Challenging Reality: A Scientist Maps the Landscape of Consciousness

BY FOUNDATIONAL QUESTIONS INSTITUTE, FQXINOVEMBER 28, 202415 COMMENTS4 MINS READ

In his taxonomy of consciousness, Robert Lawrence Kuhn categorizes theories from materialist to nonmaterialist, exploring their implications for AI, immortality, and free will. His findings, based on interviews with numerous experts, are detailed in a 2024 journal article.
Kuhn's taxonomy of consciousness connects various theories to deep questions about human existence and AI, based on his extensive dialogue with over 200 experts.

"Out of meat, how do you get thought? That's the grandest question," said philosopher Patricia Churchland to Robert Lawrence Kuhn, the producer and host of the acclaimed PBS program *Closer to Truth* and member of FQxI's scientific advisory council.

Kuhn has now published a comprehensive taxonomy of proposed solutions and theories regarding the hard problem of consciousness. His organizing framework aims to assess their impact on meaning, purpose, and value, as well as on AI consciousness, virtual immortality, survival beyond death, and free will. His work, titled 'Landscape of Consciousness,' appeared in the August 2024 issue of the journal *Progress in Biophysics and Molecular Biology*.

Exploring the Landscape of Consciousness

Since its debut in 2000, *Closer To Truth* has broadcast 333 episodes, including 30 in collaboration with Foundational Questions Institute, FQxI, a science think tank and funding agency. Kuhn's article is the culmination of numerous in-depth interviews with experts over the decades."I have discussed consciousness with over 200 scientists and philosophers," says Kuhn, who is himself trained in neurophysiology. "Landscape is the product of a lifetime."

Theories and Frameworks

The article begins with the classic mind-body problem: How do the felt experiences in our minds relate to the neural processes in our brains? How do mental states, whether sensory, cognitive, emotional, or even noumenal (self-less) awareness, correlate with brain states? "Although there are families of mind-body problems, I focus tightly on phenomenal consciousness: our inner awareness, 'what it feels like to be' something," says Kuhn.

Diverse Perspectives on Consciousness

Kuhn presents diverse theories of consciousness, from materialist/physicalist to nonmaterialist/nonphysicalist. These are categorized as Materialism Theories (philosophical, neurobiological, electromagnetic field, computational and informational, homeostatic and affective, embodied and enactive, relational, representational, language, phylogenetic evolution); Non-Reductive Physicalism; Quantum Theories; Integrated Information Theory; Panpsychisms; Monisms; Dualisms; Idealisms; Anomalous and Altered States Theories; and Challenge Theories. "Each explanation is self-described by its adherents," notes Kuhn.

The taxonomy is laid out in the accompanying figure.

