Deep dive into the foundations of anticipatory systems

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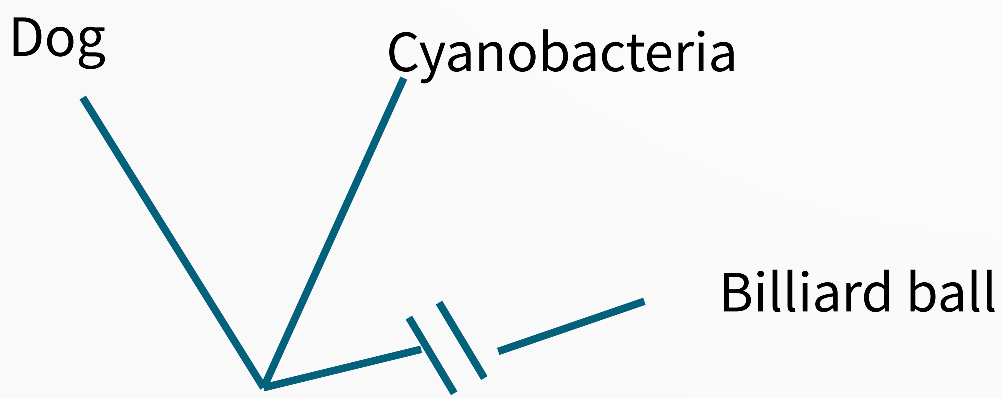
Where did anticipatory systems come from

- Theory of biology needs to be able to say what makes living systems different from non-living systems
- What is this "being alive" that all living systems have in common and all non-living things lack?

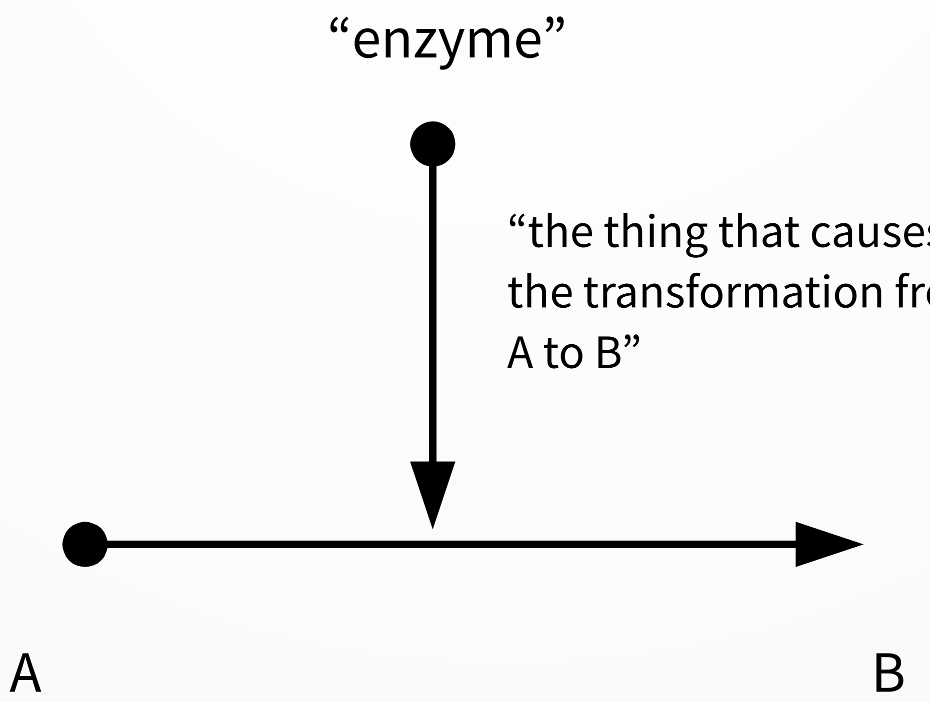


Rosen's (M-R) model of "simplest cell"

- A living cell is something that is energetically and materially open and able to maintain itself
- It has a metabolic process that converts input materials into everything that it needs to maintain its functional organization
- In other words, it has metabolism and repair

Robert Rosen, 1958. *"A relational theory of biological systems."* Bulletin of Mathematical Biophysics, 20, 245-60.

