Towards a Universal Theory of Consciousness

Ryota Kanai & Ippei Fujisawa

Araya, Inc., Tokyo, Japan

Corresponding Author

Ryota Kanai

Email: kanair@araya.org

Abstract

While falsifiability has been broadly discussed as a desirable property of a theory of consciousness, in this paper, we introduce the meta-theoretic concept of "Universality" as an additional desirable property for a theory of consciousness. The concept of universality, often assumed in physics, posits that the fundamental laws of nature are consistent and apply equally everywhere in the universe, and remain constant over time. This assumption is crucial in science, acting as a guiding principle for developing and testing theories. When applied to theories of consciousness, universality can be defined as the ability of a theory to determine whether any fully described dynamical system is conscious or non-conscious. Importantly, for a theory to be universal, the determinant of consciousness needs to be defined as an intrinsic property of a system as opposed replying on the interpretation of the external observer. The importance of universality originates from the consideration that given that consciousness is a natural phenomenon, it could in principle manifest in any physical system that satisfies certain set of condition whether it is biological or non-biological. To date, apart from a few exceptions, most existing theories do not possess this property. Instead, they tend to make predictions as to the neural correlates of consciousness based on the interpretations of brain functions, which makes those theories only applicable to brain-centric systems. While current functionalist theories of consciousness tend to be heavily reliant on our interpretations of brain functions, we argue that functionalist theories could be converted to a universal theory by specifying mathematical formulations of the constituent concepts. While neurobiological and functionalist theories retain their utility in practice, we will eventually need a universal theory to fully explain why certain types of systems possess consciousness.

Introduction

Consciousness, one of the most enigmatic and debated phenomena in science, has been a subject of numerous theories and propositions (Seth & Bayne, 2022). Each theory attempts to unravel what makes an entity conscious. Recently, the field has witnessed heated debates about testing these theories (Lenharo, 2023). The Cogitate project (Consortium et al., 2023), for instance, embarked on an ambitious journey to directly compare the global workspace theory (GWT) (Baars, 1993; Baars et al., 2021; Dehaene et al., 1998; Dehaene & Changeux, 2011; Mashour et al., 2020; VanRullen & Kanai, 2021) and integrated information theory (IIT) (Albantakis et al., 2022; Oizumi et al., 2014; Tononi et al., 2016) using empirical tests in adversarial collaboration. While the project's aim was commendable, its results presented a myriad of challenges (Lau, 2023). A central issue was whether these theories, particularly IIT, were ripe for falsification (S. Fleming et al., 2023)—a hallmark of scientific inquiry as championed by thinkers like Popper (Popper, 2005). Falsifiability has been a significant point of contention in consciousness research (Kleiner & Hoel, 2021), with IIT often at the center of such debates (Doerig et al., 2019).

However, the debate should not be confined solely to falsifiability. We contend that a theory of consciousness should possess other meta-theoretic attributes. Notably, theories such as IIT stand out for their predictive prowess beyond merely brain-centric systems—a trait conspicuously absent in many other consciousness theories. To encapsulate this essential quality, we introduce the notion of "Universality" as an additional criterion to assess theories of consciousness. This paper delves into how this criterion relates to prevailing theories of consciousness. While we argue that many current theories fall short of this benchmark, we also envision pathways for them to embrace universality.

Universality

In the landscape of scientific theories, certain criteria stand out as essential benchmarks for the validity and applicability of theories. One such criterion, which we propose as pivotal for theories of consciousness, is that of "Universality." The concept of universality, often assumed in physics, posits that the fundamental laws of nature are consistent and apply equally everywhere in the universe, and they remain the same over time. This is a crucial concept in science, acting as a guiding principle for developing and testing physical theories. The belief in universality means that the knowledge and insights we gain from experiments on Earth are applicable to the entire universe. This property is highly desirable in any theory of physics because it provides a level of reliability and predictability, allowing scientists to make confident predictions beyond what we can directly observe. The pursuit of universal laws is essentially a pursuit of the underlying, unchanging rules that govern all of nature.

Similarly, the attribute of universality is highly desirable in developing a theory of consciousness. A universal theory of consciousness would propose fundamental principles and laws that account for conscious experiences in any entity, irrespective of its physical composition or origin. This universality is desirable as it would allow for a comprehensive understanding of consciousness, since it would enable researchers to generalize findings and make predictions about consciousness beyond what we can easily observe, namely reports of consciousness in humans and close species. Such a theory would not only illuminate the nature of human consciousness but also provide insights into the potential existence and characteristics of consciousness in other forms of life and artificial entities, bridging the gap between the physical and the experiential realms.