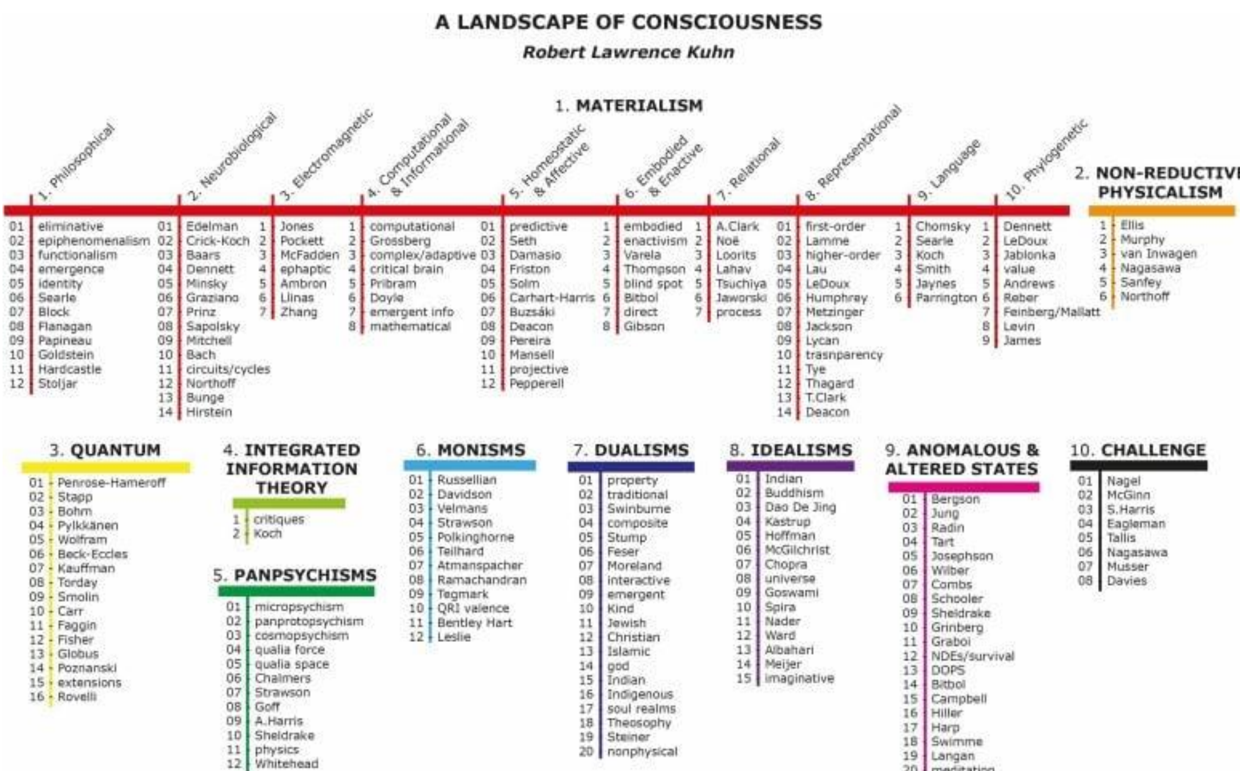

Figure created by Alex Gomez-Marin

A taxonomy of consciousness explanations. Credit: © Robert Lawrence Kuhn (2024). Created by Robert Lawrence Kuhn and Alex Gomez-Marin

Methodology and Purpose

"My purpose must be humble: collect and categorize, not assess and adjudicate," says Kuhn. "Seek insights, not answers." Kuhn produced the organizing framework for these diverse theories of consciousness in order to explore their impact on "ultimate questions," such as meaning, purpose, and value (if any), AI consciousness, virtual immortality, survival beyond death, and free will, he says. "Understanding consciousness at this point cannot be limited to selected ways of thinking or knowing, but should seek expansive yet rational diversity."

Reflections on Theories of Consciousness

Having produced an article of around 175,000 words, Kuhn found that his opinions on certain proposals had evolved. "My own hunch, right here, right now might be something of a Dualism-Idealism mashup. Second place might go to some form of Quantum Consciousness, triggered by writing this paper and surprising me. Third place, counterintuitively, to a kind of Eliminative Materialism/Illusionism, combined with Neurobiological and Representational Theories."

But, adds Kuhn, "Smart, serious folks believe radically different theories; what I believe doesn't much matter."

Reference: "A landscape of consciousness: Toward a taxonomy of explanations and implications" by Robert Lawrence Kuhn, 26 January 2024, *Progress in Biophysics and Molecular Biology*.
DOI: 10.1016/j.pbiomolbio.2023.12.003
BiophysicsMolecular BiologyNeurosciencePo

Theoretical framework for understanding consciousness

- According to 2 sources

Integrated information theory (IIT) is a **theoretical framework for understanding consciousness** developed by Dr. Giulio Tononi and collaborators at the Wisconsin Institute for Sleep and Consciousness at the University of Wisconsin–Madison.

Integrated Information Theory

integratedinformationtheory.org

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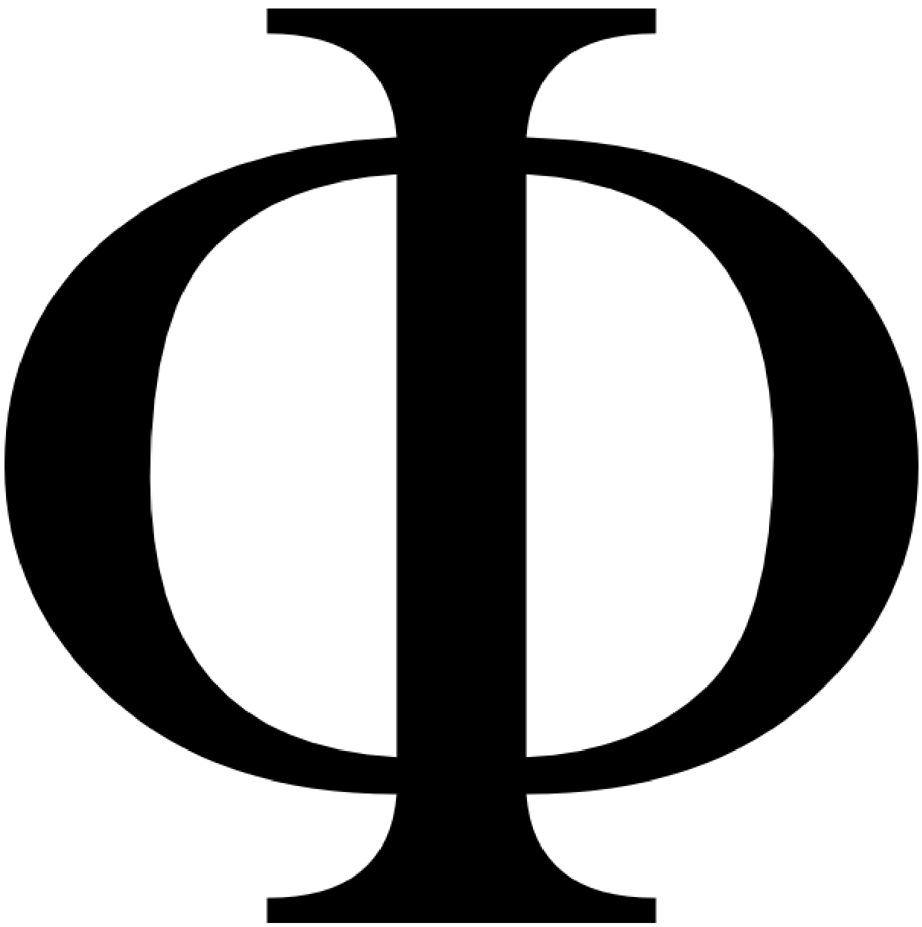