(M-R) systems

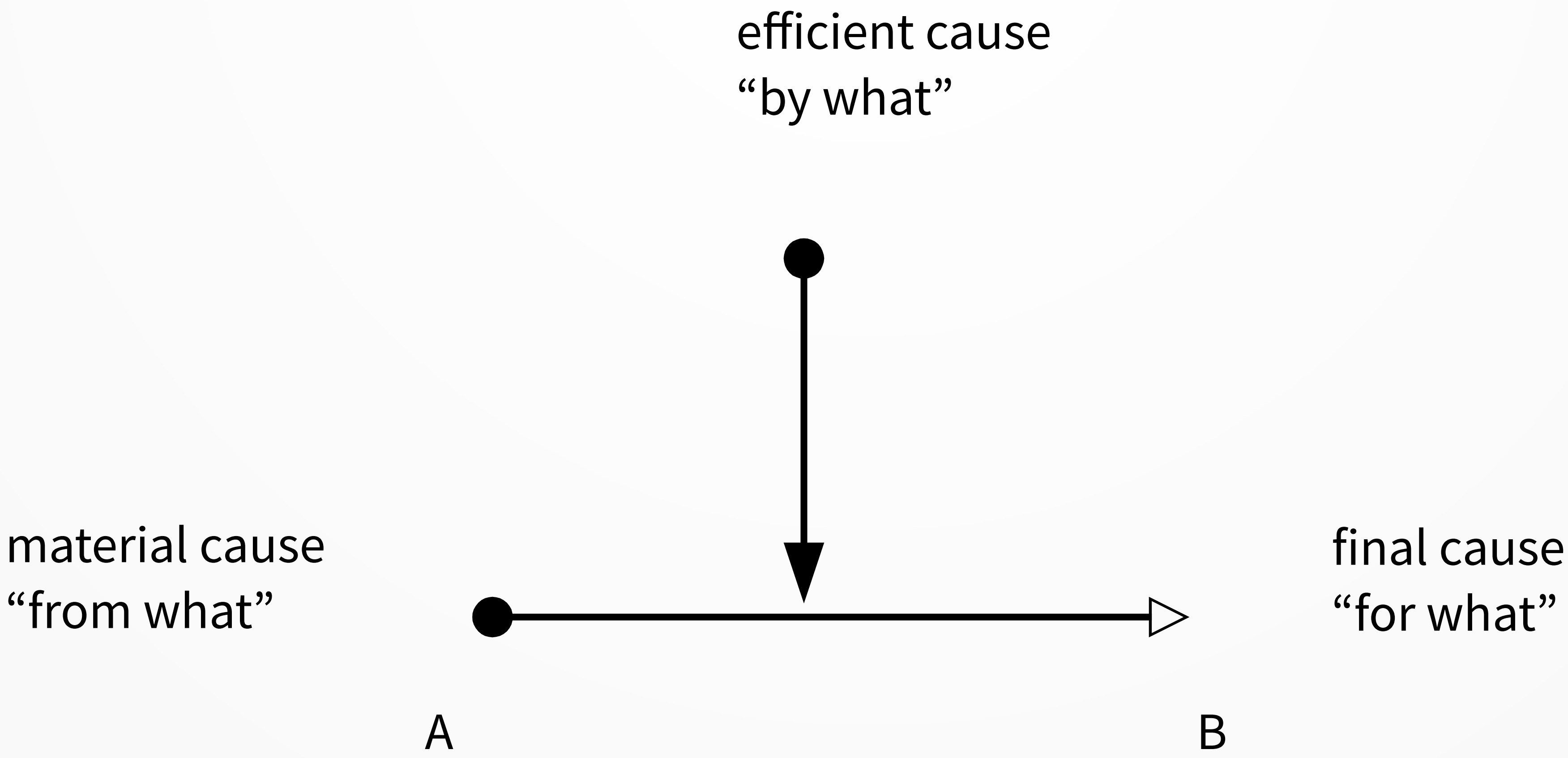


"the thing that causes the transformation from A to B"

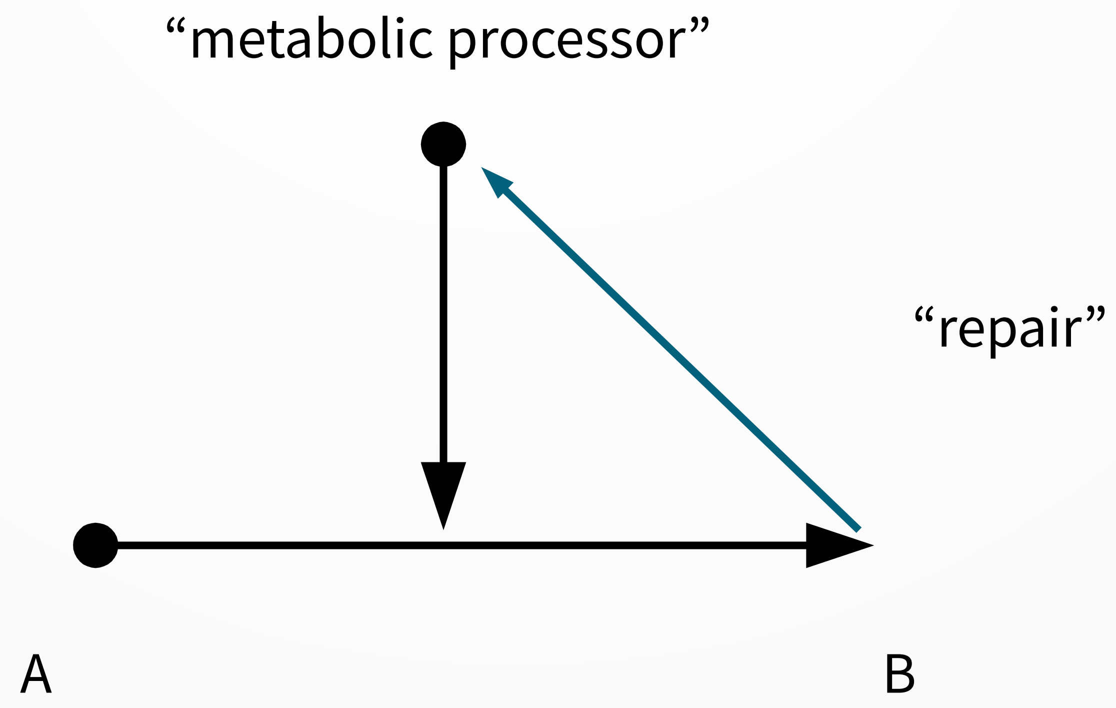
$$A \xrightarrow{f} B$$

$$f : A \to B$$

Aristotle and the causes of things

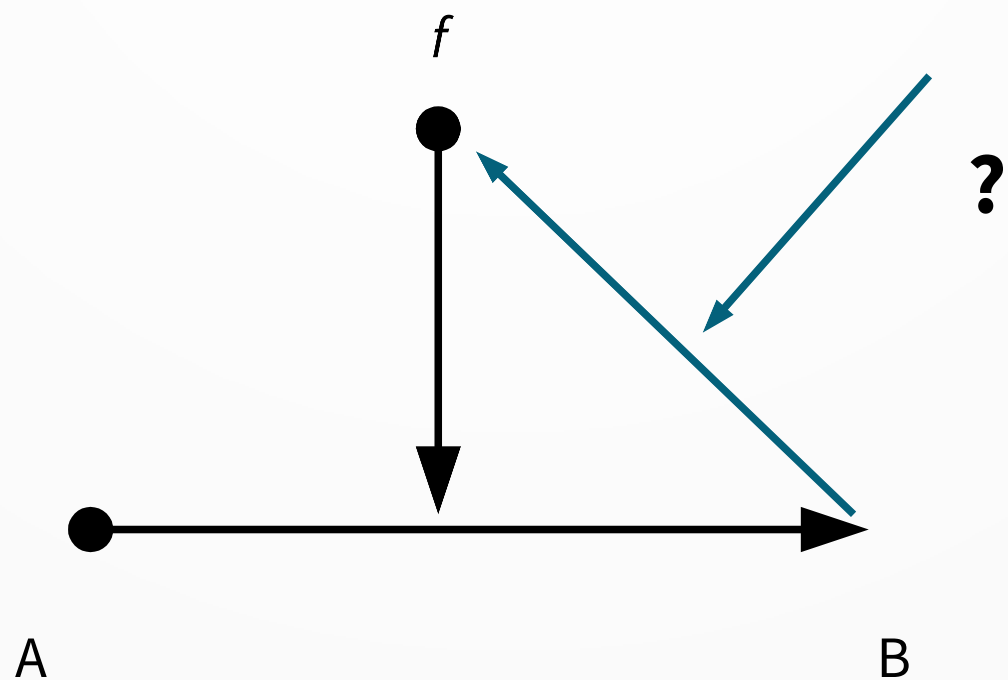


We are looking for a structure that causes itself.



… but what are the causes that make enzymes and repair the metabolic process?

