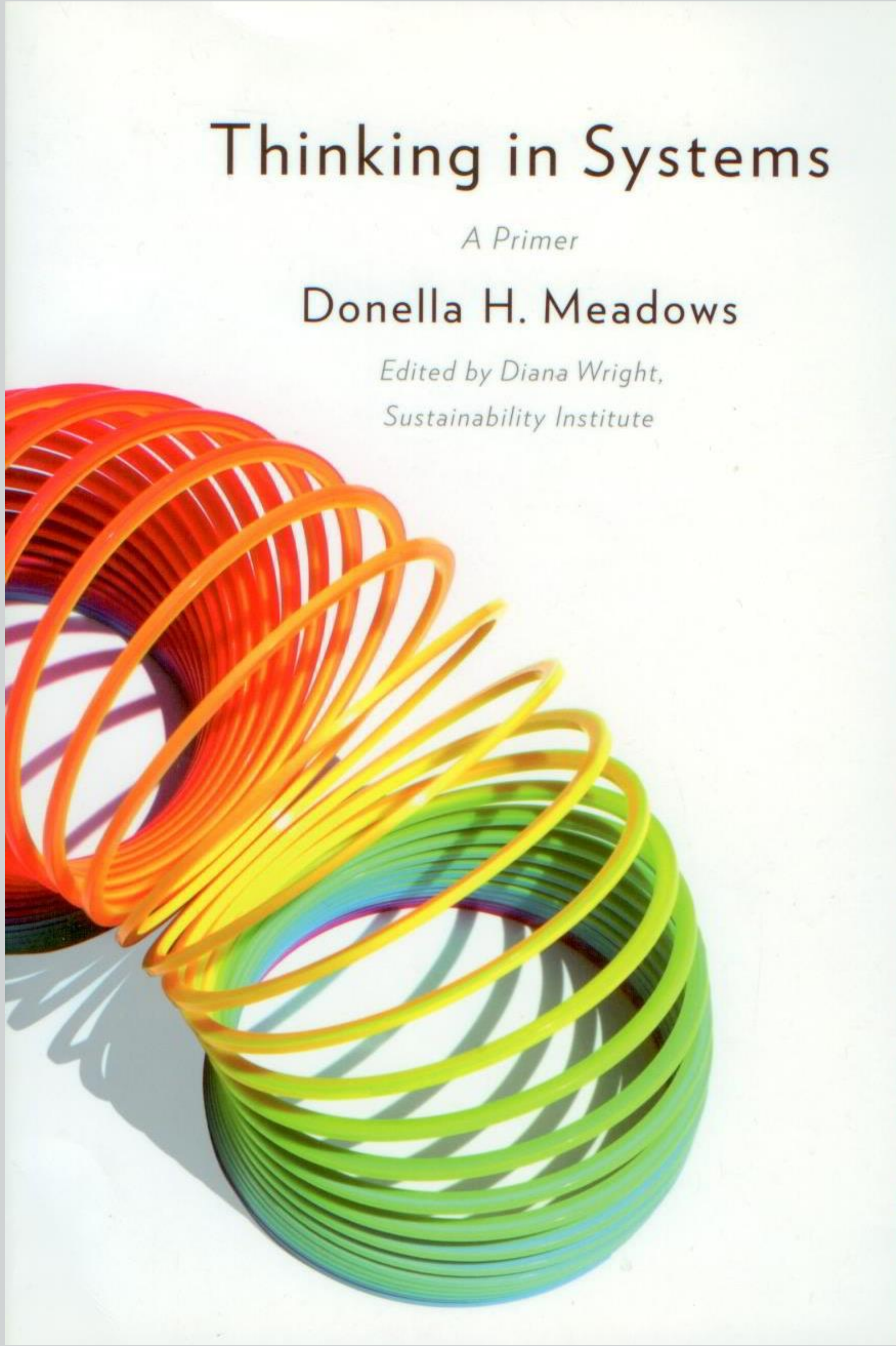
My office hours

- TBD

Lecture learning outcomes

Main points:

1. Systems are *connected* sets of elements
2. Systems are made up of systems
3. A system's environment is also a system
4. Systems are usually *open*, but we can often model them as being *closed*



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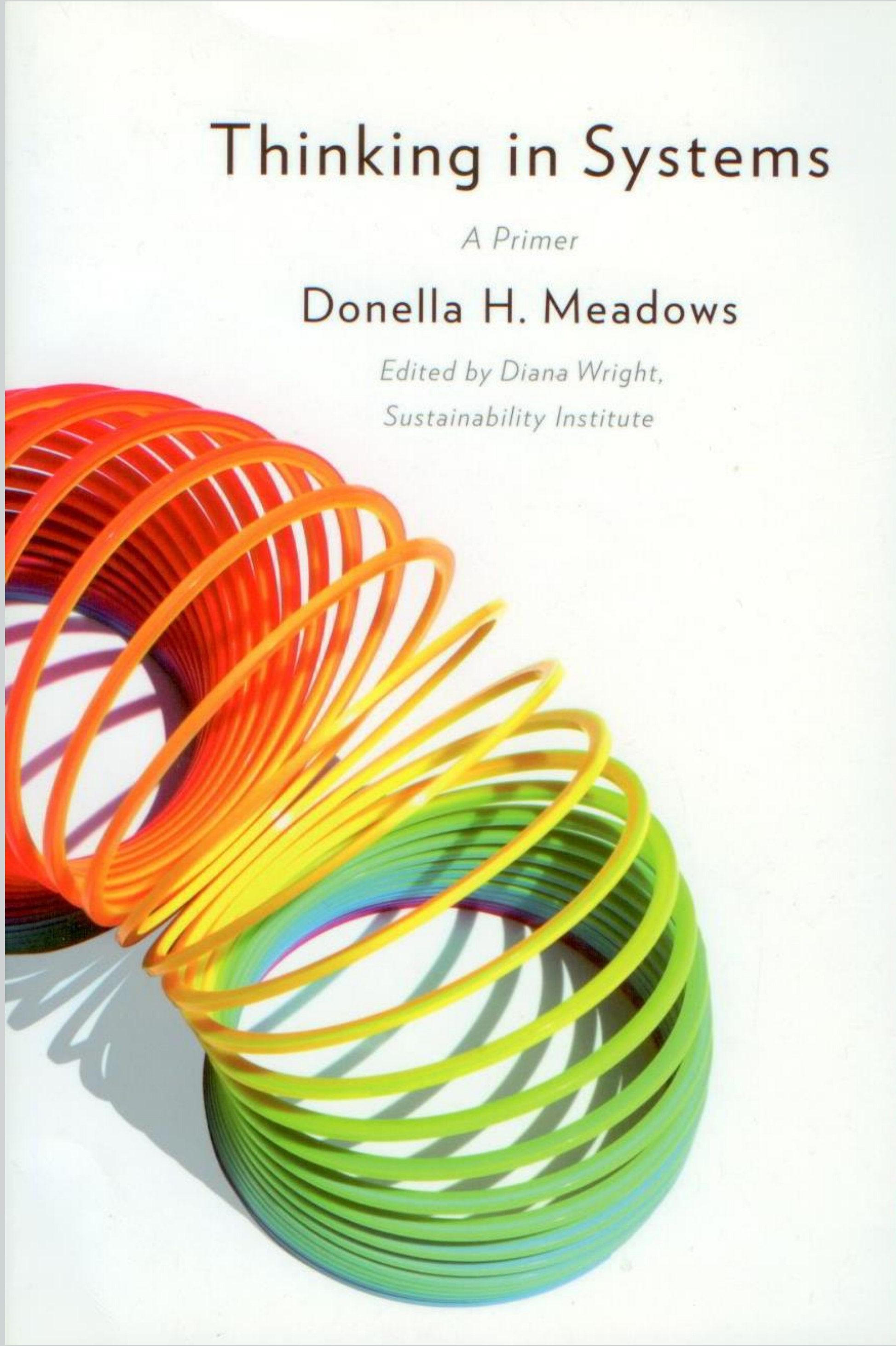
Lecture outline

1. Why use a systems approach?
2. A definition of a system
3. Causal connections
4. Systems and their environments
5. Subsystems and supersystems
6. Overlapping systems
7. Open and closed systems



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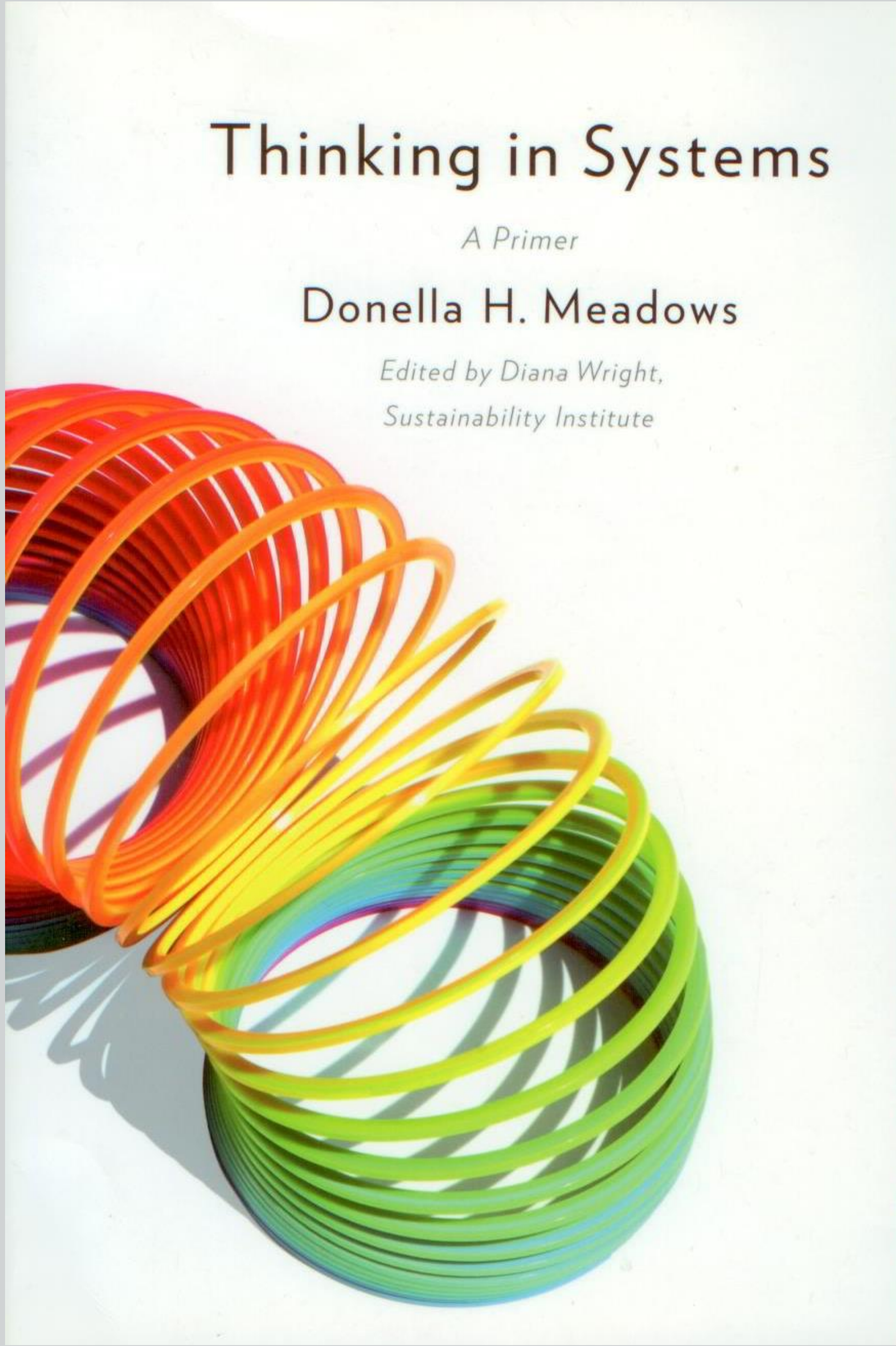
Why use a systems approach?