Resources for exploring

INTEGRATED INFORMATION THEORY

Integrated information theory (IIT) is a theoretical framework for understanding consciousness developed by Dr. Giulio Tononi and collaborators at the Wisconsin Institute for Sleep and Consciousness at the University of Wisconsin–Madison.

Overview

- Integrated information theory: from consciousness to its physical substrate
  Nature Reviews Neuroscience (2016)
- From the phenomenology to the mechanisms of consciousness: integrated information theory 3.0
  PLoS Computational Biology (2014)
- Integrated information theory
  Scholarpedia (2015)

Software

- PyPhi is a Python software package for calculating integrated information and its associated structures. For more information, please see our paper describing the software:

- Mayner WGP, Marshall W, Albantakis L, Findlay G, Marchman R, Tononi G. (2018)
  PyPhi: A toolbox for integrated information theory.
  PLOS Computational Biology 14(7): e1006343.
  https://doi.org/10.1371/journal.pcbi.1006343
- Please cite this paper if you use PyPhi in your research.

- PyPhi is open-source and available on GitHub, and can be installed on the command line with the Python package manager via `pip install pyphi`.

- **Discussion**

- For discussion about the software or integrated information theory in general, you can join the PyPhi users group.

- **Documentation**

- Online documentation is available. There are examples that demonstrate how to create a network and measure its integrated information, and comprehensive documentation of the API.

- For technical issues with PyPhi or feature requests, please use the GitHub issues page.

- **Colab Notebook**

- Please see our Colab Notebook, in which you can learn about IIT while using PyPhi interactively.

Integrated information theory: from consciousness to its physical substrate

Giulio Tononi, Melanie Boly, Marcello Massimini & Christof Koch

Nature Reviews Neuroscience **volume 17**, pages450–461 (2016)Cite this article

Abstract

In this Opinion article, we discuss how integrated information theory accounts for several aspects of the relationship between consciousness and the brain. Integrated information theory starts from the essential properties of phenomenal experience, from which it derives the requirements for the physical substrate of consciousness. It argues that the physical substrate of consciousness must be a maximum of intrinsic cause–effect power and provides a means to determine, in principle, the quality and quantity of experience. The theory leads to some counterintuitive predictions and can be used to develop new tools for assessing consciousness in non-communicative patients.

NEUROSCIENCE

Could We One Day Upload Our Minds to a Computer?

The trouble with transhumanism.

Posted February 26, 2024 | Reviewed by Gary Drevitch

- Transhumansim aims to technologically enhance humans beyond biological limits, raising many ethical concerns.
- Uploading our minds to a computer is widely discussed but remains far beyond our technological abilities.
- The complexity of the brain means that we are still far away from understanding it, let alone copying it.

The idea of uploading our minds to a computer sounds like the stuff of science fiction but it has also become more widespread among leading thinkers (Chalmers, 2024; Harari, 2015; Koene, 2012). *Transhumanism* describes the idea of using technology to enhance human capabilities beyond biological limitations—or to "liberate the human race from its biological constraints" (Fukuyama, 2004).

This may not be as eerie as it sounds: Most would agree that electronic hearing aids and glasses are a good thing (Trippett, 2018). Even bionic limbs have become widely accepted and even celebrated (Meyer & Asbrock, 2018).