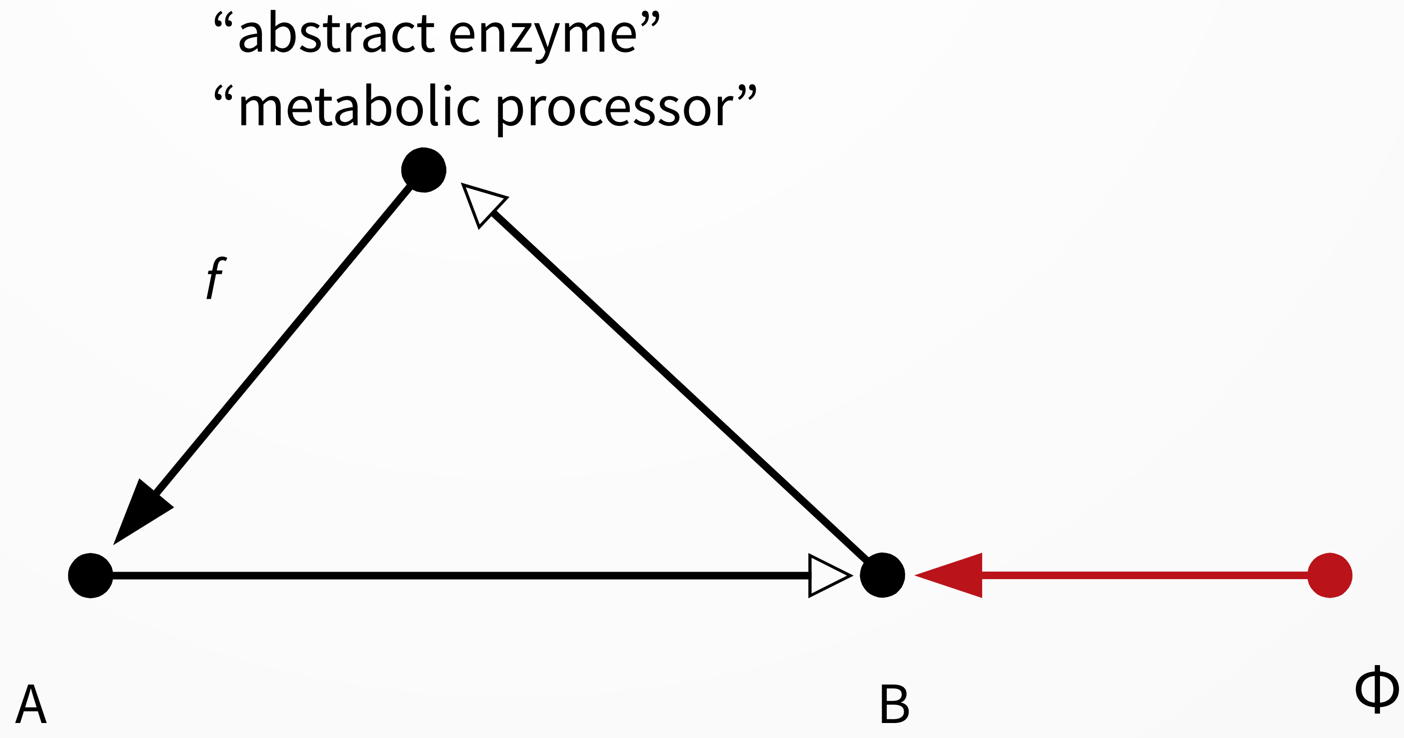
“replication” of “repair”



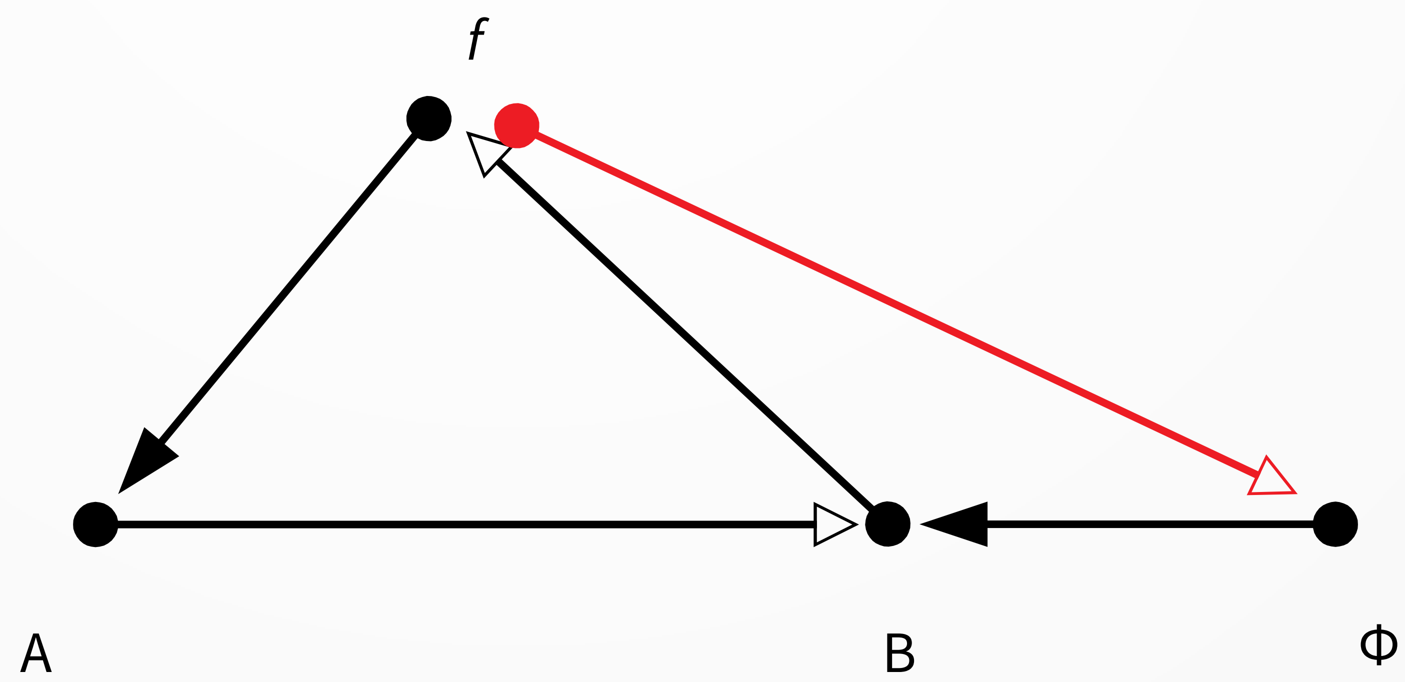
What is the efficient cause for the repair process?