- The systems approach is holistic: we study *whole* systems
  - In modelling, we use varying degrees of abstraction to make this possible
    - The more complex the system, the more abstraction is likely to be required
- The systems approach is cross-discipline - e.g. it can be applied to all of science and engineering
  - It gives us language, diagrams and tools for describing and comparing systems which may at first appear to be very different to one another
    - (more on this subject in Cybernetics lectures)

An informal definition of a system

- **“A set of elements or parts that is coherently organized and interconnected in a pattern or structure that produces a characteristic set of behaviors, often classified as its ‘function’ or ‘purpose’.” (Meadows) [1]**



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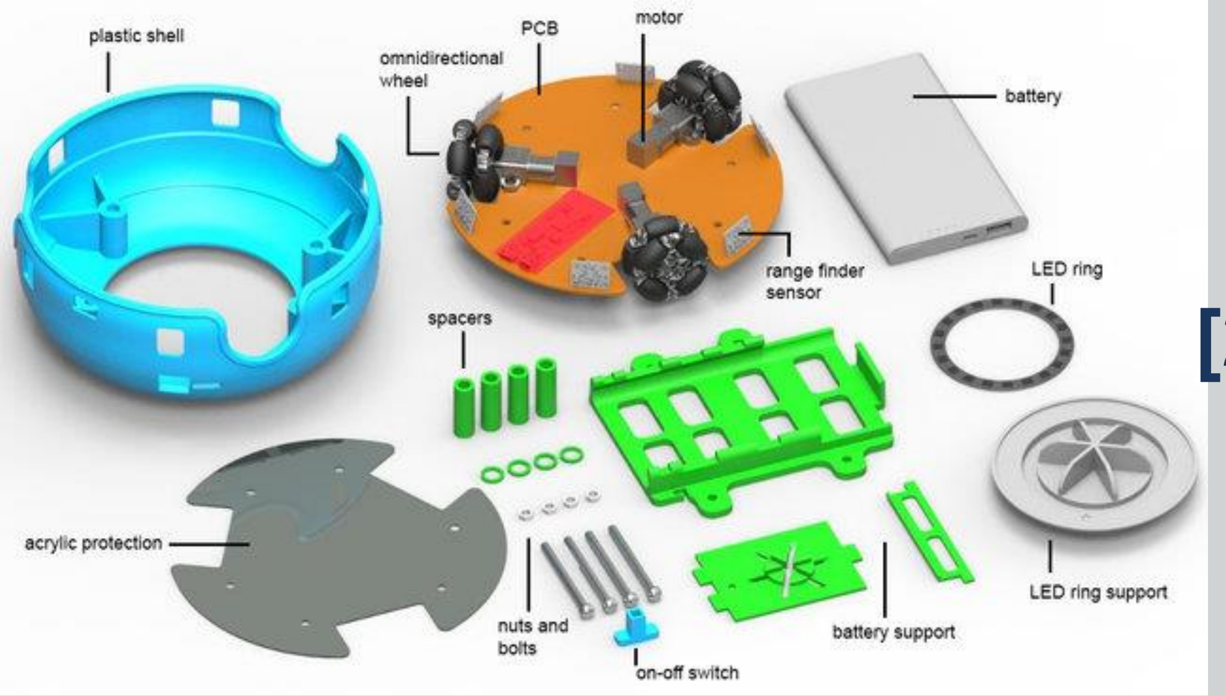

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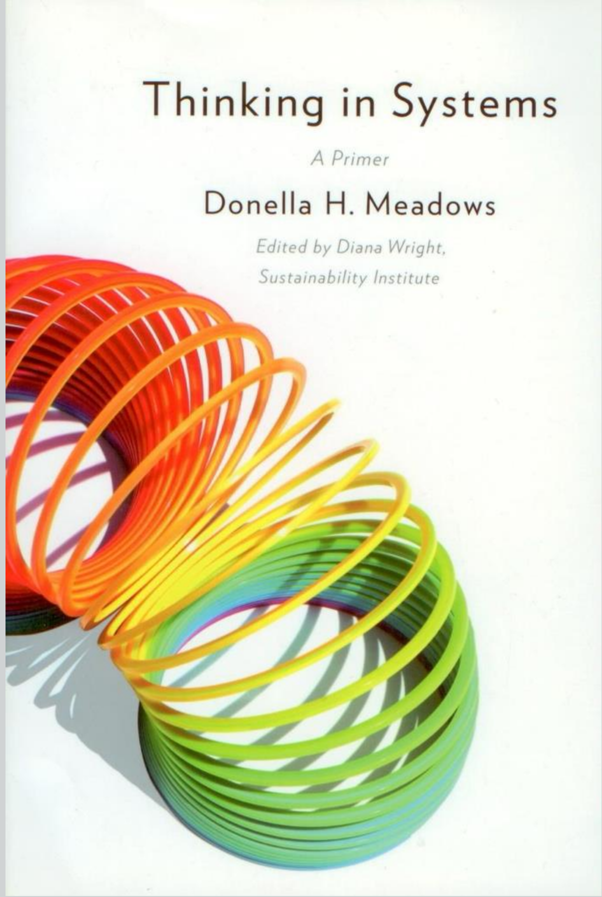

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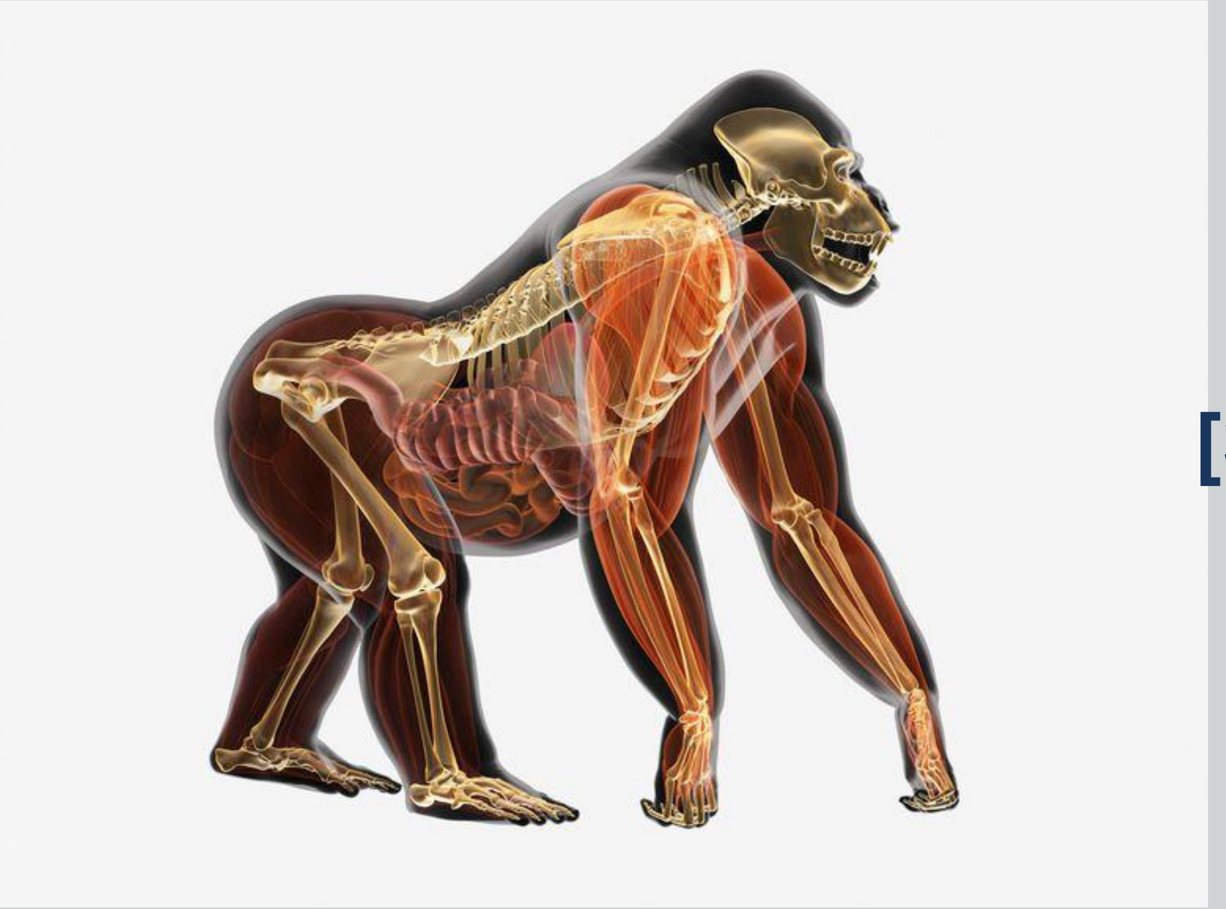

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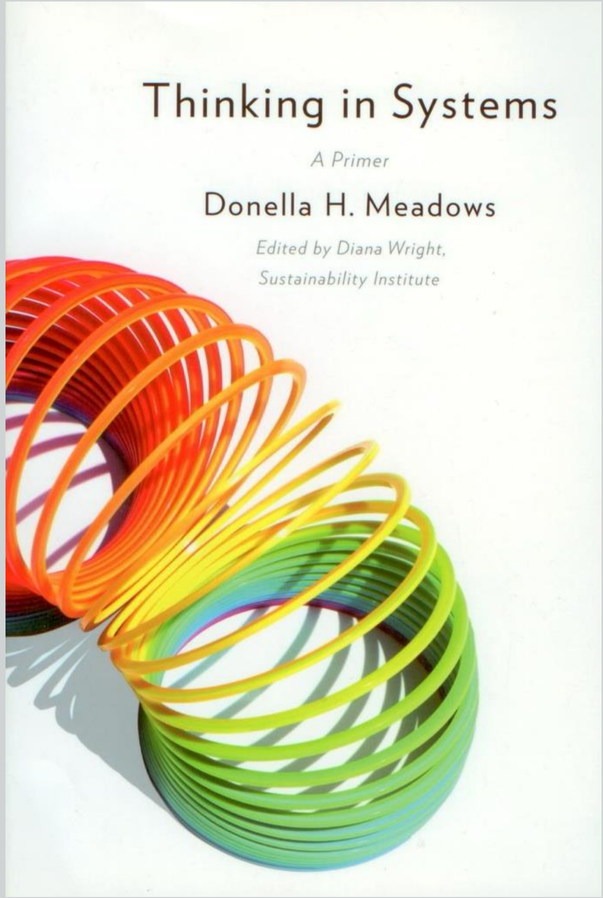

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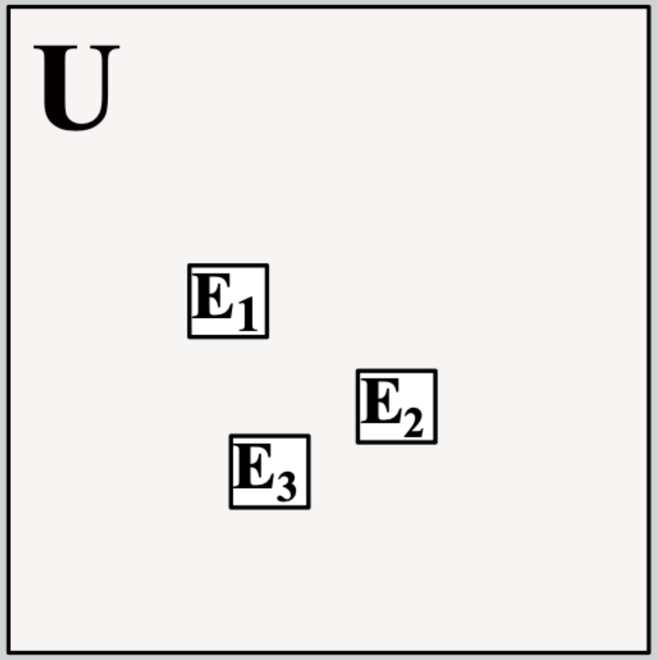
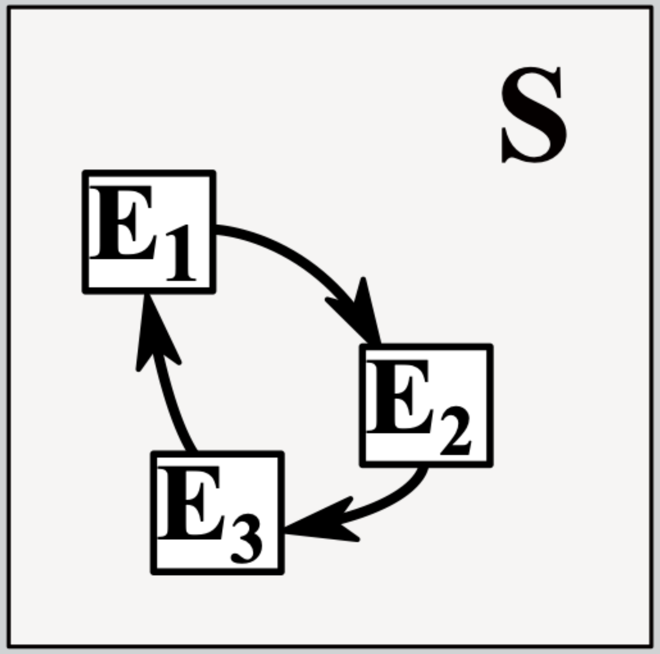


Not a system



A system

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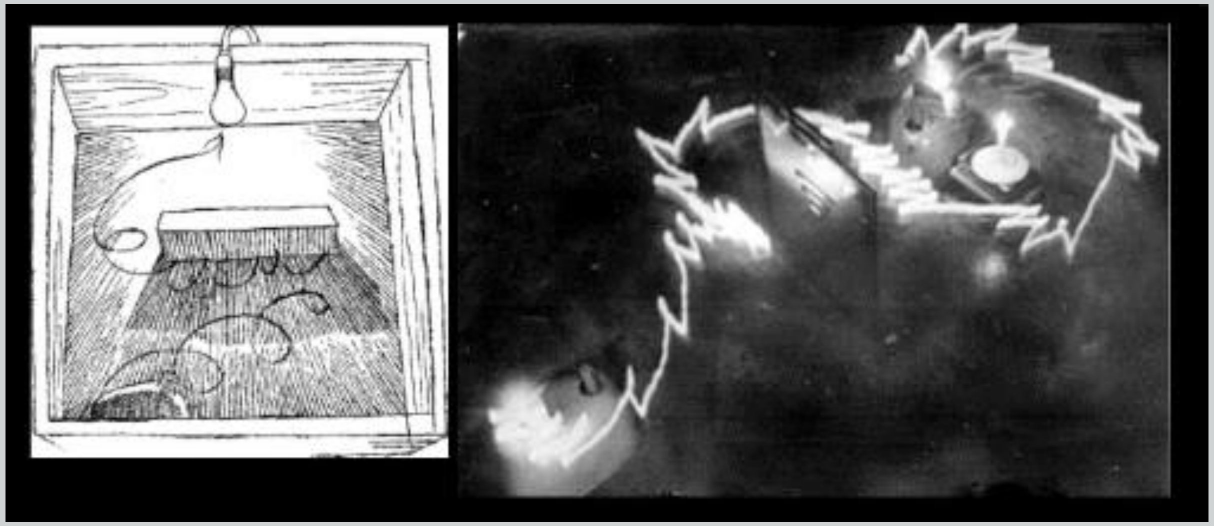
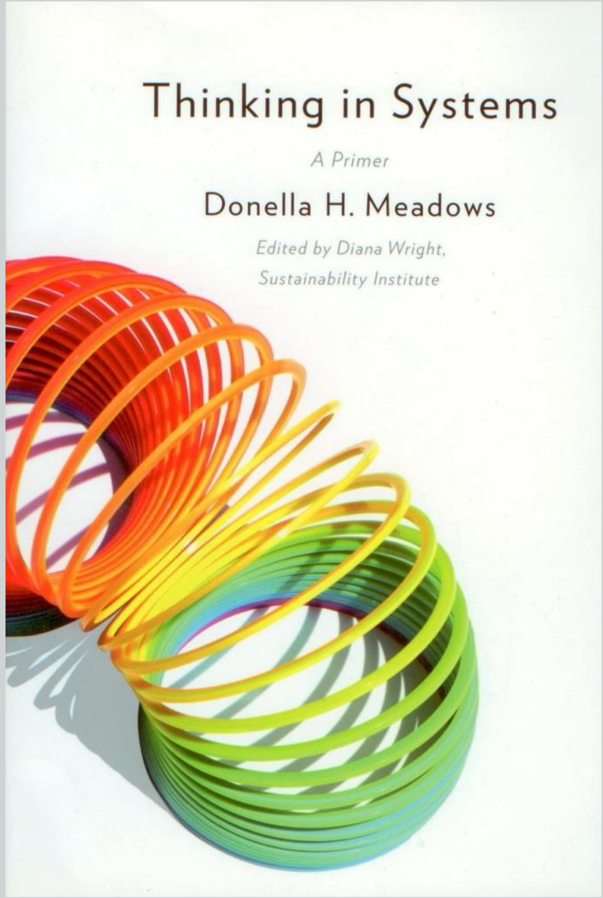