However, the eerie part returns as we dive deeper into the *uncanny valley* (Mori, 1970/2012). The idea of having our minds implemented on a computer falls into the eerie category for many—although others view it as a promising pathway to immortality. In fact, some have invested huge sums of money to ensure that their bodies (or at least their brains) will be cryogenically preserved in the hope of a future resurrection through technology (Germain, 2022).

An Ethical and Philosophical Quagmire

Transhumanism creates a plethora of ethical concerns about equity and access, consent, safety concerns, loss of human identity, and unintended consequences, to name just a few (Ebbets, 2021; Koch, 2010; Vigo, 2018). Opinions are sharply divided, with some seeing it as a pathway to a blissful future while others express concern that it may be akin to Frankenstein's creation of an uncontrollable monster.

There are other philosophical concerns: Would uploading a copy of our mind result in the existence of two separate people or can the self be transferred? Can the mind function in a disembodied way? Would a computer mind be conscious?

Although these issues are being actively debated, there is no widespread consensus on any of them. We simply don't know the answers to most of these questions. These discussions may be important, but they may not be as urgent or relevant as some have proposed: The notion of uploading our minds to a computer is still merely a fictional concept unlikely to be feasible any time soon, if ever.

Staggering Complexity and Mystery

While there is some benefit in discussing such foundational questions, we are still very far away from trying to upload a mind to a computer.

Two of the main limitations have to do with the incredible complexity of the human brain (see Pang, 2023a) and the current state of neuroscience: Although supercomputers are inching their way toward competing with human brains in terms of raw computing power, we are still far away from being able to accurately simulate the more than 100 trillion connections inside each human brain (Caruso, 2023; Zimmer, 2011).

The other problem is that even if we could simulate such complex interactions, there is no way for us to currently measure all the states of a brain. Think of it as a photocopy machine: Even the best printing technology cannot produce a copy without an accurate scanner attached.

The largest ever research project in Europe (500 scientists working for 10 years with a budget of €600 million; Naddaf, 2023) failed to completely map the human brain—that is, to describe its basic structure: It did not even attempt to record the states of its components at all. At the moment, we don't even have a roadmap or basic understanding of how it would be possible in the future to scan a brain in sufficient detail to upload its information to a computer.

But there is an even bigger challenge: We still have no idea how consciousness works (Pang, 2023b; Pang, 2023c). Even if we managed to upload all the information inside our brains onto a computer, there is no clear evidence that that information alone would be sufficient to produce consciousness.

Our brain is a complex biological organ and while a lot of what the brain does has to do with information—processing, storing, retrieving, and evaluating it—there is no hard evidence that this is itself what creates our conscious experiences. Information fills the content of our experiences but what exactly it means to experience something remains a mystery.

Conclusion

The idea of uploading our mind to a computer has been gaining popularity but remains firmly in the realm of science fiction: We are still very far from even mapping the human brain, let alone measuring the state of every part of it and replicating it on a computer. We also don't understand what makes us conscious and have no evidence that simply uploading the information present in a brain to a computer would generate subjective experiences.

At this stage, it does not look like something that would be possible any time soon—but it raises interesting philosophical and ethical questions about what makes us human and what the limits of technology should be.

Facebook/LinkedIn image: Gorodenkoff/Shutterstock

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Kardashev scale

From Wikipedia, the free encyclopedia

"The Kardashev Scale" and "Galactic civilization" redirect here. For the album by Greydon Square, see The Kardashev Scale (album). For the video game, see Galactic Civilizations.

At the Cerro Paranal Observatory, a laser beam is used to create an artificial star to tune the Very Large Telescope (VLT). The search for exoplanets on which extraterrestrial civilizations could be found is one of the many missions of the VLT.

The **Kardashev scale** (Russian: Шкала́ Кардашёва, romanized: *Shkalá Kardashova*) is a method of measuring a civilization's level of technological advancement based on the amount of energy it is capable of harnessing and using. The measure was proposed by Soviet astronomer Nikolai Kardashev (1932–2019)[1] in 1964[2] and was named after him.

Kardashev first outlined his scale in a paper presented at the 1964 conference that communicated findings on BS-29-76, Byurakan Conference in the Armenian SSR (which he initiated), a scientific meeting that reviewed the Soviet radio astronomy space listening program. The paper was titled "Передача информации внеземными цивилизациями" ("Transmission of Information by Extraterrestrial Civilizations").[2] Starting from a functional definition of civilization, based on the immutability of physical laws and using human civilization as a model of extrapolation, Kardashev's initial model was developed. He proposed a classification of civilizations into three types, based on the axiom of exponential growth:

- A **Type I** civilization is able to access all the energy available on its planet and store it for consumption. Hypothetically, it should also be able to control natural events such as earthquakes, volcanic eruptions, etc.
- A **Type II** civilization can directly consume a star's energy, most likely through the use of a Dyson sphere.
- A **Type III** civilization is able to capture all the energy emitted by its galaxy, and every object within it, such as every star, black hole, etc.