We define universality as the ability of a theory to determine whether a given dynamical system is conscious, irrespective of its origin or composition (e.g. whether it is biological brain, hurricane or computers). This means that the theory must be applicable to any physical system as long as its dynamics is fully described with, say, a transition probability matrix (TPM), or a Langevin equation.

What aspects of a theory of consciousness should predict is also important when we consider universality. The primary target is the presence of consciousness within a system. A theory should be able to tell which part of the system corresponds to a conscious system as opposed the environment. In the case of the biological brain, a theory must be able to predict which set of neurons corresponds to the content of conscious experience, and which part remains unconscious.

Additionally, the next target of prediction is the qualitative aspect of consciousness. Once the theory manages to successfully identify the parts of the system that correspond to consciousness, it is desired that the theory makes predictions about the quality of conscious experience. For example, this could be about whether the conscious experience of the system is more like vision or audition (Kanai & Tsuchiya, 2012; von Melchner et al., 2000). Once this is achieved, one could address the famous question of what it is like to be a bat (Nagel, 1980) by showing the experience of sensing the spatial environment with echolocation is more like seeing or hearing (Tsuchiya, 2017).

The impetus behind the universality stems from the premise that consciousness also obeys certain laws of nature. As such, it should not be bound by the specifics of human biology or Earth's evolutionary history. If certain physical conditions are met, consciousness could, in theory, emerge in non-biological systems, artificial intelligences, or even extraterrestrial entities with entirely different evolutionary trajectories. A truly comprehensive theory of consciousness should, therefore, be able to address these diverse manifestations. If the ultimate aim of a theory of consciousness is to tackle the Hard Problem, then the theory must extend beyond the confines of the biological brain. A theory that merely predicts which regions of the primate brain correlate with consciousness is inherently limited. It would fall short in elucidating the 'why', 'how', and under which conditions consciousness arises from a physical entity. This underscores our conviction that the universality criterion is indispensable for the evolution of a comprehensive theory of consciousness.

Theories in physics possess the characteristic of universality. The laws of physics, once discovered and validated in one part of the universe, are expected to hold true across varied locations and times. This consistency and ubiquity underscore the very essence of laws of natural sciences. In the annals of physics, there was once a belief that the laws governing Earth differed from those that ruled celestial bodies. Newton's groundbreaking realization was that both terrestrial and celestial realms obeyed the same universal laws of physics. This revelation of universality illustrates that the strength of theories lies in their ability to be conceived and tested within our immediate realm yet remain applicable to phenomena beyond our direct reach or measurement.

Such potential for universality is not only a testament to the elegance of physics but also a cornerstone of its success as a scientific discipline. Similarly, for theories of consciousness to be truly comprehensive and effective, they too should embody this principle of universality, ensuring their applicability across a diverse range of entities and scenarios.

Drawing a parallel to consciousness research, a fundamental theory of consciousness should exhibit a similar universality. Just as physical laws do not change from one galaxy to another, a theory crafted and tested for consciousness as we know it—primarily within the human brain—should be equally applicable to other species and even non-biological systems. Consciousness, being a natural phenomenon, arises when specific physical conditions are met. Therefore, any comprehensive theory of consciousness should transcend the limitation of our immediate understanding, offering predictions about the existence of conscious experiences across diverse physical systems.

Limitations of Current Theories of Consciousness

While many theories in consciousness research offer valuable insights into specific aspects or manifestations of consciousness, they often do so within a limited scope, primarily focusing on human or mammalian consciousness. The universality criterion challenges these theories to broaden their horizons, to consider consciousness in its myriad potential forms, and to offer predictions that can be tested across a wide range of systems.

Now let us consider whether the universality criterion is met by some of the current theories. In this section, we will delve into prominent theories, Integrated Information Theory (IIT), the Global Workspace Theory (GWT) and the Higher Order Theory (HOT), to elucidate these constraints.