External behaviour



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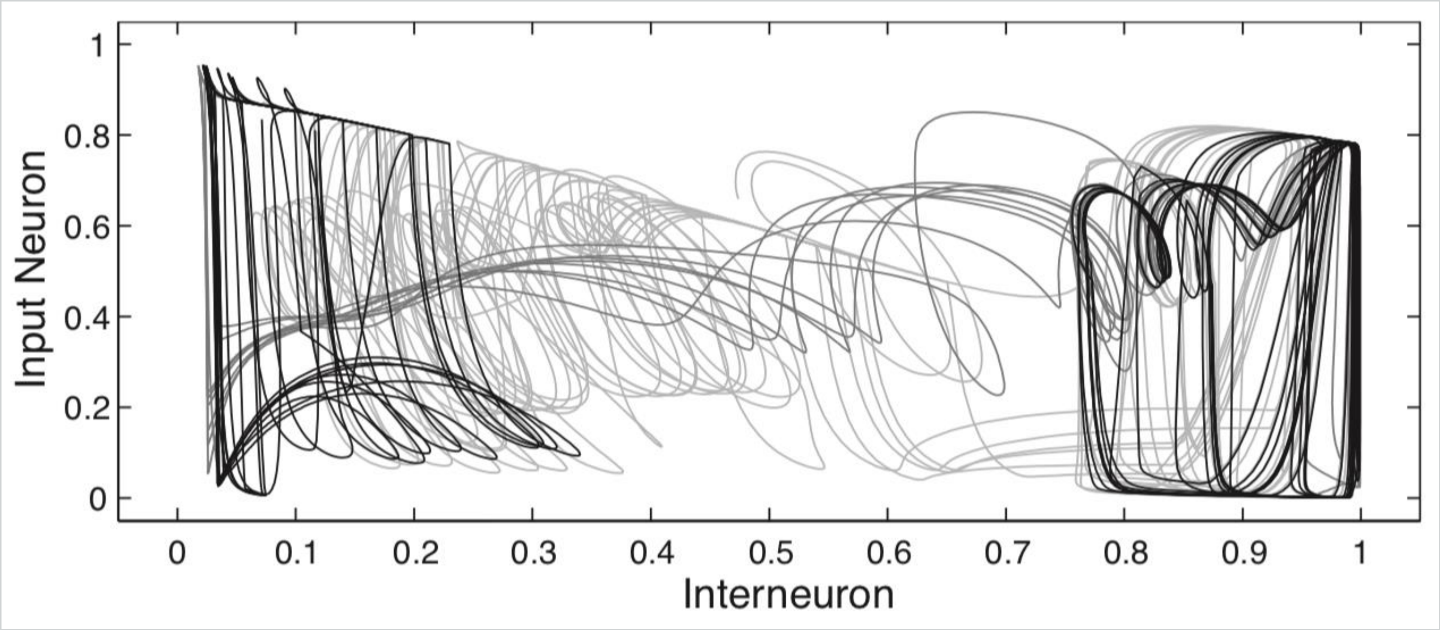

Internal behaviour [5]

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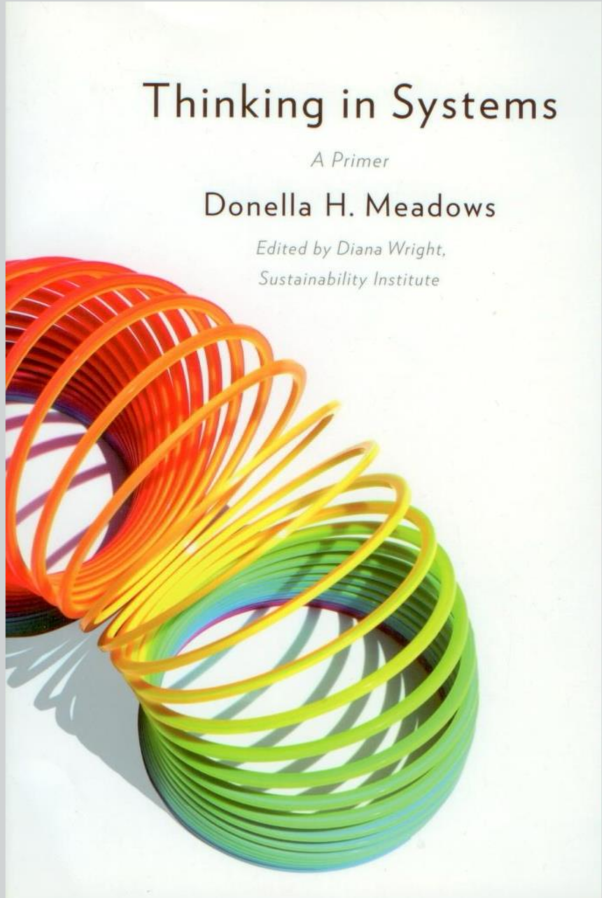


[1]

- The function of an object may be what it was *designed* for
    - e.g. the function of a pen is for writing
- Or it may be what it has *evolved* to do (*discovery*, rather than design)
    - e.g. the function of a heart is to pump blood
- Philosophically speaking, defining the "purpose" of a system is more controversial!

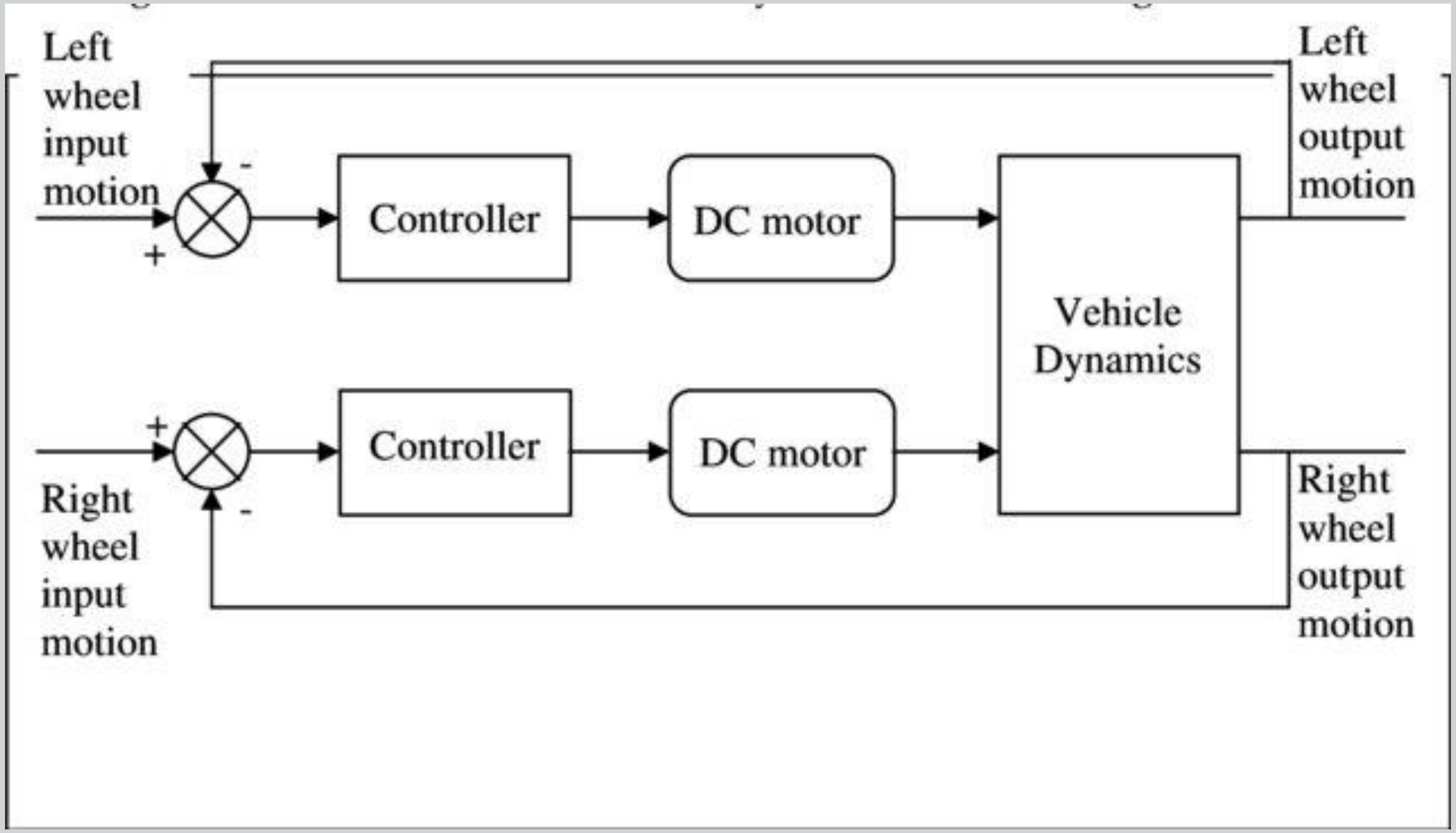
Some basics

Causal connections

System elements are **causally** connected. They can transfer:

- Information
- Energy
- Matter

Or, typically, some simultaneous combination of some of the above



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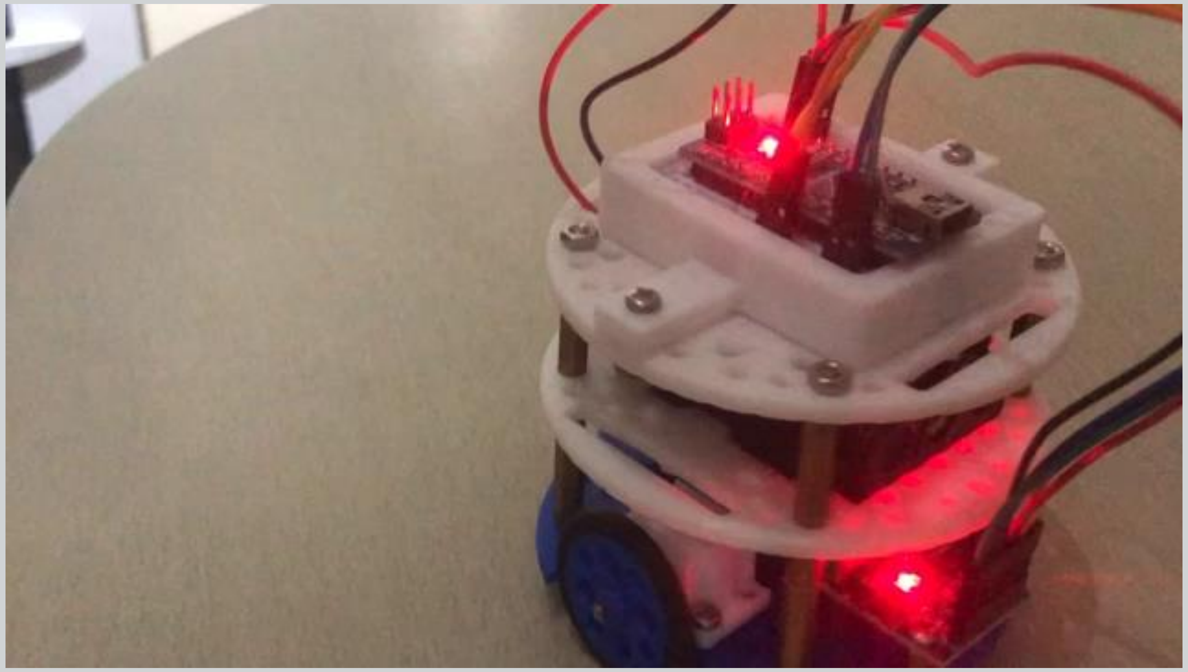
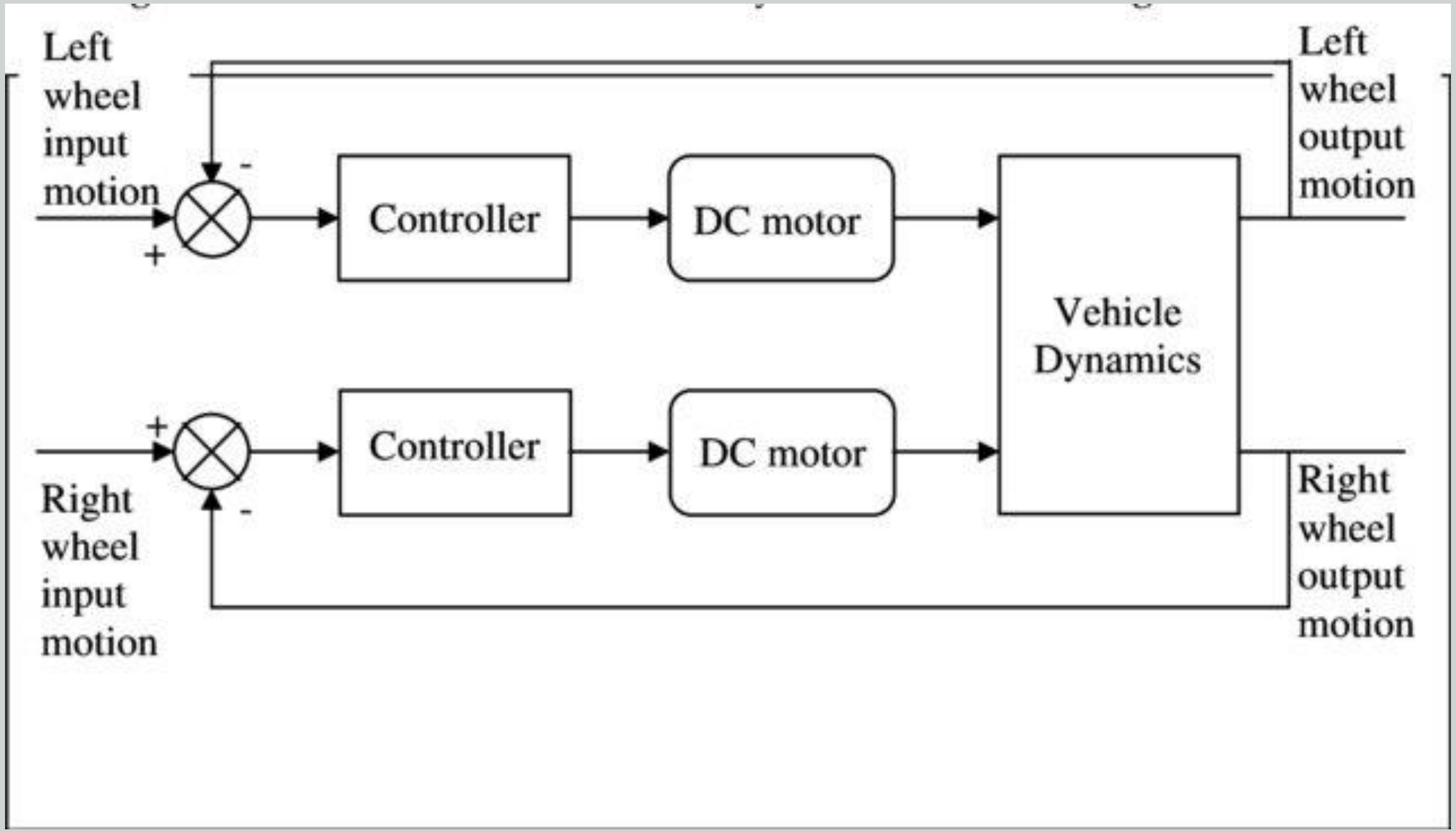