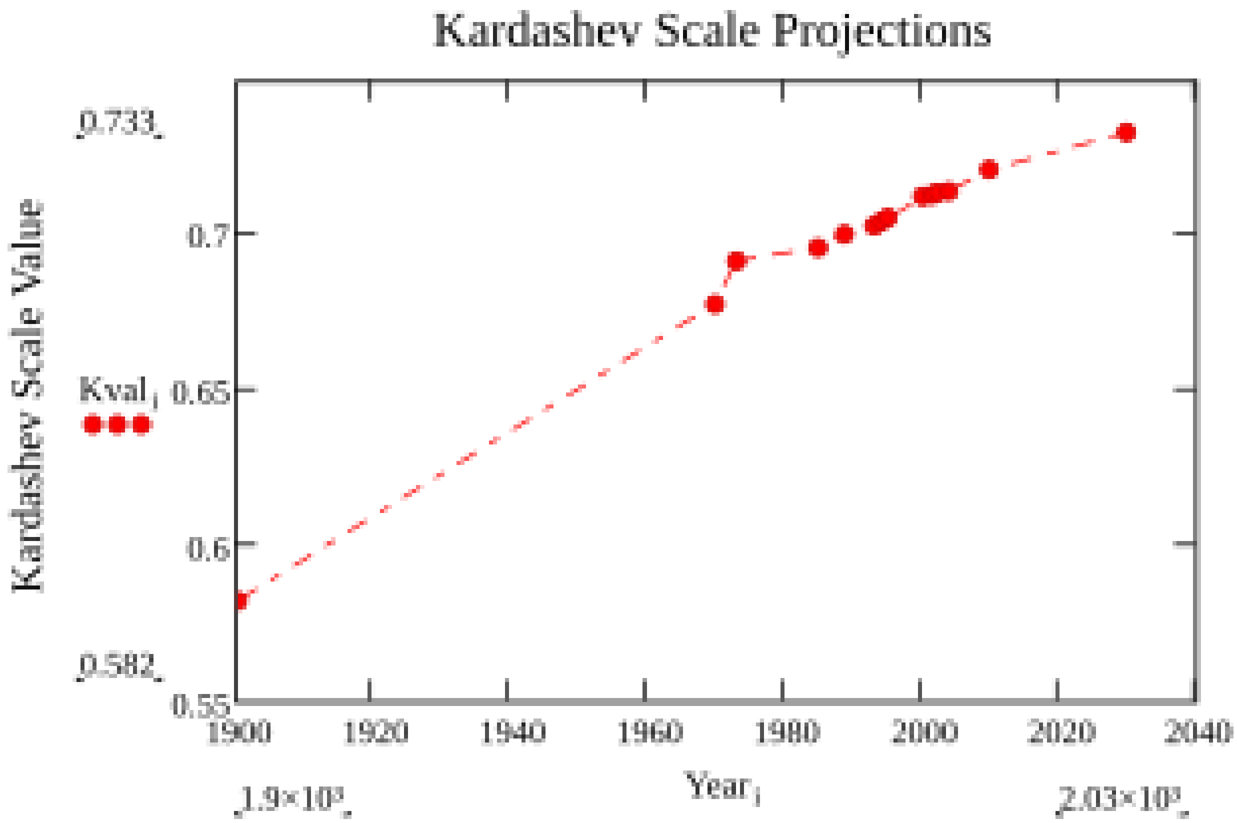
Under this scale, the sum of human civilization does not reach Type I status (though it continues to approach it). Various extensions of the scale have since been proposed, including a wider range of power levels (Types 0, IV, and V) and the use of metrics other than pure power (e.g., computational growth or food consumption).[3][4]

In a second article, entitled "Strategies of Searching for Extraterrestrial Intelligence", published in 1980, Kardashev wonders about the ability of a civilization, which he defines by its ability to access energy, to sustain itself, and to integrate information from its environment.[5] Two more articles followed: "On the Inevitability and the Possible Structure of Super Civilizations" and "Cosmology and Civilizations", published in 1985 and 1997, respectively;[6][7] the Soviet astronomer proposed ways to detect super civilizations and to direct the SETI (Search for Extra Terrestrial Intelligence) programs.