Integrated Information Theory

First, IIT appears to satisfy the universality criterion. It is in principle applicable to any (discrete) dynamical system. It delineates which part of the system corresponds to a conscious entity separated from other entities or the environment. Regarding the second desiderata, IIT could in principle be used to identify the structure that correspond to vision or hearing. While it remains challenging to actually compute constructs of IIT in practice for real complex systems such as the brain, the structure of IIT meets the universality criterion. It is worth noting that IIT is not the only theory that satisfies this criteria (e.g. Information Closure Theory could also identify the conscious entity (Chang et al., 2020)). Also, as we discuss later, other theories could potentially be re-formulated as a universal theory.

Global Workspace Theory (GWT)

GWT posits that consciousness arises from the widespread sharing of information across various brain networks. When specific information becomes globally available, it enters our conscious awareness. GWT is primarily rooted in the understanding of the human brain. Its principles, while robust within this context, may not easily extend to non-biological or radically different biological systems. For example, in the current form of the theory, it is difficult whether an AI system possesses a global workspace.

For GWT to satisfy the Universality criterion, it needs clear mathematical definitions for each theoretical components such as global workspace, broadcasting and ignition. What exactly constitutes a "global workspace" in mathematical or system terms? Without this clarity, GWT is not applicable to diverse systems. To satisfy the Universality criterion, we need to be able to say whether a particular system possesses a global workspace and what constitutes broadcasting and so on. A recently proposed Conscious Turing Machine (CTM) proposes a computational architecture similar to GWT but without relying on specific implementation (Blum & Blum, 2022) . Such functional abstraction may be useful for capturing key components.

Higher Order Theory (HOT)

The Higher Order Theory (HOT) offers to elucidate what differentiates a conscious mental state from an unconscious one, particularly in cases where there's a dissociation between performance and subjective report, such as in blindsight phenomena. At its core, HOT proposes that there are distinct stages for first-order processes, which drives performance and higher-order processes for conscious report. This framework captures the essence of 'awareness' as a form of access to primary information.

While the overarching premise of HOT is consistent, the theory itself has manifested in various forms (Lau & Rosenthal, 2011). HOT suggests that consciousness arises when a cognitive system possesses a higher-order representation of its own mental states. From the perspective of the universality criterion, it remains vague what it means to have a higher order representation or meta-representation unless we have a rigorous way to define meta-representations so that we can determine whether a given dynamical system contains a meta-representation or not.

The difficulty of detecting higher order representations in a non brain system becomes apparent when we consider whether deep neural networks (DNN) possess higher-order representations. A naïve interpretation might suggest that any transformation qualifies as higher-order (meta-) representation. For instance, if a meta-representation y of a first-order representation x is merely a transformation, $y=f(x)$, then every subsequent layer in a neural network becomes a meta-representation of its predecessor. Such a broad definition dilutes the significance of meta-representation, making it far from the coveted "holy grail" of consciousness and inadvertently endorsing a form of panpsychism. Another perspective is uncertainty estimation. The correlation between confidence and performance in a primary task is frequently used as evidence of awareness in cognitive neuroscience (Fleming et al., 2012; Fleming & Lau, 2014; Kanai et al., 2010; Sandberg et al., 2010). This implies that estimating uncertainty could be a form of meta-representation. In deep learning contexts, this might be achieved through rather simple mechanisms like softmax operation over the output layer. This too seems rather simple to capture the essence of consciousness, rendering most neural networks used in computer vision conscious.

While the mathematical definition of meta-representation remains elusive, a comprehensive exploration of this topic is beyond the scope of this paper. Here, we raised this as an example to illustrate the difficulty of finding a good definition that applies to a broader range of systems beyond human and animal behavioural paradigms. While both GWT and HOT offer valuable insights into the nature of consciousness, their current formulations seem tethered to human-centric perspectives. To truly embrace the universality criterion, these theories, among others, need to incorporate rigorous mathematical definitions applicable to a spectrum of systems.

Functionalist Theories Can Be Made Universal

Given our discussion so far, where IIT was presented as an exemplar of a theory embodying Universality in contrast to functionalist theories like GWT and HOT, one might be tempted to view this distinction as rooted in metaphysical differences. However, this is not our intention. We posit that functionalist theories have the potential to be Universal, if more rigorous definitions are provided for their constituent concepts.

At its heart, functionalism is predicated on the idea that mental states are constituted solely by their functional role, meaning their causal relations with other mental states, sensory inputs, and behavioral outputs. This perspective, in principle, is not restricted to human cognition or biological systems. It can be applied to any system that exhibits the requisite causal relations, be it a machine, an alien life form, or a complex network.