Causal connections

Every arrow in a system diagram represents some kind of causal relationship:

- In this system diagram of a mobile robot, most of the arrows represent electrical signals, or the transmission of *information*
    - We know that this requires energy (electrical), but usually only in very small quantities
- The arrows from the DC motors, on the other hand, represent the transfer of kinetic *energy*
    - In this case, the quantities of energy involved are large, but the quantities of information *may be* very small



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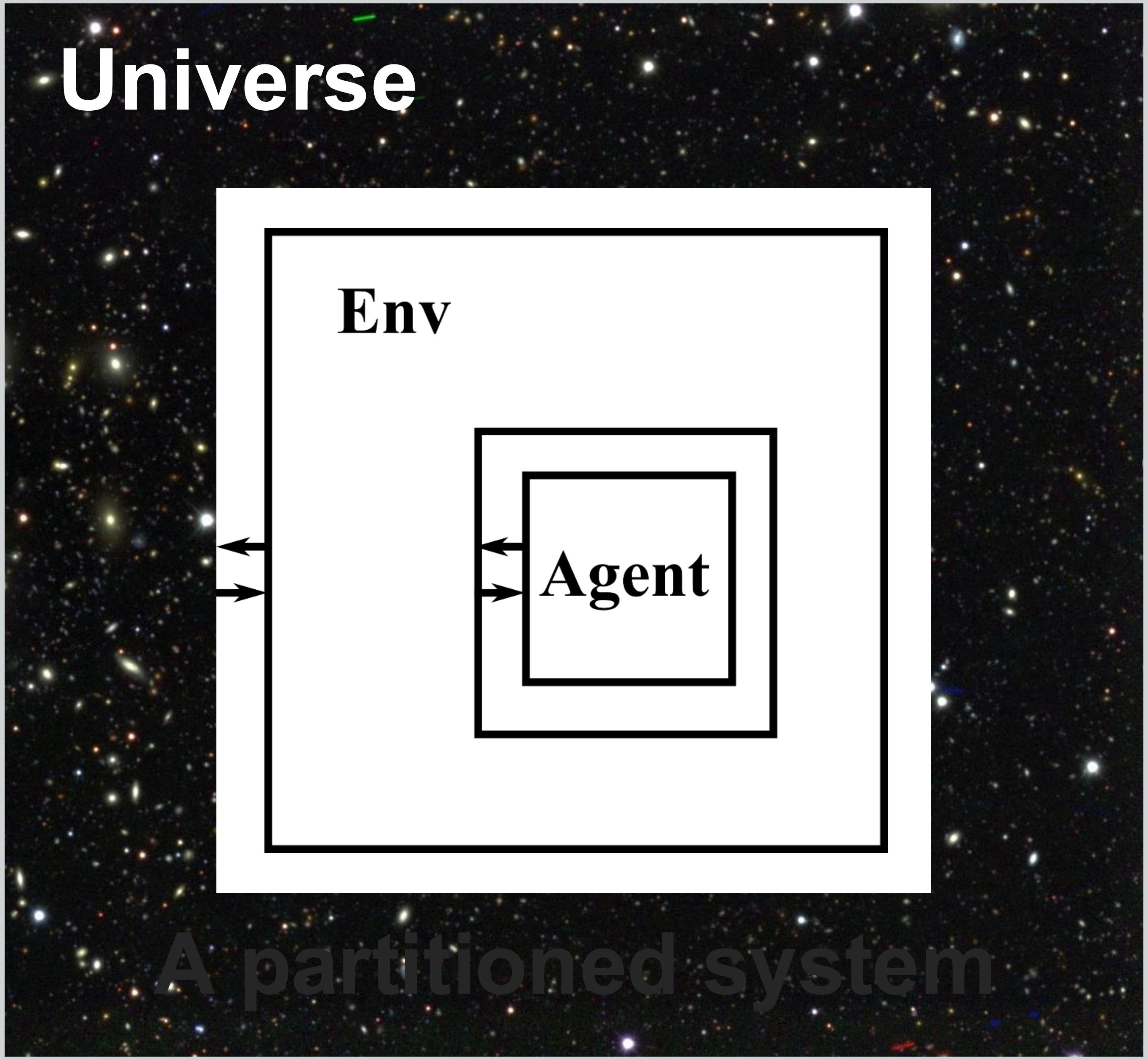
Systems and their environments

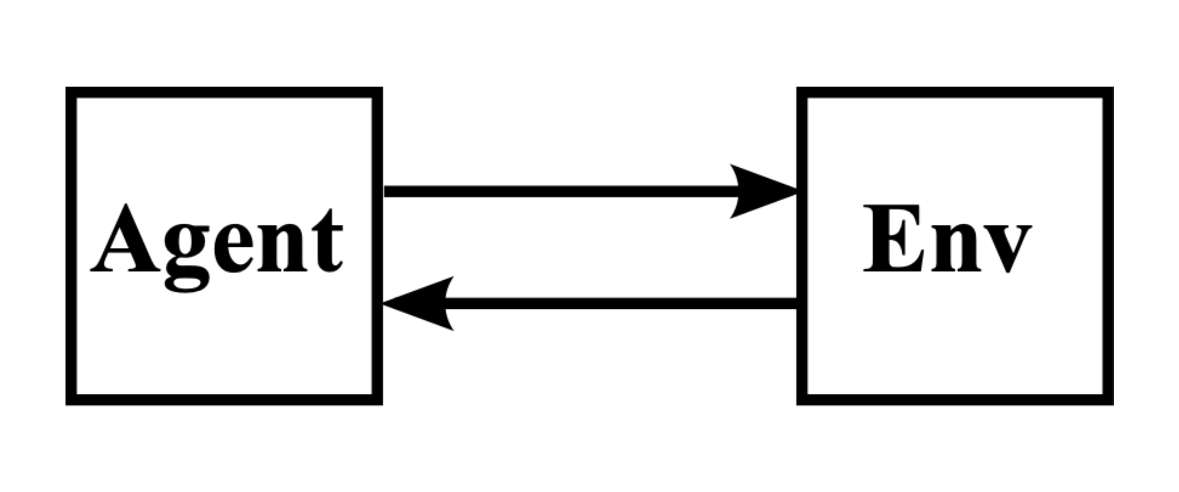
Defining systems by partitioning

- When we define a system by its boundary, we make a partition between system and environment
    - Or often, an agent and its environment, as in this case
- We may also differentiate between the agent's immediate environment and the rest of the universe



- (Later, we will encounter the *umwelt*, which clarifies the concept of an agent's environment further)

Systems and their environments

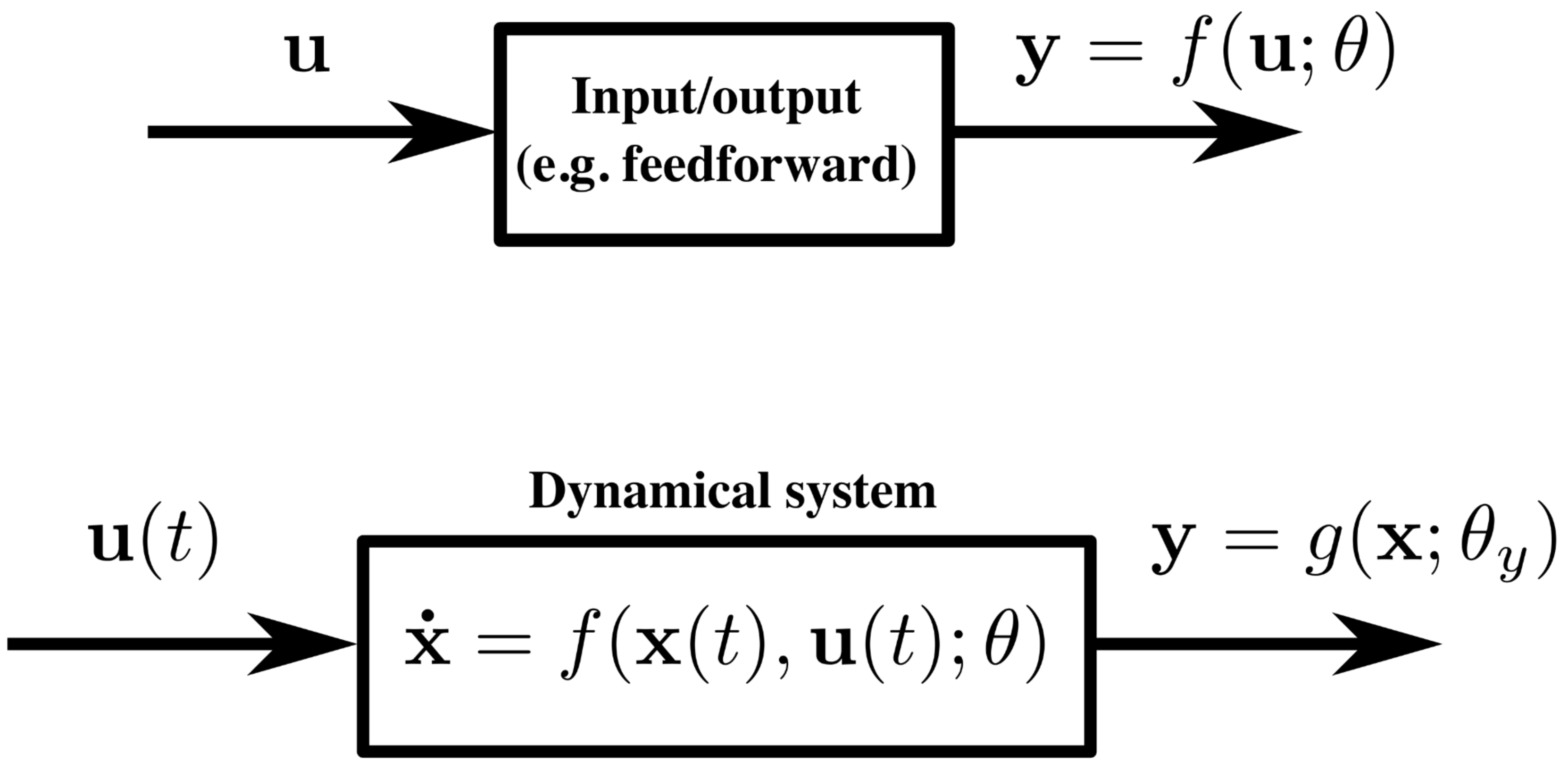


Coupled systems

- In this diagram, we have an arrow from the environment to the agent, and an arrow from the agent to the environment
- This is an example of a **closed loop** or **circular causality** in a system, where each subsystem has an effect on the other
  - And therefore, on itself! (Agent affects Env, which affects Agent, and so on)
- We will see a lot more about closed loops later

Brief look forwards

Systems and their parameters



$$\theta = \begin{bmatrix} \theta_1 \\ \theta_2 \\ \vdots \\ \theta_p \end{bmatrix}$$

$$\mathbf{u} = \begin{bmatrix} u_1 \\ u_2 \\ \vdots \\ u_l \end{bmatrix} \qquad \mathbf{x} = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} \qquad \mathbf{y} = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_m \end{bmatrix}$$