A number of scientists have conducted searches for possible civilizations, but with no conclusive results.[8] However, in part thanks to such searches, unusual objects, now known to be either pulsars or quasars, were identified.[9]

Origin of the classification

First publication (1964)



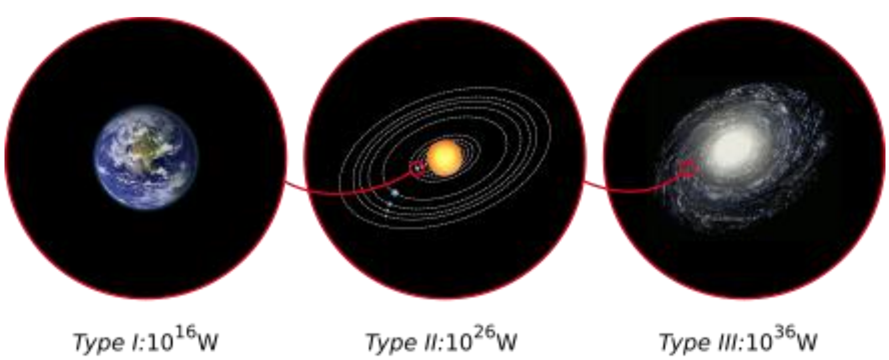
Projection of the Kardashev scale to 2040 based on data from the International Energy Agency World Energy Outlook

Kardashev presented for the first time a classification of civilizations according to their level of energy consumption in an article entitled *Transmission of Information by Extraterrestrial Civilizations*, published in 1964 first in Russian in the March–April issue of the Astronomicheskii Zhurnal,[2] then in English in the September–October 1964 issue of the Soviet Astronomical Journal.[2] In this article, the scientist presents a calculation of the evolution of the energy needs of humanity, and calculates that the energy consumption of the latter will be equal to that emitted by the Sun, evaluated at 4×10^{26} watts (W), in about 3,200 years, then will be equal to that emitted by 10^{11} stars similar to ours (which corresponds to the estimated number of stars in the Milky Way) in 5,800 years. Based on this observation, and considering that there is no reason to assume that the evolution of humanity's energy consumption can decrease, Kardashev comes to propose a classification of technological civilizations into three types.[2][10]

A civilization known as "Type I" is able to collect and use all the available energy on its planet, that is, the theoretical equivalent of 10^{16} watts. According to Kardashev, it is the type of civilization that Earth was closest to achieving in 1964. A civilization known as "Type II" would surpass the first by a factor of 10 billion, reaching a consumption of 10^{26} watts, this time using all the power emitted by its star. Finally, a civilization known as "Type III" would be able to collect and consume all the energy emitted by its galaxy, which is equivalent to 10^{37} watts.[2]

Assuming the development of radio, Kardashev predicted that in the following two decades (i.e. in the 1980s) it would be possible to build antennas of 100,000 m^2 capable of detecting Type II and III civilizations. A Type I civilization like that of earth would be able to receive the extraordinary energetic emissions of the other types of civilizations, which would supposedly be able to emit continuously.[2][11]

Kardashev then examined the characteristics of a transmission from an artificial source. He mentioned the two cosmic radio sources discovered in 1963 by the California Institute of Technology, CTA-21 and CTA-102 in particular, which would have characteristics close to those of a presumed artificial source. The most suitable region of the galaxy for observing Type II and III civilizations would then be the Galactic Center, due to the high density of the stellar population it harbors. He then recommended that the search programs for such artificial sources should focus on other nearby galaxies, such as the Andromeda Galaxy, the Magellanic Clouds, M87, or Centaurus A. Kardashev concluded his paper by noting that the possible discovery of even the simplest organisms on Mars would increase the likelihood that Type II civilizations exist in the galaxy.[2]



Energy consumption in three types of civilization as defined by Sagan's extended Kardashev scale