Let’s format a bit:

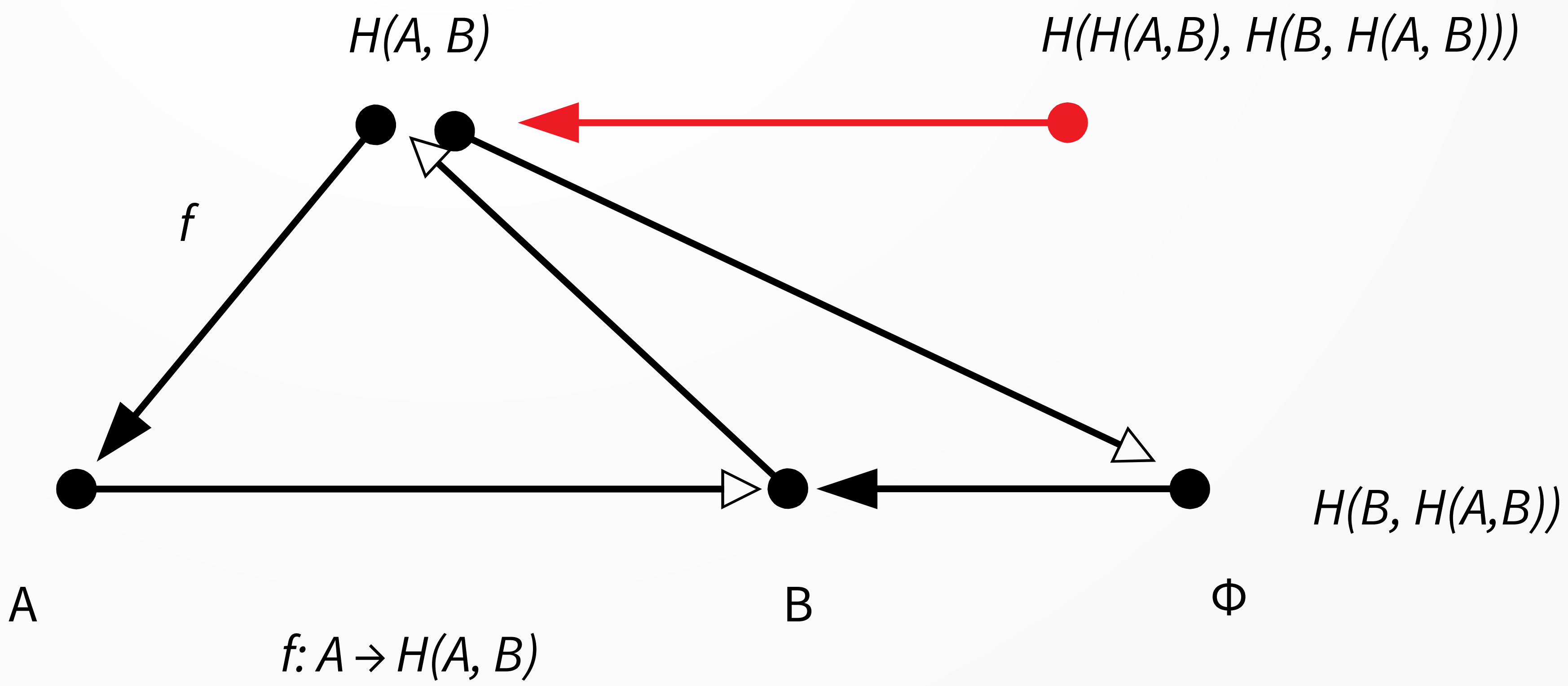
… we need something that causes the metabolic processors



And we need something that causes that:



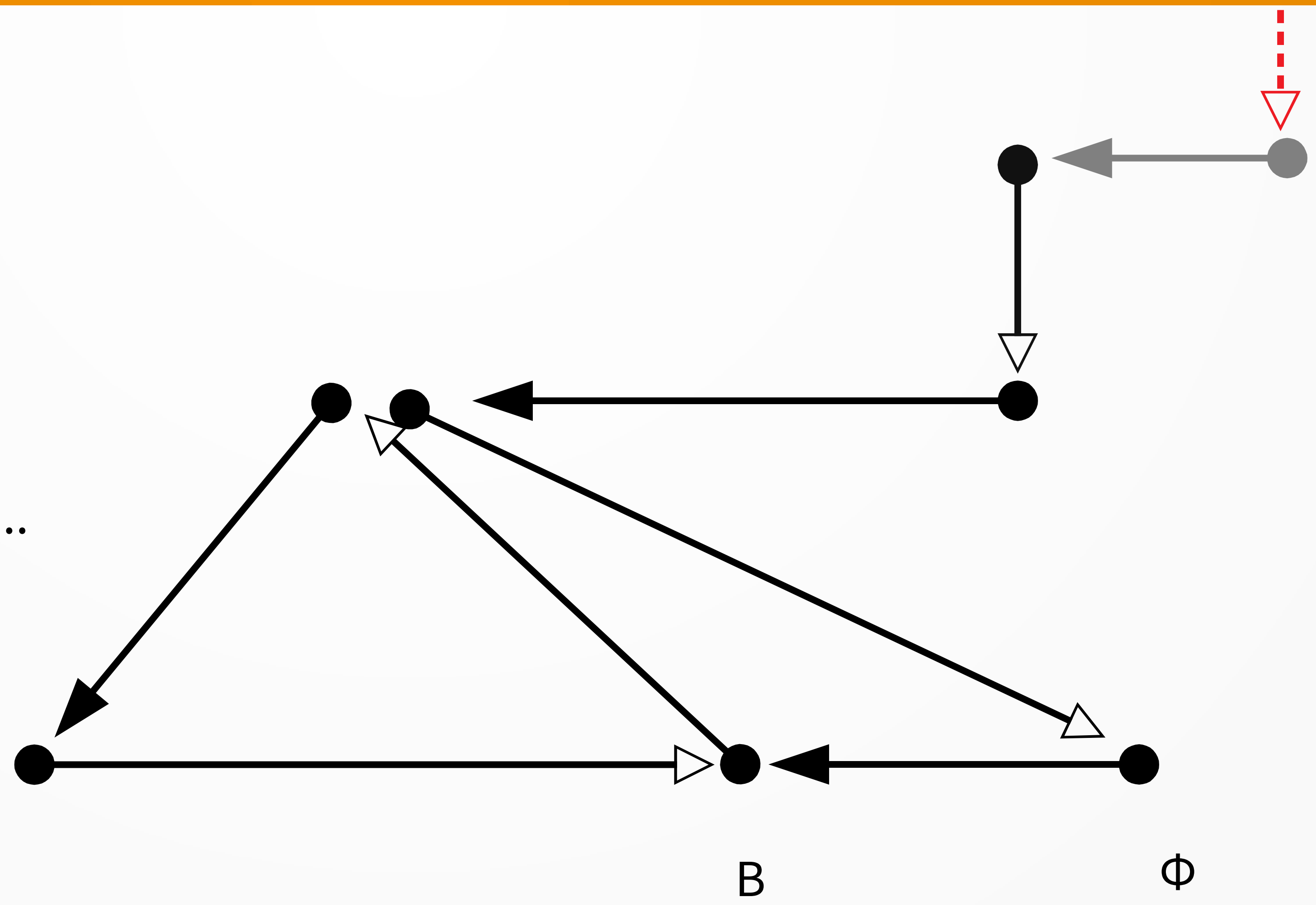
And something that causes that:



. . . back to St Aquinas...