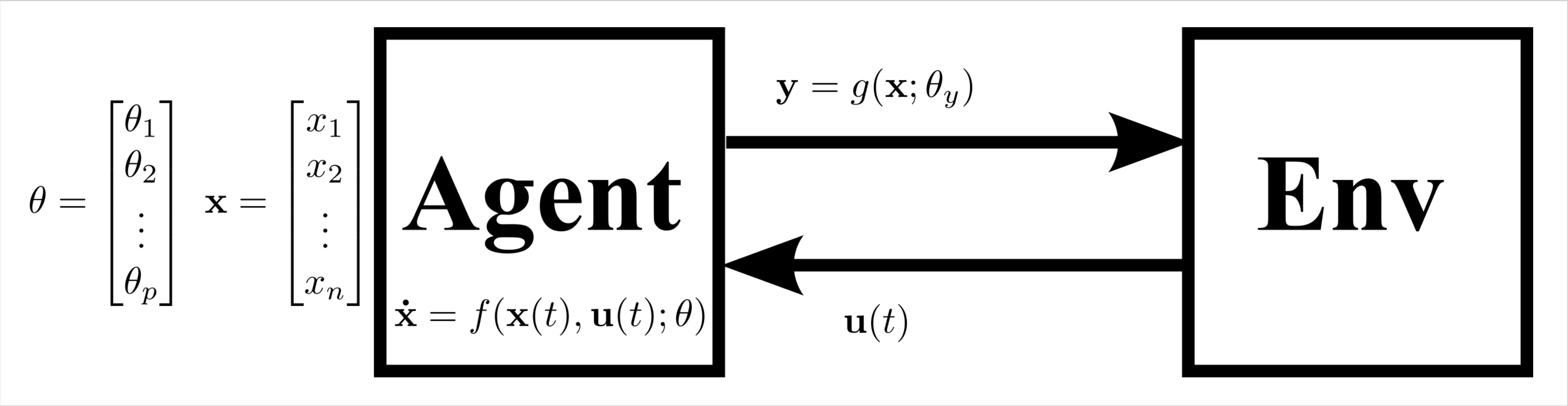
Systems and their parameters

Why, when, and how?

- Often, the power of a system to adapt (or be adapted) will lie in its parameters
- Which leads an adaptive system designer to the following questions:
  - **Why** do we want (or need) to adapt the system?
    - i.e. what do we hope to achieve?
  - **When** do we want (or need) to adapt the system?
    - i.e. when should we adjust its parameters?
  - **How** should we adjust its parameters?
    - i.e. through which mechanisms or algorithms?

$$\theta = \begin{bmatrix} \theta_1 \\ \theta_2 \\ \vdots \\ \theta_p \end{bmatrix}$$

Systems and their environments



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    - And therefore, on itself! (Agent affects Env, which affects Agent, and so on)

- We will see a lot more about closed loops later

Continuing with some basics

Subsystems

“Zooming in” on a system

- **An element in a system is often also a system**
- **When this is the case, we can refer to the element as a subsystem**
    - **Example: an artificial neural network (ANN) is a system**
        - **And it is composed of other systems:**
            - **Each artificial neuron is a subsystem of the ANN**
            - **Each *connected* group of neurons is also a subsystem of the ANN (two are shown in the diagram)**

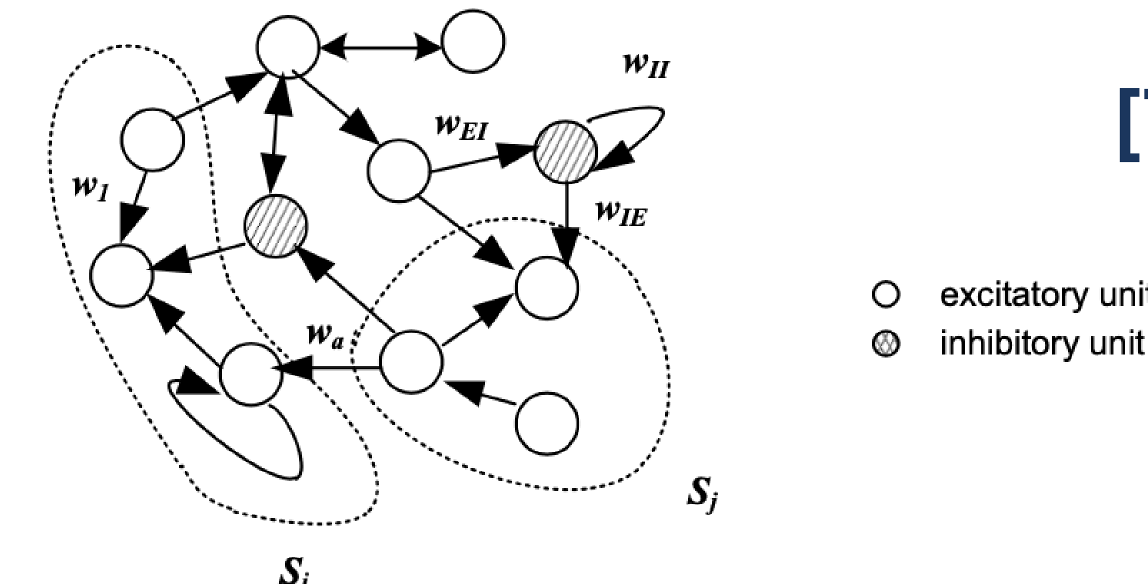
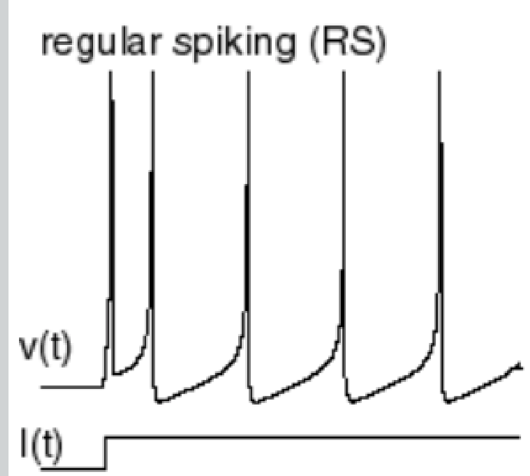


Figure 1 A schem… spiking neural network.

[7]

$$v' = 0.04v^2 + 5v + 140 - u + I$$
$$u' = a(bv - u)$$

if $v = 30$ mV,
then $v \leftarrow c$, $u \leftarrow u + d$



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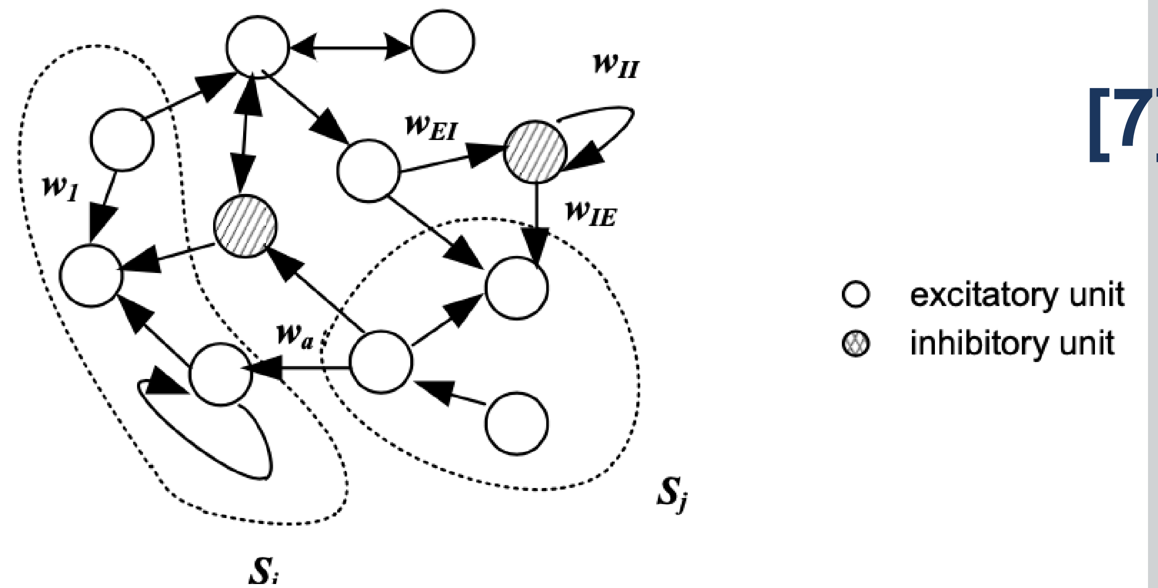
Izhikevich model neuron

Subsystems

What are the subsystems of a neuron?



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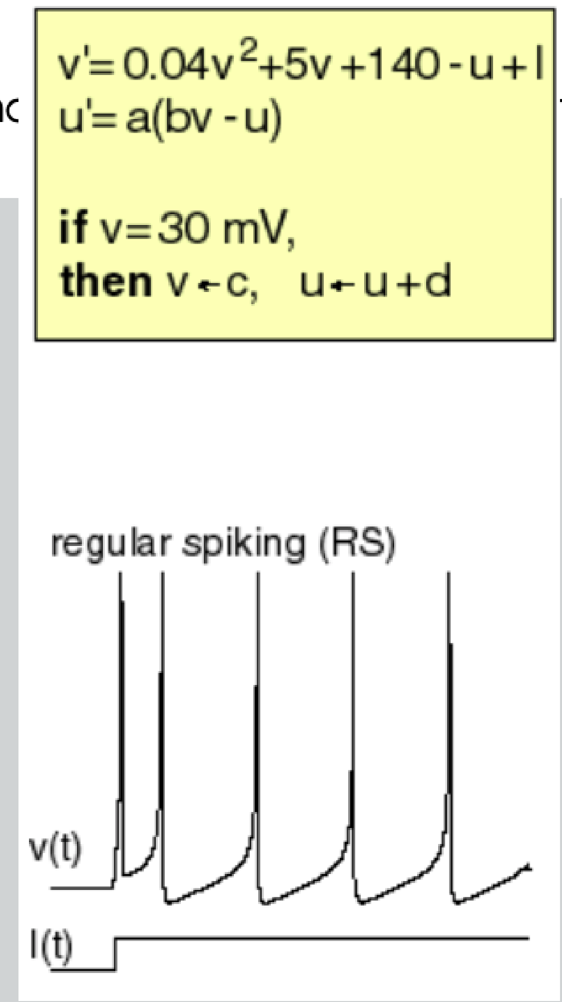


[8]

Izhikevich model neuron

Supersystems

Zooming out

- **We saw before that a system and its environment can be viewed as coupled systems,**
- **But an environment, *together with* the systems in it, can also be viewed as a supersystem**

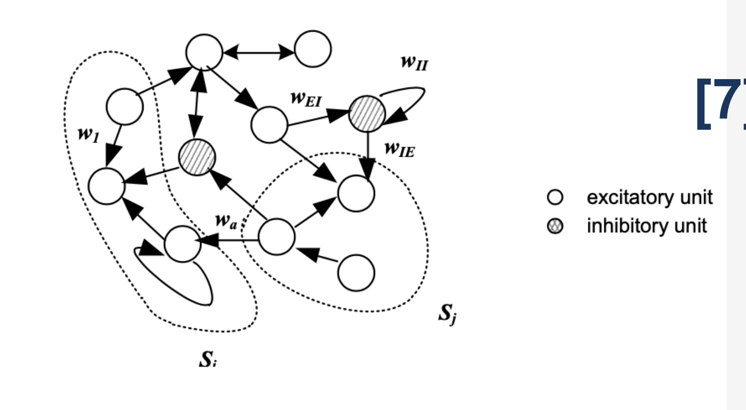
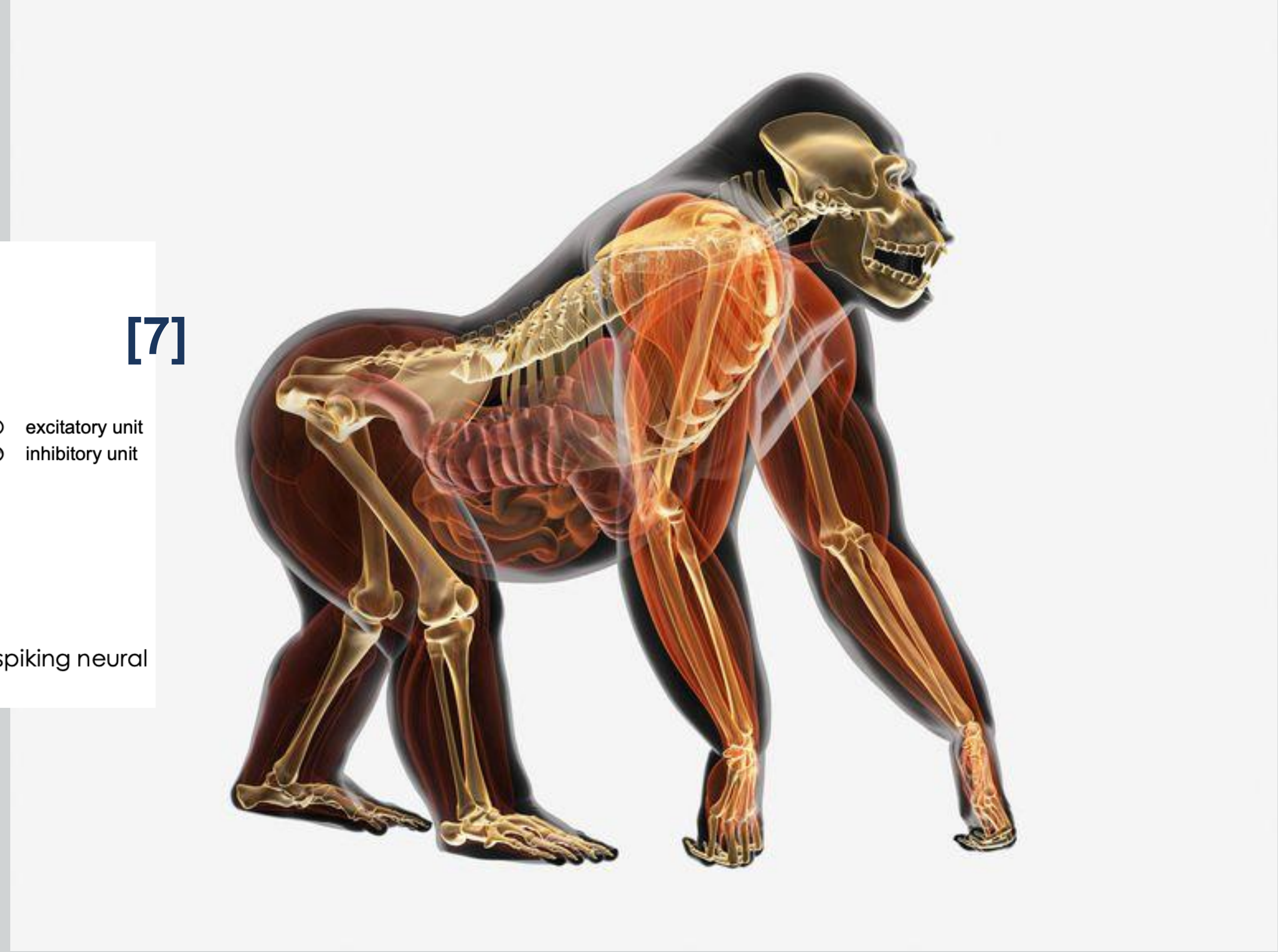


Figure 1 A schematic diagram of a recurrent spiking neural network.