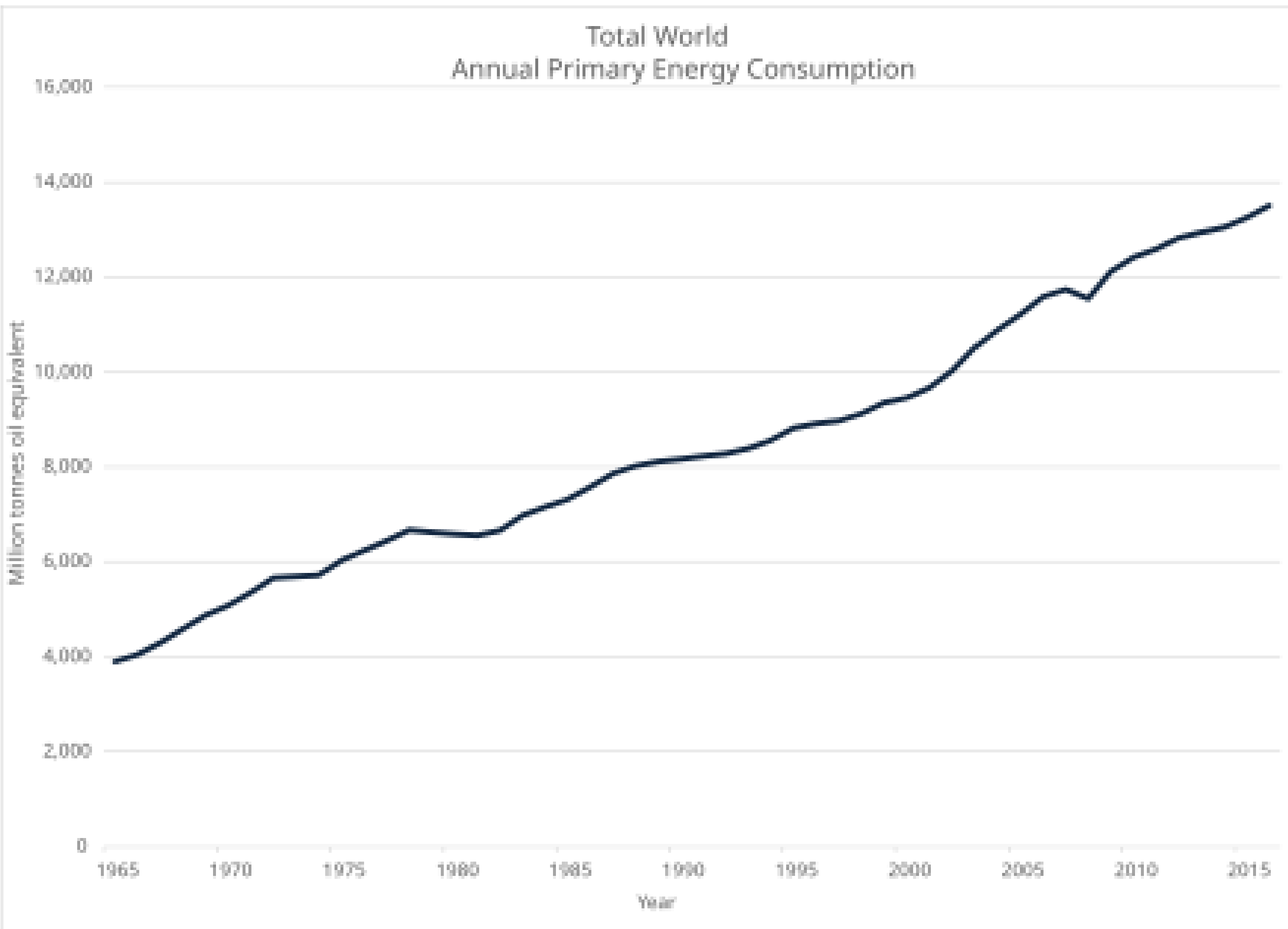
Second publication (1980)

Towards an energetic definition of civilization

In 1980, Nikolai Kardashev published a second article entitled *Strategies of Searching for Extraterrestrial Intelligence: A Fundamental Approach to the Basic Problem,*[5] in which he stated that:

Detection and studies of extraterrestrial civilizations constitute a problem of immense significance for the progress of humanity and for its culture and philosophy. The discovery of intelligent life in the Universe would provide a guideline to the possible development of our civilization over astronomical time spans.

—*Nikolai Kardashev, Strategies of Searching for Extraterrestrial Intelligence: A Fundamental Approach to the Basic Problem*



Graph of world primary energy consumption in 2011 according to the BP *Statistical Review*

According to the Soviet astronomer, our civilization would be too young to be able to contact another civilization that would certainly be more advanced than us; the solar system is too young with its five billion years, and the first ancestors of today's man appeared only 6 million years ago at the earliest;[12] the oldest celestial objects are between 10 and 14 billion years old; it is clear that the other civilizations are incomparably older than the human civilization. Therefore, the knowledge of these civilizations must be greater than ours, and, he reasoned, they must surely be aware of what we are doing.[5]

Kardashev believed it is probable that the present state of our civilization is only one of the stages through which civilizations pass during their evolution. It is thus possible to define civilization on the basis of this universal characteristic, which allowed Aleksandr Lyapunov to define life as "a highly stable state of matter, which uses information encoded by the states of individual molecules to produce maintaining reactions", which Kardashev calls the "functional definition of civilization".[5] He therefore suggests thinking of civilization as a "highly stable state of matter capable of acquiring, making abstract analysis of, and utilizing information to obtain qualitatively new information about its environment and about itself, to improve its capabilities of gathering new information for producing sustaining reactions." Civilization is therefore characterized by the quality of the information acquired by its operating program, and by the energy required to implement these functions. By "information about its environment and about itself", Kardashev specified that it is data about organic or inorganic nature, science, technology, economy, culture, arts, etc. From this definition, he proposed a diagram representing the interactions between a civilization and its environment, and enumerated a number of scientific problems arising from these interactions with the information available in the Universe.[5]