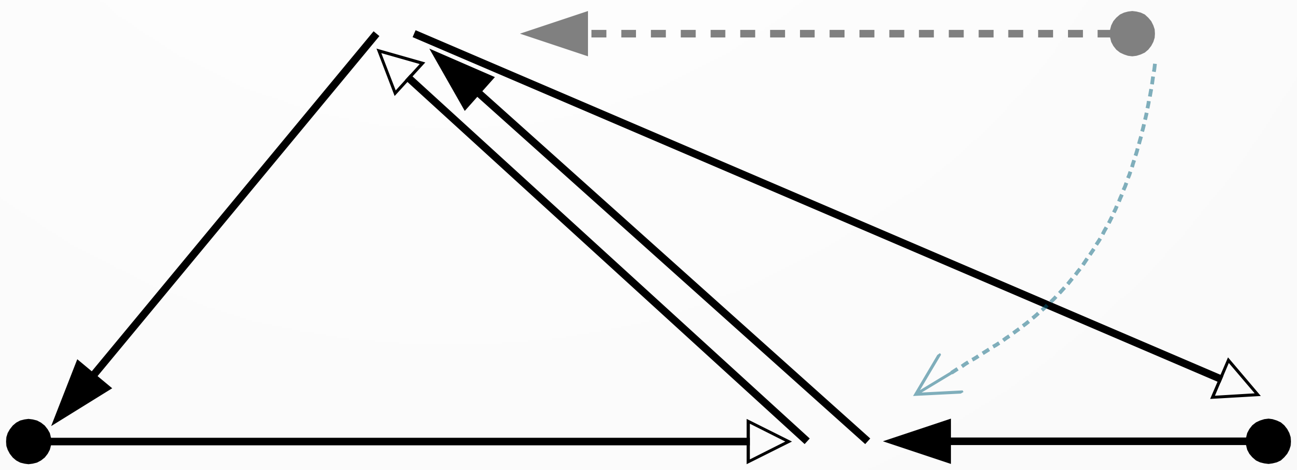
. . . and so on, until eternity. . .

...until we meet the God"...



Rosen's proof

… under stringent, but not too stringent conditions, there is a well-defined mathematical structure where every "processor" is caused / entailed within the system...



… and this is an abstract model of the simplest living cell…

c.f. Louie, A.H. More Than Life Itself, 2009

So far we have learned:

- To model living systems, we can use set theory and need to study the mappings between the sets involved
- A living thing cannot be described simply by its material components; you need to describe its organization
- Life becomes specified by a special type of organization
- Such a system is called “closed to efficient cause” (CLEF)
- This is the domain of relational biology:
  - Physics throws away the organization, focusing on the matter. Relational biology throws away the matter, focusing on the organization.

Now things start to become interesting...

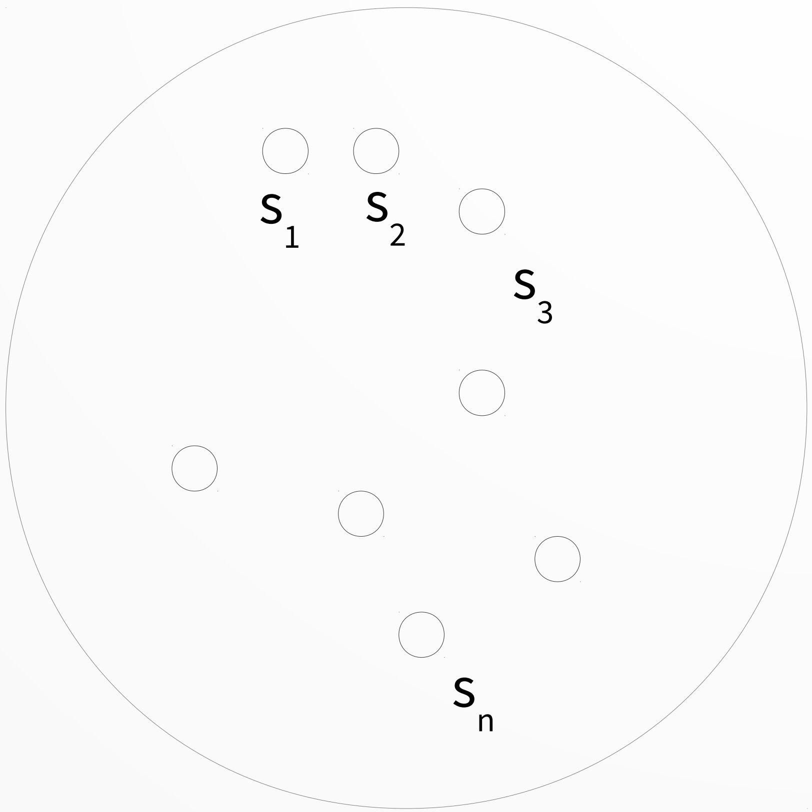
- The essential characteristics of biological systems cannot be reduced to Newtonian physics (or its quantum variant)
- Biology needs a different approach to physics

Rosen’s rewrite of science

- Let’s redo physics from the simplest possible assumptions:
- Proposition 1: Physics is about observable events
  - “The only meaningful physical events which occur in the world are those represented by the evaluation of observables on states.”
- Proposition 2: Every observable can be regarded as a mapping from states to real numbers.
- Proposition 3: No more propositions

