

How can living systems understand external reality to survive better?

Do data given to a subject contain information about something existing outside the subject, or are they mere mental states of the subject? This is a long-standing philosophical problem about the reality of percepts, asking whether sense data can constitute evidence of real objects existing independently of the subject. This problem also exists for organisms as a subject system of information processing. Organisms subject to illusions would fail to survive in the material universe. How can organisms, or living systems in general, determine the external reality from within?

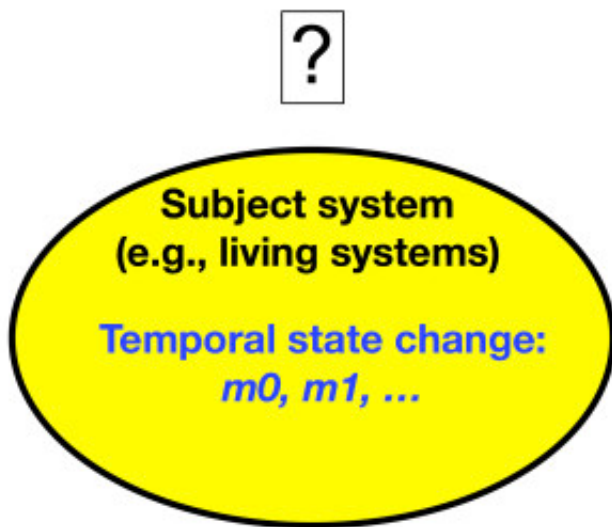


Fig. 1. How can a subject system derive symbols that refer to unknown objects ("?") outside the system?

Shannon's information theory presupposes an object as information source, and defines information as something that reduces the uncertainty about the object for an information receiver—the amount of information is defined as the degree to which uncertainty (measured as entropy) is reduced. However, from the subject's viewpoint, it is unclear whether data, in the first place, come from the external object as an information source.

We need to formalize this unsolved problem into a tractable form. Consider a following simple model. A subject system has a particular state every moment, which changes temporally and form a state sequence during a particular period of time, such as $m_0, m_1, \dots$ ($m_i \in \mathbf{M}$). Then, we can ask how the system can generate new symbols that do not belong to set $\mathbf{M}$, by using a particular algorithmic process (Fig. 1).

For such an algorithm, the following process, called *inverse causality* (hereafter, IC), can be introduced based on the unique successor principle. Let us consider, for example, a finite sequence of system states, such as

$m0, m1, \dots, m0, m2, \dots$

The unique successor principle says that any state has a unique successor. In this example, $m0$ does not have a unique successor, because the first $m0$ is followed by $m1$ whereas the second one by $m2$. IC is the process to generate a new symbol for the sequence to obey that principle. By introducing different symbols ($e0, e1$) behind the first and second $m0$, respectively, IC process transforms the previous sequence into

$(m0, e0), m1, \dots, (m0, e1), m2, \dots$

This sequence now fulfills the principle. Here, we can introduce a meta-observer who views both the subject system and its environment from outside. Interestingly, if the sequence is replayed in the ordinary time direction from the meta-observer's viewpoint, it represents a measurement process. That is, the system in $m0$ measures different states ($e0, e1$) of the external object by changing to $m1$ when the object is in $e0$ while to $m2$ when it is in $e1$. The IC process can thus generate new symbols ($e_i \in \mathbf{E}$) foreign to $\mathbf{M}$, functioning as a sign for an external object, by which the system can determine the existence of the outside world or its environment. Hypothetically, the IC process may be ubiquitous in living systems. For example, a neural cell has membrane potential (voltage); it can change from the resting potential state (minus) to an action potential (plus) when it is stimulated from outside, then returning to the original resting potential.

To conclude, IC is an information process to construct signs or symbols for external reality by a subject system, and at the same time, a measurement process of the object by the subject system from the meta-observer's viewpoint. Information can be defined as a state change of an entity that occurs in relation to the state of another entity. IC and measurement processes are two sides of the same coin (information). We need to investigate further how IC takes place materially in living systems to understand biological adaptation deeper from a subject's viewpoint.

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