[7]



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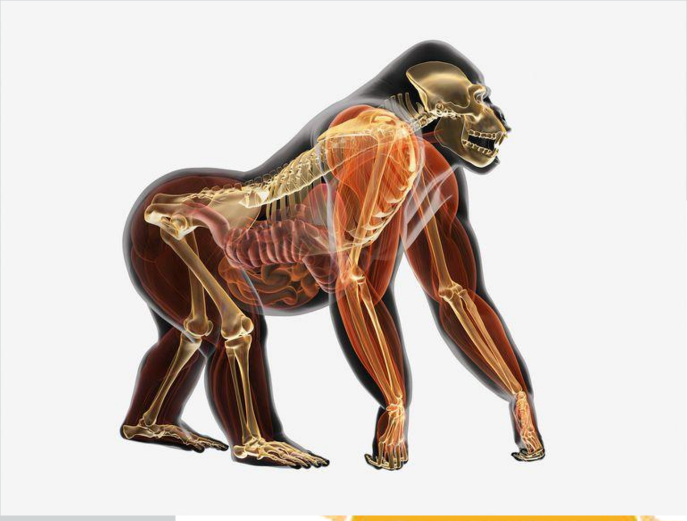
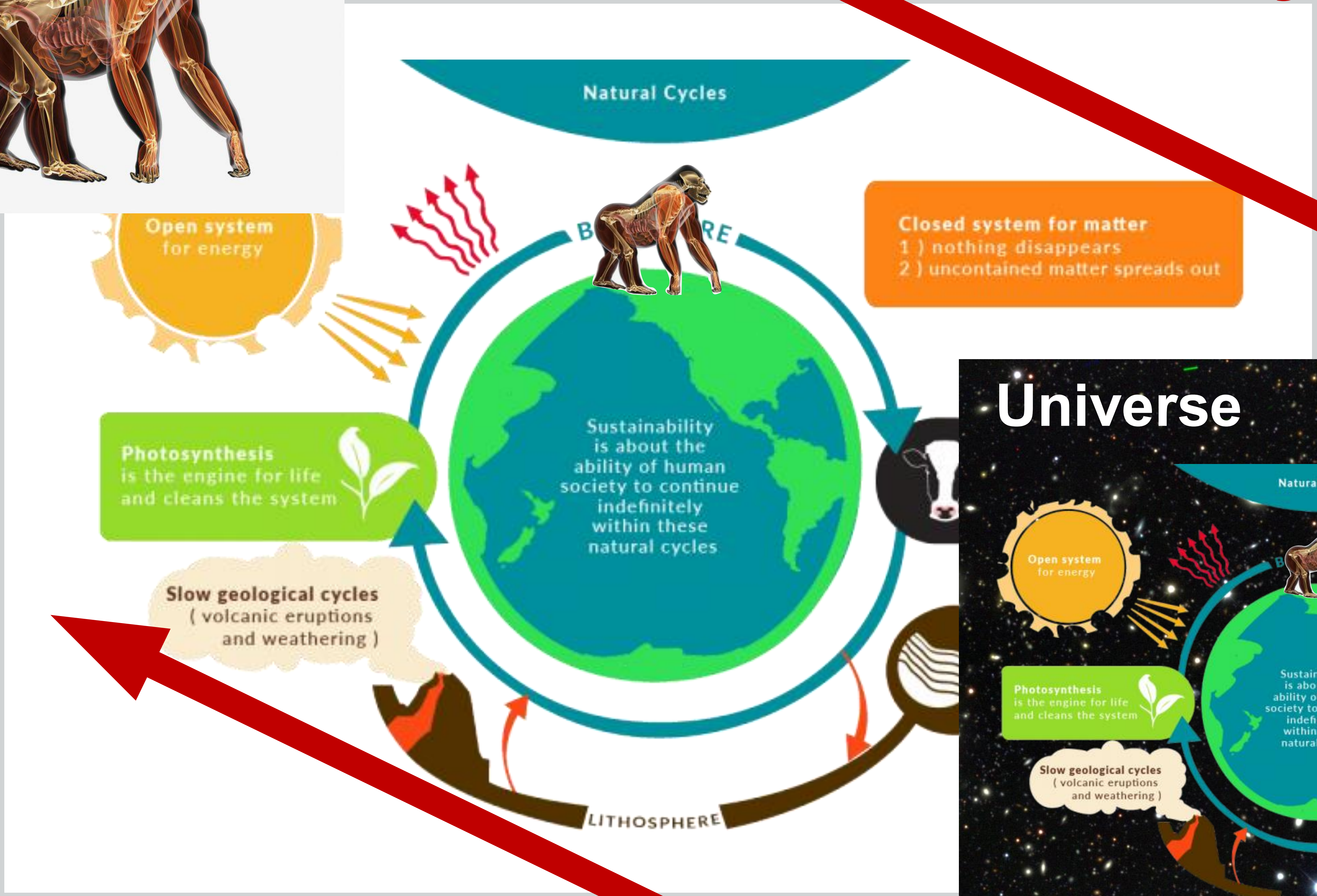
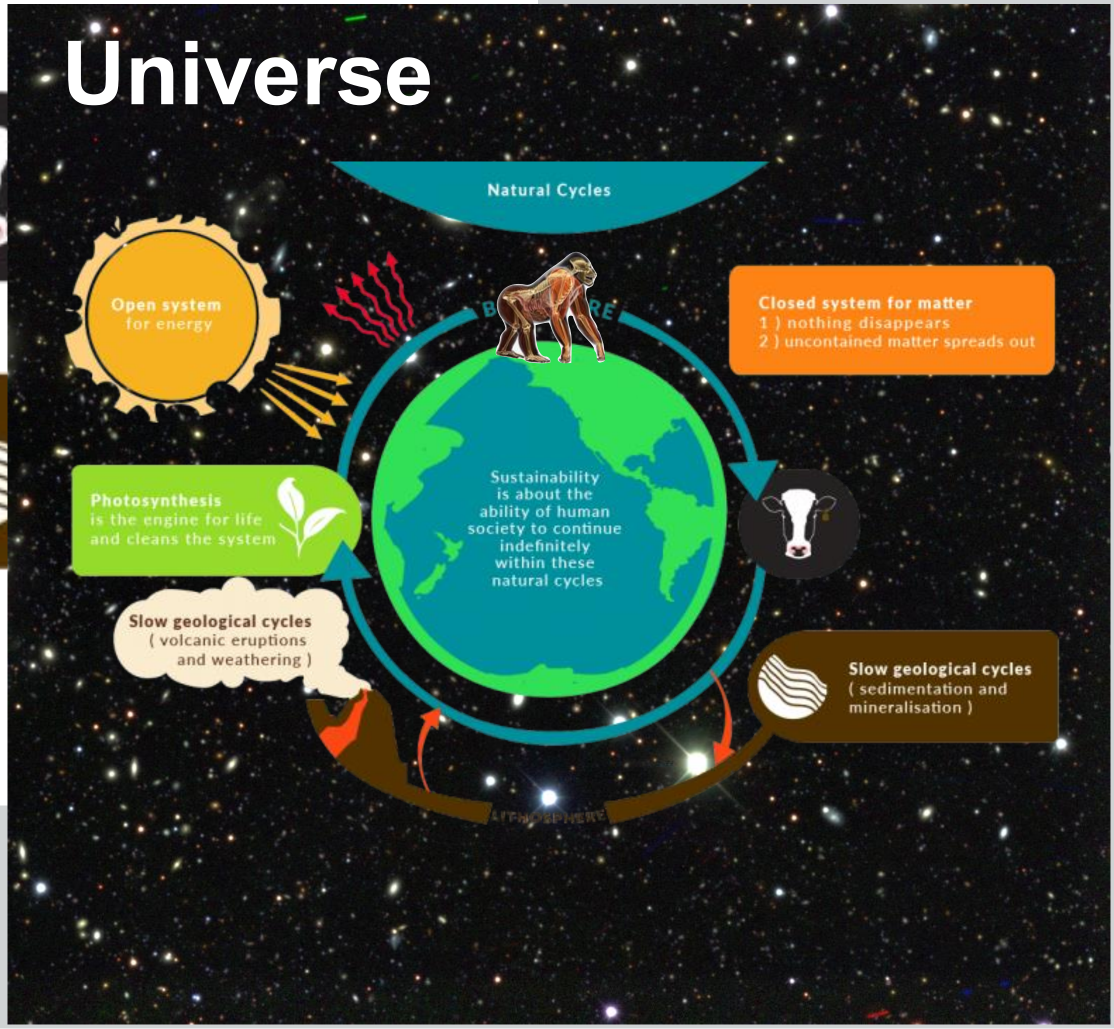
Supersystems