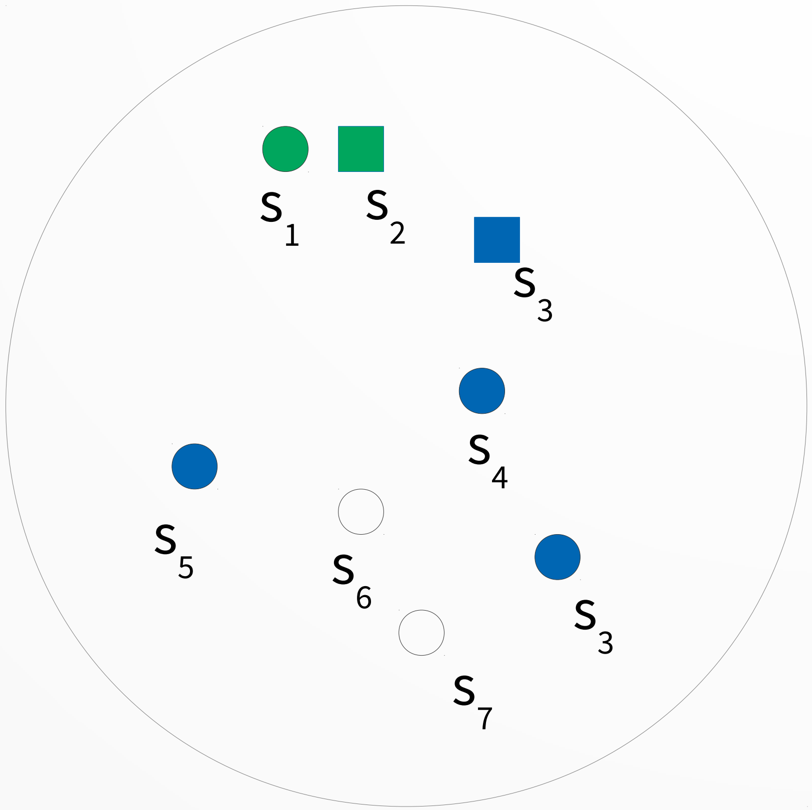
Rosen, Robert. Fundamentals of Measurement and Representation of Natural Systems. New York: North-Holland, 1978.

We have a system with states



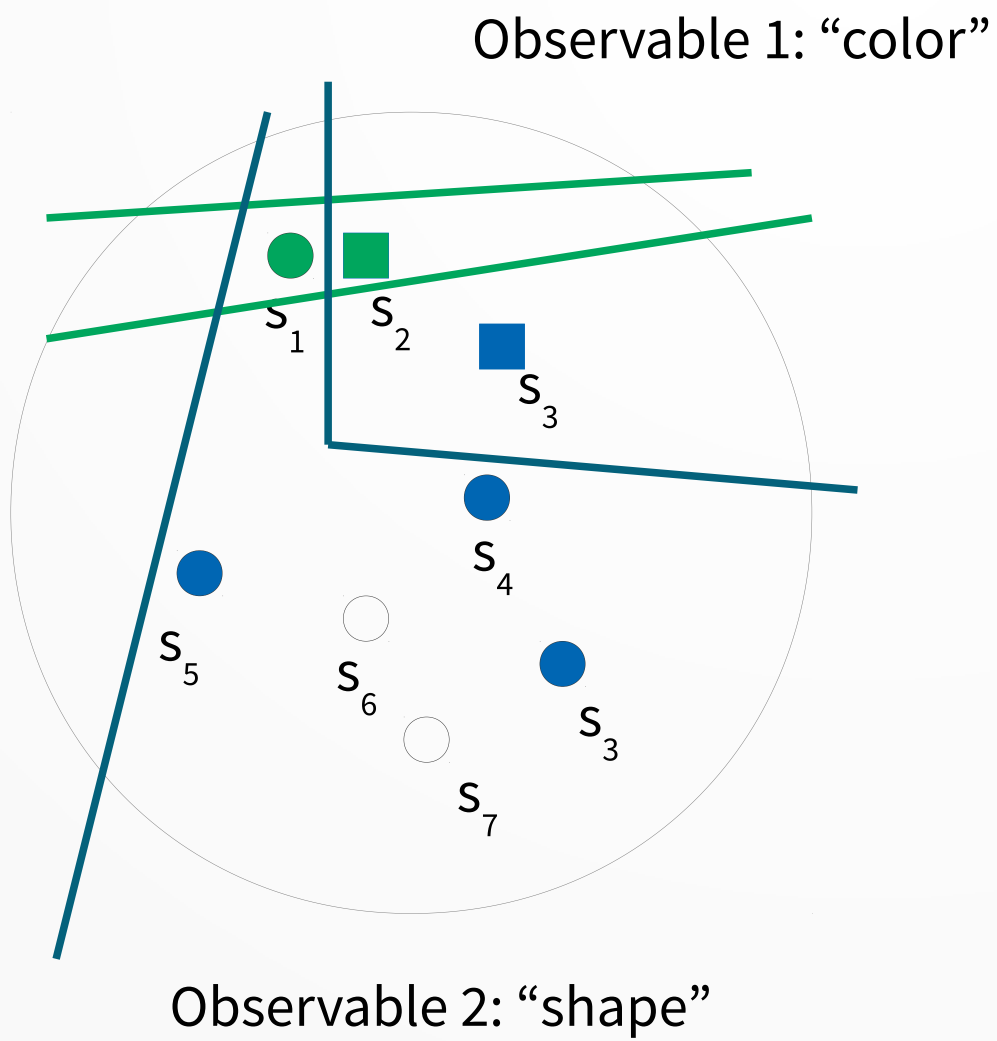
S: the set of all possible system states

The states are different



S: the set of all possible system states

How do we know which state the system is on?



Each possible observation represents a class of equivalent states.

If two states produce the same value for an observable, they belong to the same class.

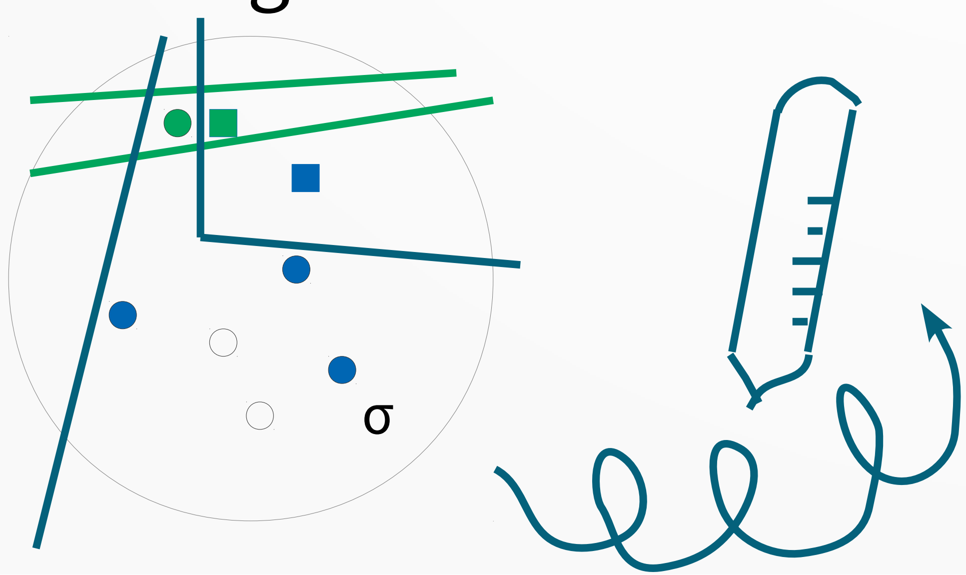
Rosen's Proposition 1 said that all physical events are evaluations of observables on states; any physical interaction can not know better