For example, the building blocks idea of consciousness proposes that consciousness arises when a set of key functions are instantiated in a system (Tait et al., 2023). This is a generalizable theory in the sense that any entity that satisfies those conditions are considered conscious. Thus, a functionalist theory does not have to be constrained to a neurobiological study and can potentially be extended beyond the brain.

Intrinsic Property

A pivotal challenge to render functionalist theories universal is to define those concepts as an intrinsic property of the system (not to be confused with the intrinsic perspective in IIT literature). Here, the term “intrinsic” denotes that the property is inherent to the system, independent of external interpretation, but is instead defined as a property possessed by the system. For instance, the presence of recurrence through feedback can be considered an intrinsic property of the system. Reflecting on how various concepts integral to major functionalist theories can be defined intrinsically would be a constructive step forward.

Concepts such as "global workspace" or "higher-order representation" are understood by human neuroscientists. However, deciding whether they are present in an arbitrary physical system requires more precise mathematical definitions to allow their identification.

There have been several proposals to implement the functional building blocks of consciousness using deep neural networks (Butlin et al., 2023; Juliani, Arulkumaran, et al., 2022; Juliani, Kanai, et al., 2022; VanRullen & Kanai, 2021). A functional theory of consciousness could be used as a way to determine whether a given system is conscious based on the functional properties of the system. However, for such a theory to attain universality, it is crucial that these functions are articulated as intrinsic properties, ensuring that assessments of consciousness are not contingent on the interpretations of an external observer.

Extrapolation and Panpsychism

Once a universal theory of consciousness is formulated, we can first test its validity in systems where the presence of consciousness is largely undisputed, such as humans and certain animals. After accumulating substantial empirical support for a specific theory, it becomes plausible to extrapolate the theory to non-biological or non-brain-based systems, making informed inferences about the presence of consciousness in artificial intelligences or extraterrestrial beings. While the consciousness of such entities remains unobservable and speculative, drawing inferences from well-supported theories is a foundational practice in science.

For instance, we infer the existence and characteristics of exoplanets, the composition of the Earth's core, the properties of dark matter, and the behaviors of subatomic particles, all of which are not directly observable but are inferred through the lens of well-established theories and indirect observations. Although consciousness poses unique challenges due to its subjective nature and our inability to directly observe it in entities other than ourselves, the process of making informed inferences about unobservable systems is a common thread running through various scientific disciplines. The development and refinement of a universal theory of consciousness would thus enable us to extend our understanding of consciousness beyond the confines of our immediate experience, potentially unveiling the mysteries of consciousness in entities vastly different from ourselves.

However, it should be noted that a universal theory of consciousness does not imply panpsychism. Although a universal theory renders every physical system a potential target, it does not necessarily imply that every physical system is deemed conscious. Whether a given system should be regarded as conscious ultimately depends on the specifics of the theory applied. Furthermore, some theories might not simply categorize consciousness in a binary fashion but might quantify the degree of consciousness, perhaps on a continuum like real numbers.

Concluding Remarks

In conclusion, we proposed the notion of universality as an additional criterion to characterize the nature of a theory of consciousness. The universality criterion serves as both a challenge and a guidepost for consciousness research, pushing the boundaries of current theories and pointing the way towards a more comprehensive understanding of consciousness in all its forms. The potential of formulating functionalist theories to be universal is an exciting future direction. By refining and rigorously defining their core concepts, these theories can begin to address consciousness in diverse systems beyond the brain-centric perspective.

The aim of this paper is not to assert the superiority of IIT over other theories but to underscore its unique fulfillment of the universality criterion, a rarity among existing theories of consciousness. While various theories of consciousness have been proposed to elucidate diverse facets of consciousness (Seth & Bayne, 2022), they can yield valuable insights even without adhering to the universal criterion. Nonetheless, by delineating differences through the lens of universality, we aspire to clarify why IIT often diverges from, and may seem counterintuitive compared to, other prevailing theories.

Should other theories undergo rigorous mathematization of their pivotal concepts, capturing them as intrinsic properties of a system, we anticipate that they might appear more similar to IIT, facilitating more direct comparisons. While neurobiological and extrinsic functionalist theories retain their utility, the pursuit of a comprehensive understanding of consciousness necessitates the development of a universal theory, we will eventually need a universal theory to fully explain why certain types of systems possess consciousness while others do not.

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