Supersystems

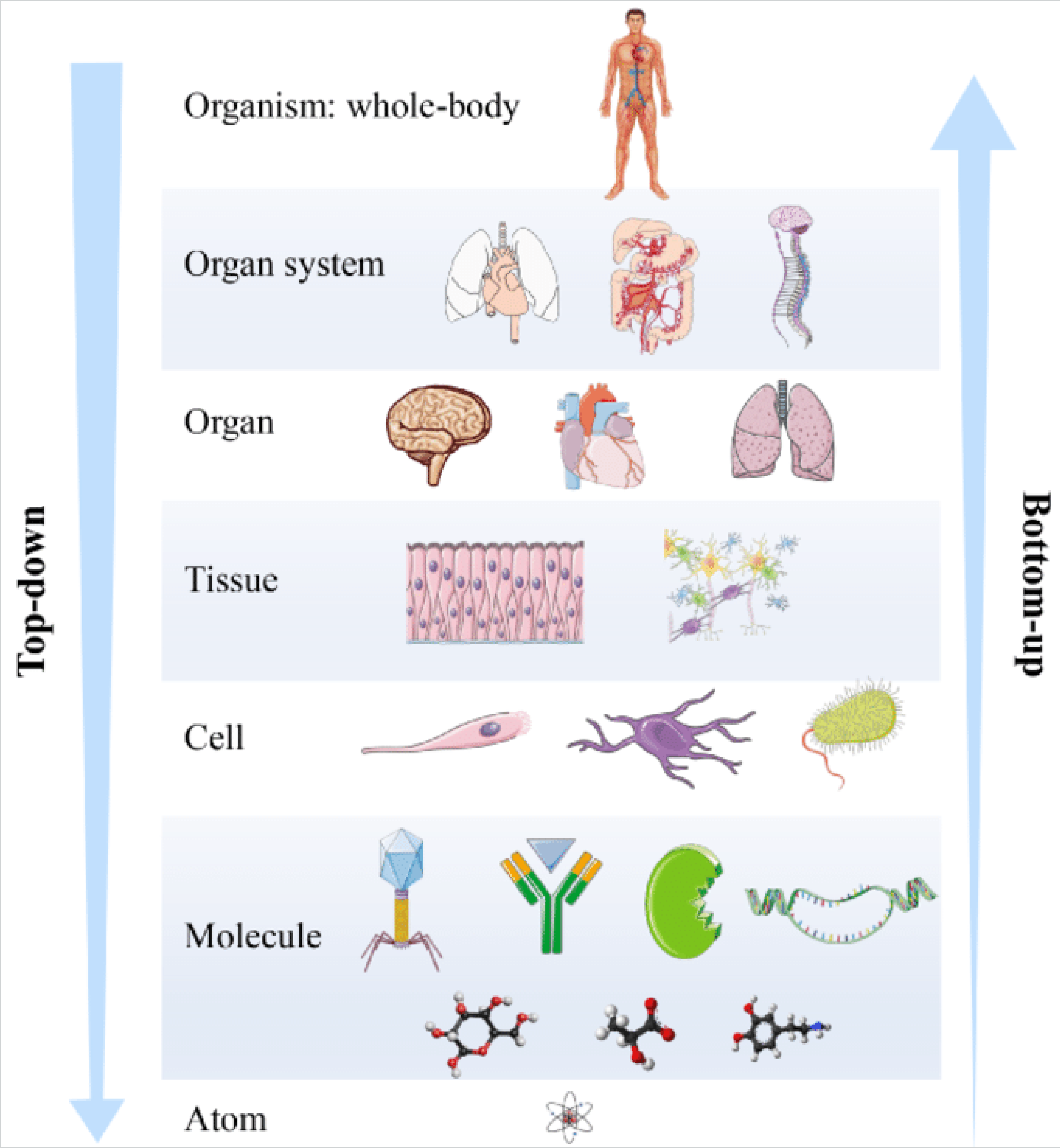




Subsystems

Hierarchies

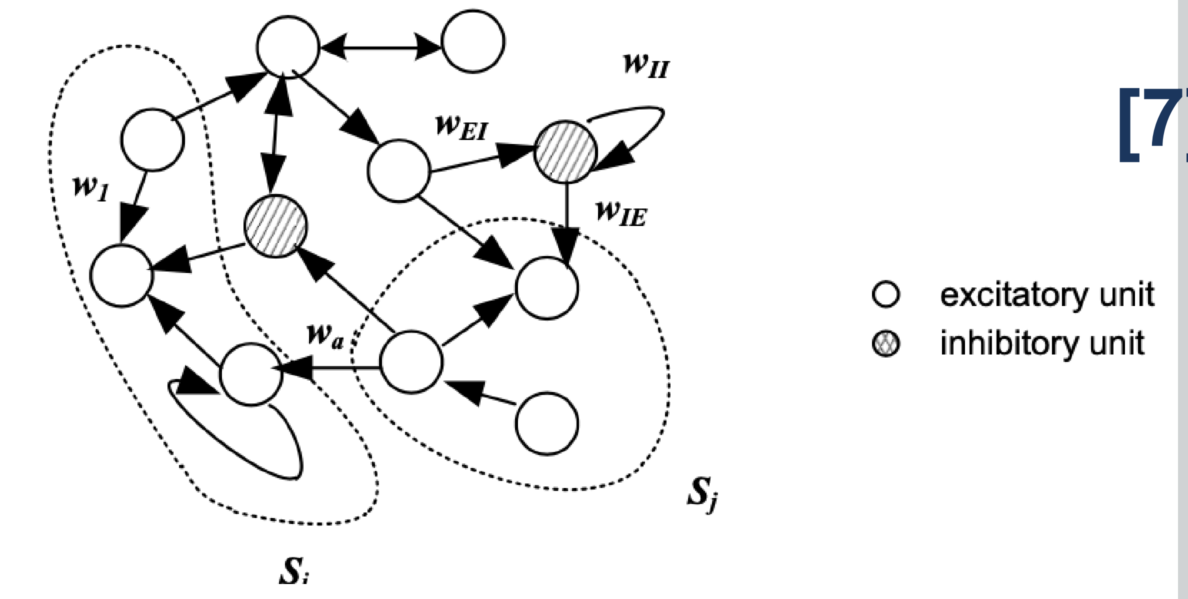
- Complex systems are often hierarchical
  - Systems made of systems, with an increasing number of subsystems from higher to lower levels
- Holism vs reductionism?
  - Some argue that the holistic approach of systems theory is opposed to reductionism
    - Holism moves towards higher levels
    - Reductionism drills down to lower levels
  - But this is a false dichotomy
    - Good systems thinkers move or and down through the levels as the moment requires



[13]

Overlapping systems

- In the ANN (or spiking neural network, SNN, to be precise), S_i and S_j indicate subpopulations of neurons
    - Or subsystems of the larger SNN system
- Although some groupings of connected neurons may be more logical than others (e.g. because they have similar properties, or because their behaviours are highly correlated), in principle we can define many subsystems here



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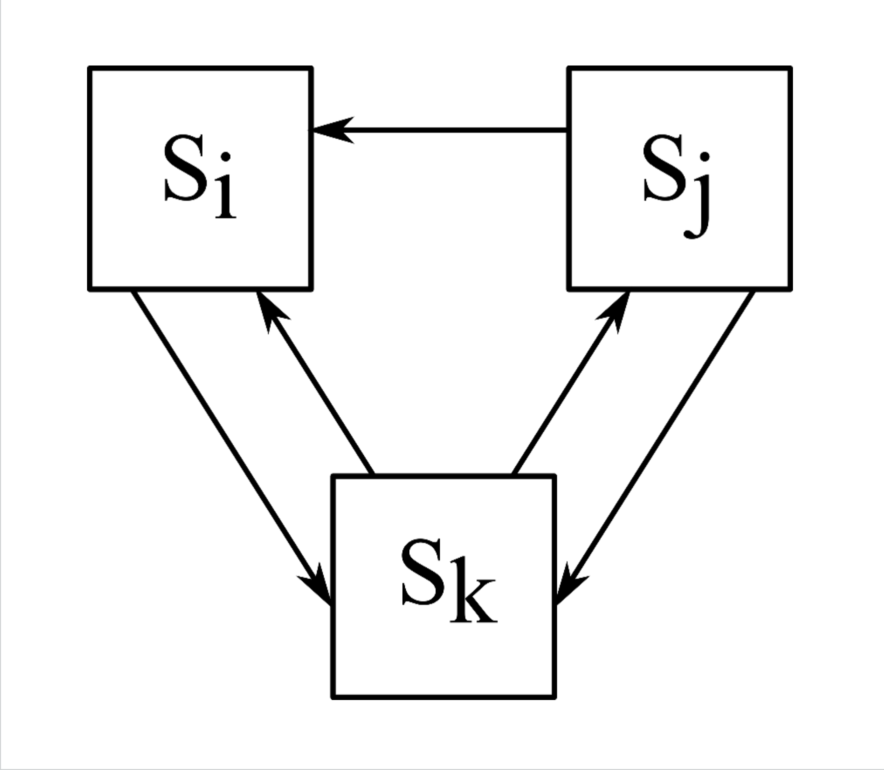

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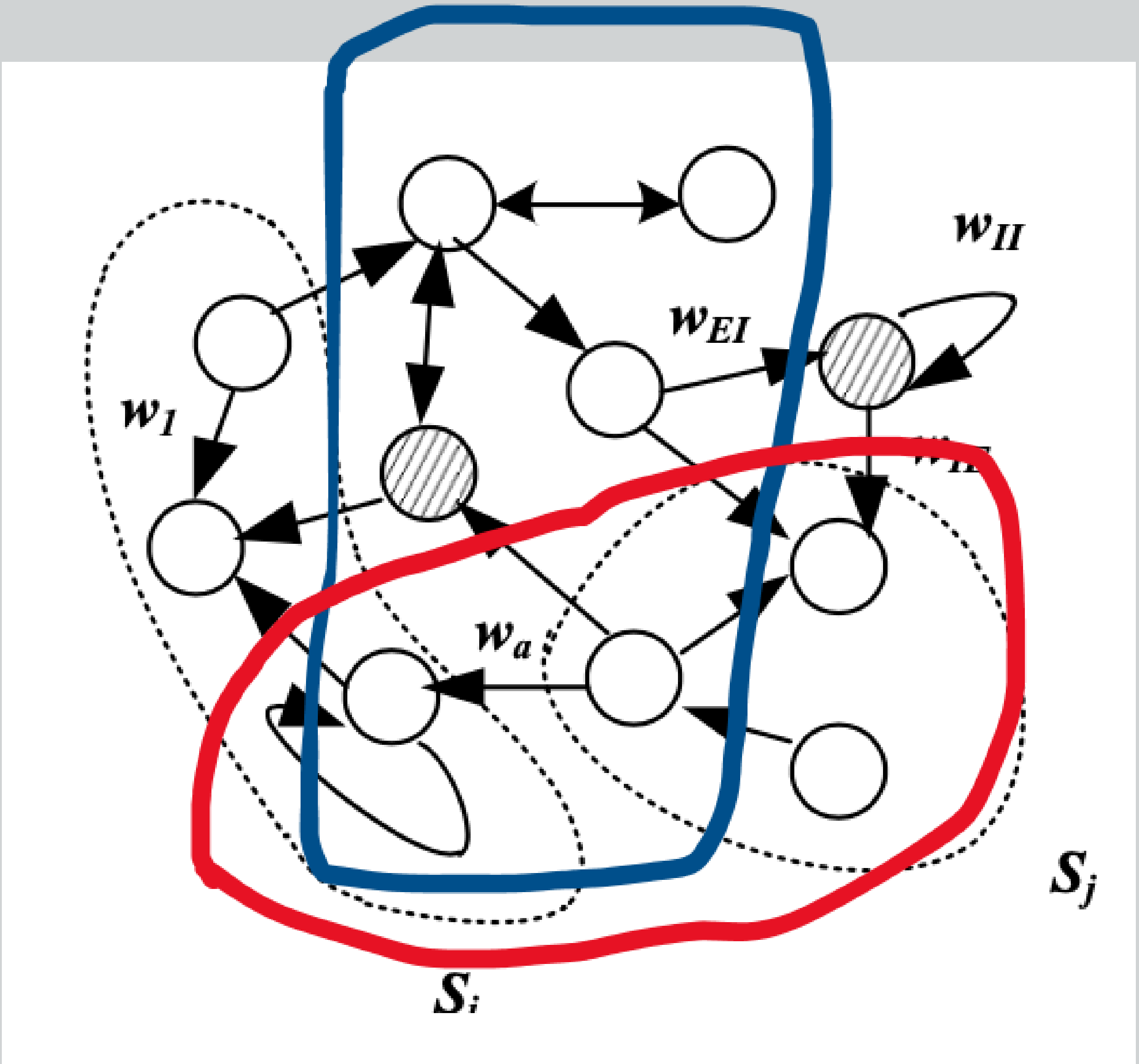
  - Which groupings are more or less valid is not immutable - this depends on what it is we are trying to study
  - Some will have sub- and super-system relationships
  - And some will overlap



[7]

Overlapping systems

- In the top diagram, we see a model of a sensorimotor system
- The model includes:
  - Part of a human's nervous system (and brain)
  - The human's arm
  - the human's eyes
- The model does not include:
  - The human's heart
  - The human's nose
- It also only includes only some objects or features from the human's environment

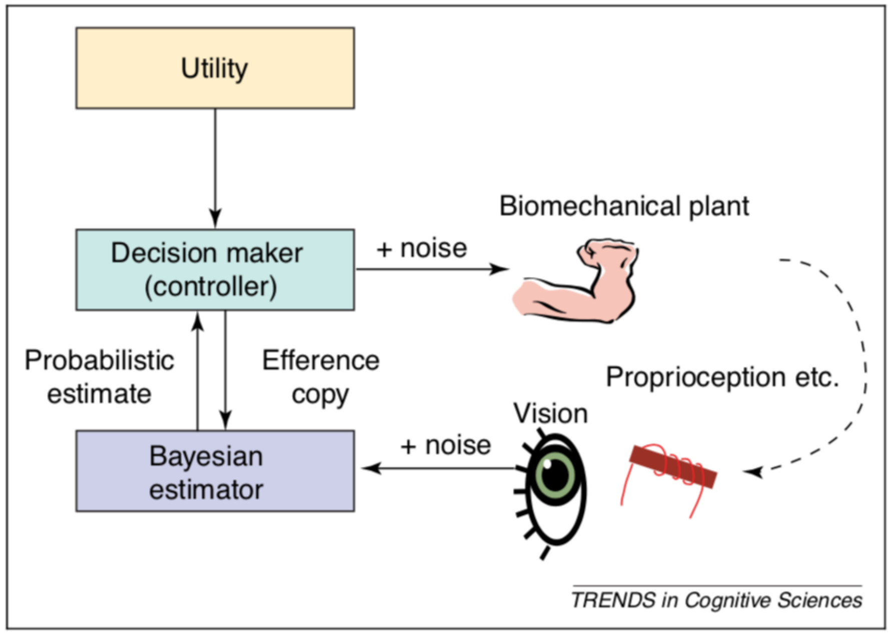
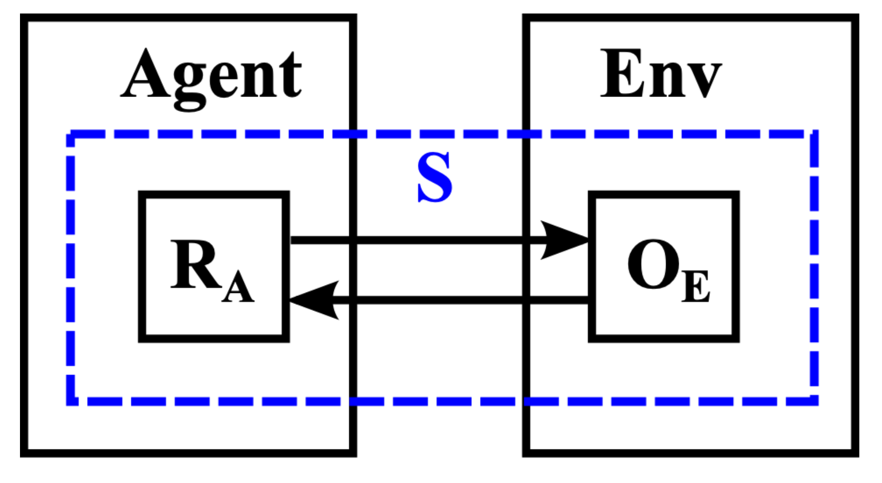


Figure 3. Optimal controllers. In generating a movement, the controller, an optimal decision maker, takes into account both the output of the Bayesian estimation process as well as the utility function. The Bayesian estimator combines inputs from the sensors (for example, about limb positions) with prior knowledge in addition to the efference copy – the signal sent by the CNS to the muscles.