Different observables provide different points of view

- Observables can be totally linked, linked, or unlinked
- If the value of one observable (its equivalence class) does not restrict the values of another observable, the latter is unlinked from the former
- If the value determines the value of the other observable, they are totally linked (at that state)
- In general, observables are linked
  - E.g., if we measure “solidness” and “temperature,” water cannot be solid if temperature is 100 ° C

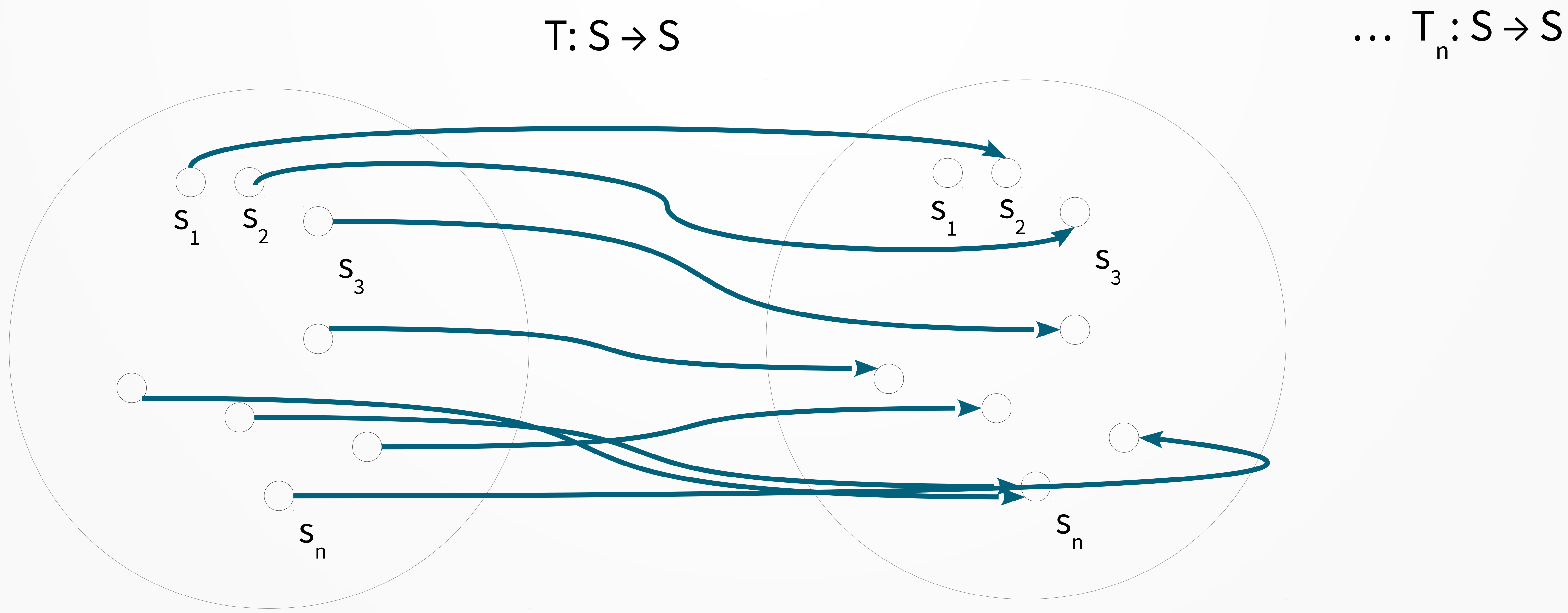
A prototype observation: meter

- Meter is something that observes system states and produces a real number
- It has a reference state (m_0)
- When it is brought in contact with the system, the interaction changes the state of the meter



S → M → R

Dynamics



Dynamics is a sequence of mappings from the set of states to this same set. (Often indexed by "time".)

Some fundamental questions:

- How can a system be fractioned into subsystems without changing the observables
  - By dividing the original system into subsystems, we can study simpler systems without losing the phenomena
- If we have a full set of meters (all possible modes of interactions of the system), is there a "minimal" set of observables that has the same resolution?
  - These would be called "state variables" in trad. physics. All the observables can be computed as functions of these.
- … and the answer is…

Many complementary representations are needed

- Only in very special cases there is one minimal set of state variables that fully distinguish system states
- These are, roughly, systems where you can isolate any part of the system without affecting observables or dynamics
  - When you keep on doing this, you get small particles called "atoms"
  - These systems are characterized by the fact that system organization (linkages between state variables) does not matter

Meters change system dynamics

- In general, the evaluation of an observable changes the set of states that is needed to describe system dynamics
- A much larger set of states is needed, which combines the states of the meter with the states of the observed system
- When the dynamics of the system is described using the original set of states, state variables become “uncertain” (quantum theory) or the impact of unaccounted interactions shows up as “probabilistic” states (statistical physics)
- Some important concepts in classical physics, e.g., entropy, are shown to be artifacts of the inadequate representation used

Complex and simple systems

- When all system descriptions can be derived from a single set of system variables, the system is a *simple system*
  - Rosen calls these *mechanisms*
- When many irreducible sets are needed, the system is *complex*
- Examples of simple systems: Newtonian particle physics, Turing machines
- Examples of complex systems: Biological systems, anticipatory systems