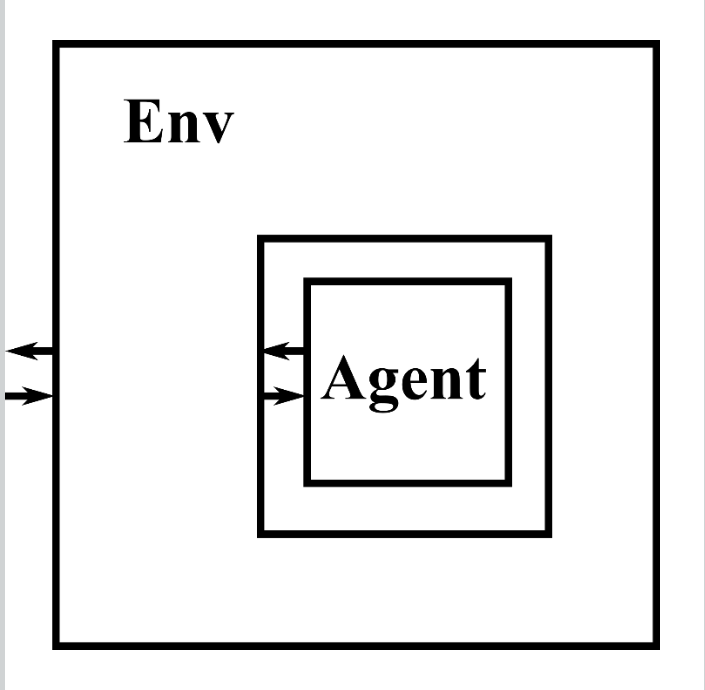
[9]



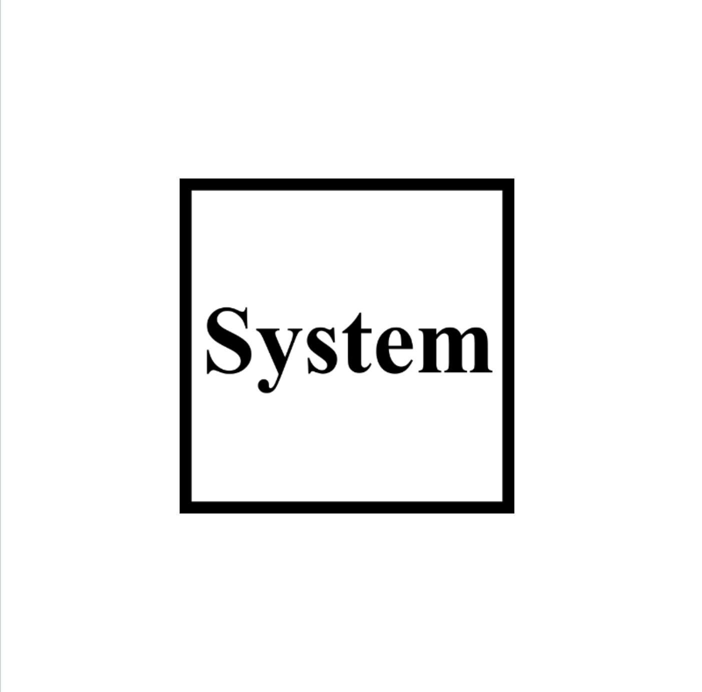
The system S is a coupled system of subsystems in Agent and Environment

Open and closed systems

- Systems can be **open** or **closed** (or isolated)
- Open systems can be open to:
  - matter
  - energy
  - information
- Or any combination of the three
  - (some sciences use slightly different definitions of open, closed and isolated systems)

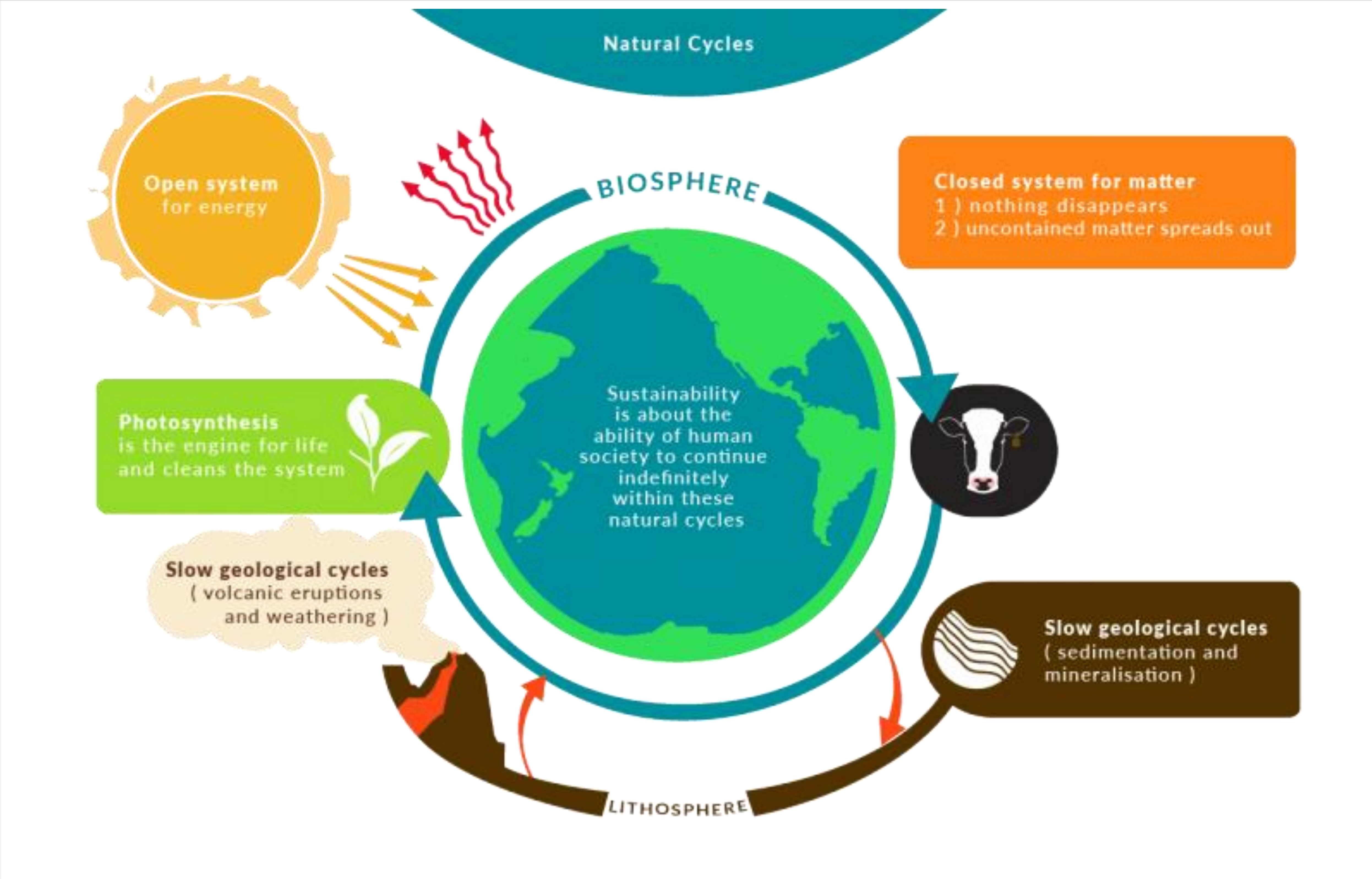


An open system



A completely closed (isolated) system

Open systems



[10]

Open systems

[11]

We are open systems too!

Closed systems

[12]

- Some would say that the universe is the *only* closed (or isolated) system
- As it contains everything, there is nothing for it to be open to
- And the physical laws of conservation seem to support this view
    - But do we really *know* this? There is some debate…

Closed systems

- Even though almost all systems are open, there are some which we can treat as approximately closed
  - Especially when we are modelling systems
- Often, systems will appear to be either open or closed, depending on how long we observe them for
  - Example: a double-walled flask (or bottle)
  - Over a period of a few hours, the temperature of the inside of the bottle barely changes
    - It appears to be closed to energy
  - But over a period of a few days, the temperature of the inside of the bottle will equalise with the exterior
    - It is clearly open to energy!

Closed systems

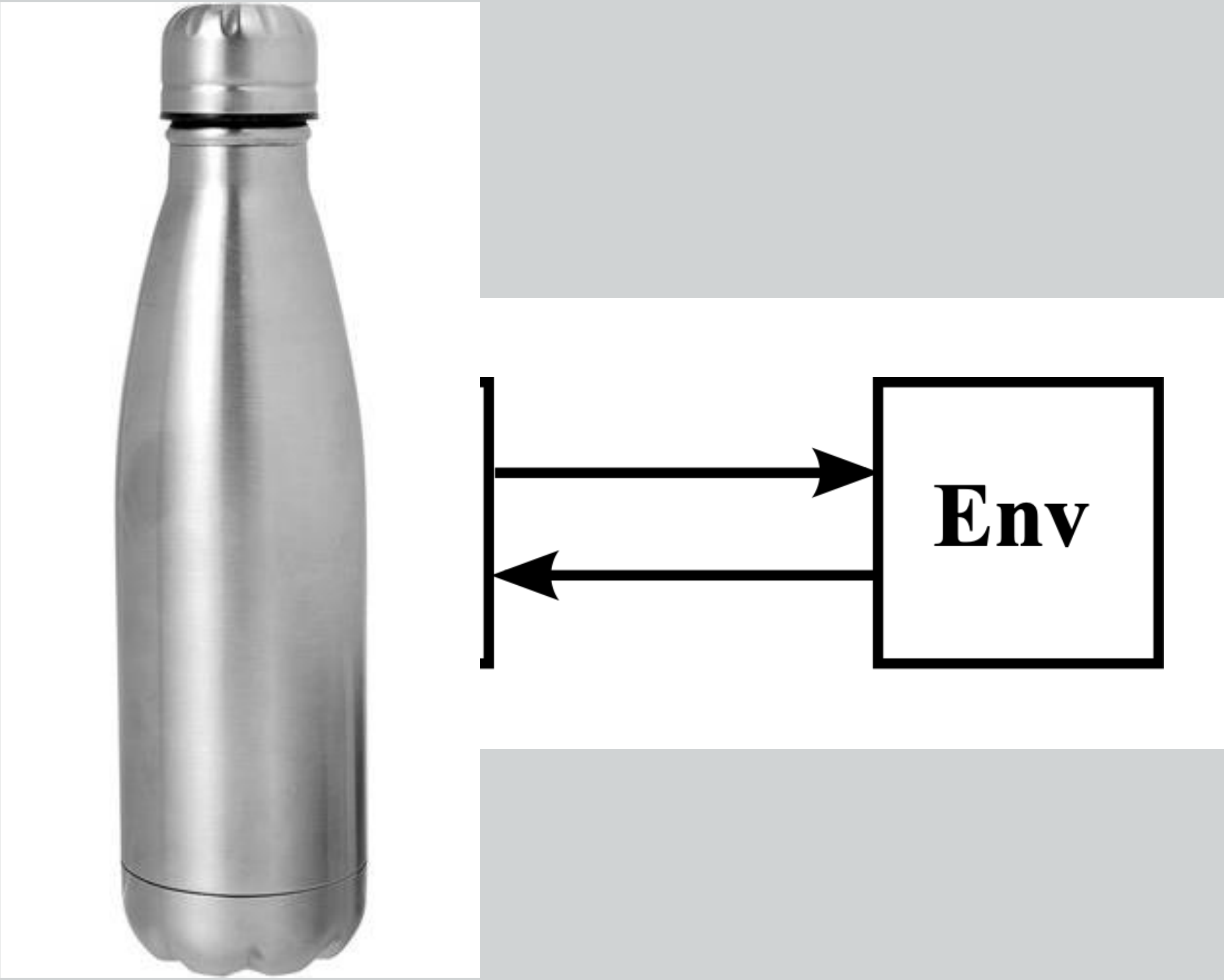
Over a short timescale:

- Temperature changes are negligible
- We can model the system as closed
  - Which means that we can ignore its environment

Closed systems

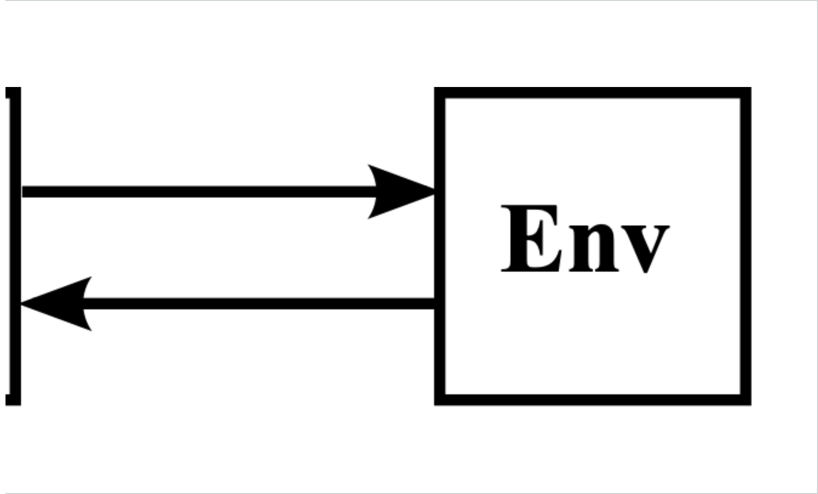
Over a long timescale:

- **Temperature changes are *not* negligible**
- **We have to model the system as open**



Closed systems

Can you suggest any similar examples?



Summary

1. Systems are *connected* sets of elements. Unconnected elements are not systems.

2. Systems are made up of smaller systems (subsystems).

3. A system's environment is also a system (and together, they form a supersystem)

4. Systems are usually *open*, but we can often model them as being *closed,* because many connections between elements only have negligible effects, (especially over short periods).

Bibliography

Recommended articles and books

[1] Donella H Meadows. Thinking in Systems: A primer. Chelsea Green Publishing, 2008.

[5] Fine, P., Di Paolo, E., and Izquierdo, E. (2007). Adapting to your body.
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[13] https://www.researchgate.net/figure/Scheme-of-hierarchical-levels-of-a-biological-system_fig3_345776491