Emergence and stability

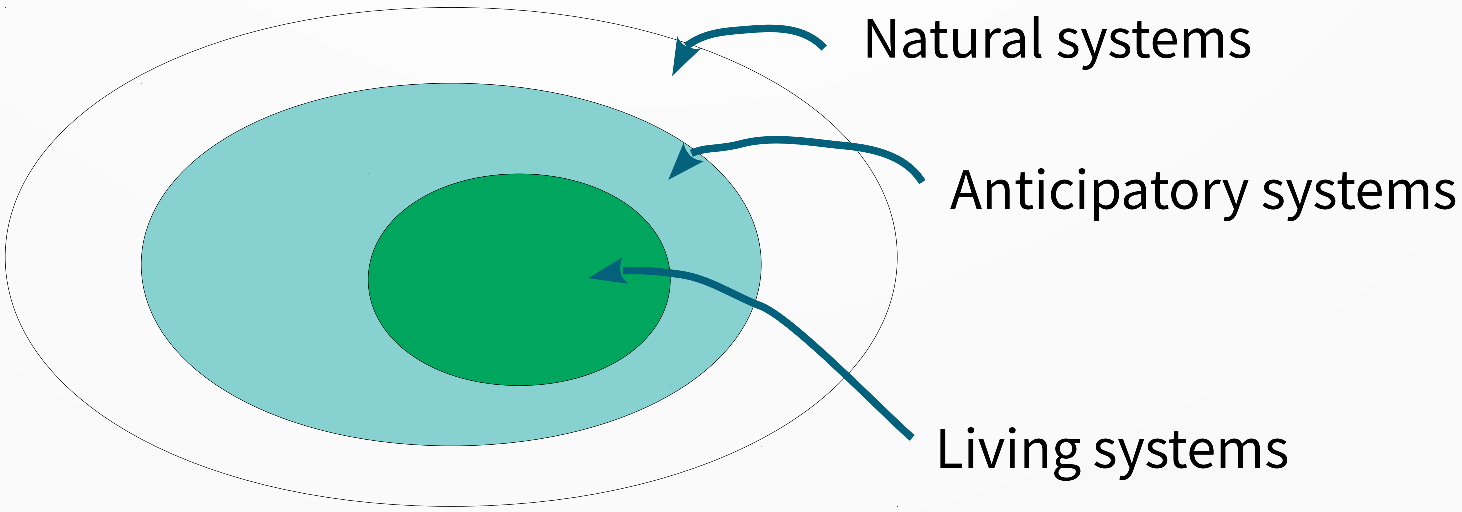
- Assume the observation of two states produces values that are close to each other (remember Proposition 2: observations map to real numbers)
- Are the values of some other observable also close to each other?
- In other words, can two states that look the same be very different?
- In yet other words, can a small perturbation produce drastically different consequences?

No emergence in simple systems

- Dynamics creates “trajectories” from one system state to another. At one point, two states may look the same for one meter. (The states belong to the same equivalence class.)
- If they look different for another meter (physical interaction), the “same” state may change to states that belong to different classes.
- One original state (as seen for one observer) can transition to two different states, without any apparent cause.
- To an observer looking the first meter, this appears as *acausal* change and a miracle.
- In special cases, when all the observables are unlinked and you have a *single representation of the system*, you can avoid such non-causal dynamics. This is the case for Newtonian physics and all other simple systems.

From system states to classes of systems

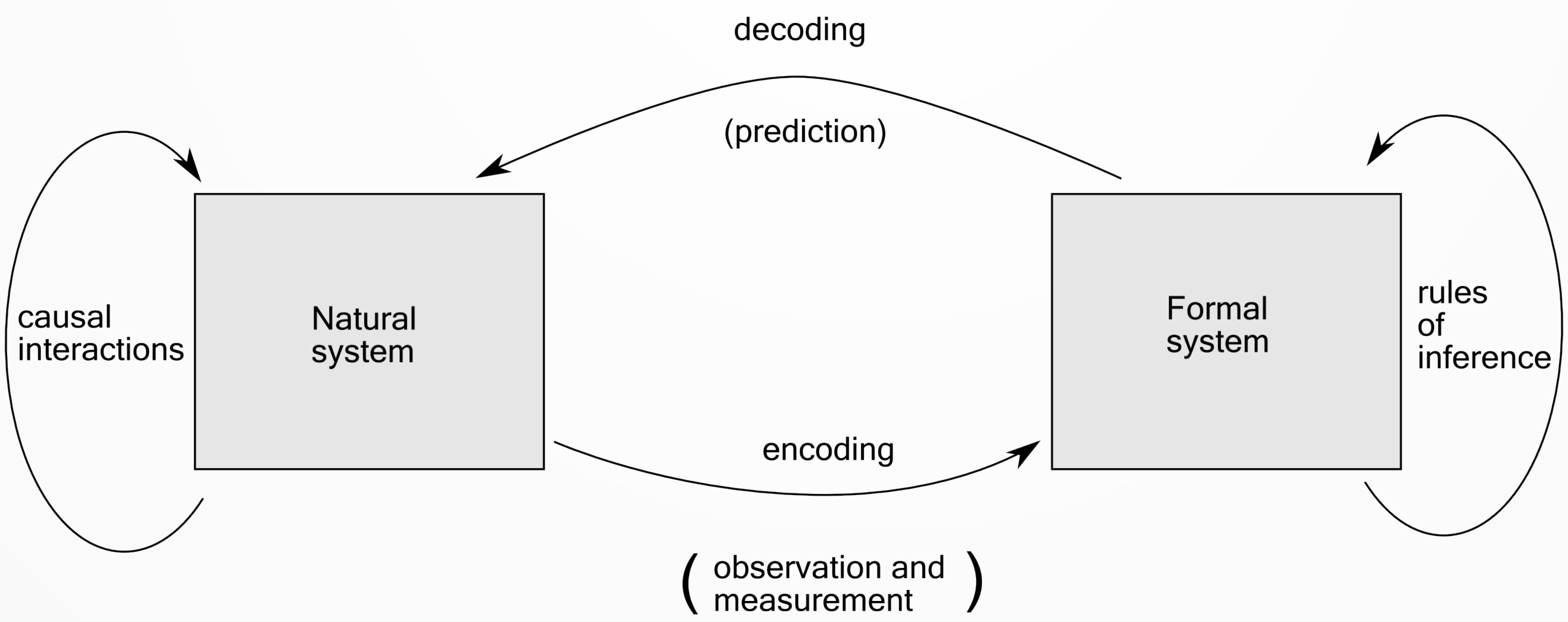
- OK, now we know a lot of system states, observation and how systems can be represented. This is where mathematics shows its true force.
- We can ask similar questions about sets of <u>systems</u>.



Enter models

- When two systems have the same subsystem, they are analogs
- Two systems can share different types of subsystems
  - Shared subset of observables, subset of dynamics, subset of states
- When the systems share a subsystem, they have a shared model
- A complex system is a system that has several models that are irreducible to each other

The modeling relation



Rosen, Robert. Anticipatory Systems: Philosophical, Mathematical and Methodological Foundations. Oxford: Pergamon Press, 1985.

Anticipatory systems

- A system that contains a model of itself and / or its environment is an anticipatory system
- Its looks as if the future would influence its behavior
- It has many incompatible and irreducible models.
- No “maximal model” means that any simulation of its behavior will have errors (no algorithm or Turing machine can predict its behavior)

Anticipatory systems and foresight

- This means that anticipatory systems theory leads to foresight methods that explicitly integrate multiple models and multiple points of view
- Forecasting, dynamical systems models, system dynamics, econometric models, for example, are theoretically unable to model anticipatory systems
- Biological, cognitive, social, and economic systems are anticipatory systems; they cannot be reduced to conventional physics without losing their essential characteristics

Thank you!