From this definition, Kardashev drew three conclusions. The first postulated that because of the vast and unlimited set of activities required by scientific problems, the period during which civilizations must transmit and communicate is necessarily long, even unlimited. On the other hand, since our present development covers only a negligible fraction of this communication phase, Kardashev hypothesized the high improbability that we will meet "brothers in intelligence" who are at the same stage of evolution as are we. After all, highly advanced civilizations know and use the laws of physics to a degree that we have yet to suspect. Kardashev asserted that "this last point should be taken into account in the research programs of extraterrestrial civilizations" and concluded that it is very likely that our present state is only one of the stages through which every civilization passes during its evolution.[5]

Kardashev then analyzed various models and hypotheses of the evolution of civilization. Answering the question of the Russian astronomer Iosif Shklovsky, who in an article published in 1977 and titled *Possibility of the Intelligent Life in the Universe Being Unique* found it strange that the "shock wave of intelligence" of a supercivilization had not yet reached the limits of the whole Universe, Kardashev put forward two explanatory hypotheses. In the first, he postulated that it would not be useful for a supercivilization to expand the space it occupies in order to maintain its activity, and in the second, it is possible that a civilization, instead of dispersing itself in space, would rather continue its activities of information analysis in order to discover new fundamental laws (such as the exploration of the microcosm, or black holes for example).[5]

However, such civilization activities require the use of abundant energy. According to the laws of thermodynamics, an important part of this consumed energy must be converted into radiation of a bolometric magnitude approximately equal to that of the radiation background surrounding the source. The spectral distribution of this intensity must be close to that of a black body. This would be a possible way to search for extraterrestrial civilizations. Such energy consumption would also require a large amount of solid matter for stellar engineering activities, which Kardashev called "cosmic miracles". In short, information about the possible existence of an extraterrestrial civilization would come in the form of electromagnetic radiation.[5]

With regard to the fate of civilizations, Kardashev saw two concepts, from which two strategies for the search for extraterrestrial civilizations can be derived. The first, which he called "terrestrial chauvinism", is based on the principle that civilizations can only stabilize or perish at a level of development close to ours currently reached. The second, which he called the "evolutionary concept", holds that civilizations are capable of reaching higher levels of development than that of contemporary humanity. In the first case, the best search strategy using astronomical detection means (e.g., the SETI program) would be to observe the most powerful (and often the most distant) sources of radiation in space. The observer will then be able to determine if they are natural emission sources, and only then can the search focus on objects with weaker radiation. In the second case, he recommended to search for new and powerful sources of radiation, especially in the poorly known regions of the electromagnetic spectrum. These sources could be significant or periodic monochromatic signals from the galactic center, from other galaxies or from quasars and other exotic cosmic objects. Kardashev believed that the search should focus on the millimeter wavelength spectrum, close to the maximum intensity of the cosmic microwave background, rather than in the 21-centimeter band (which is the domain of investigation of the SETI program). According to Kardashev, in order to capture the significant radiation of an advanced civilization emitted by a megastructure (such as a Dyson sphere), a radio telescope with a diameter larger than the diameter of the Earth would have to be placed in orbital space.[5]

Kardashev concluded by predicting that the search for extraterrestrial civilizations would lead to positive results in the [then] next decade, giving humanity access to a vast amount of information about the Universe and its evolution over a period of several billion years.[5]

Third publication (1985)

Discovering super civilizations

In the article *On the Inevitability and the Possible Structure of Supercivilizations* published in 1985, Kardashev evokes the possible scenarios and the means of investigation available to humanity for the detection of hypothetical extraterrestrial supercivilizations. The Soviet astronomer reminds us that we search for these supercivilizations on the basis of our own development criteria, and that predictions are possible only for extraterrestrial worlds close to our technological level, the others being beyond our intellectual representation. Nevertheless, it seems useful to him to conceive models of supercivilizations based at the same time on imagination and on our present scientific knowledge. Since the laws of physics are immutable, even if new laws are discovered in the future, they will not abolish those already known.[6]

According to Kardashev, theoretical models of supercivilizations must meet two basic assumptions. The first is that the range of supercivilization activities that obey the laws of physics is limited only by natural and scientific constraints, while the second is that the evolution of supercivilization activities cannot be interrupted or limited by intrinsic, inherent contingencies, such as large-scale social conflicts. For Kardashev, unlike other scientists, supercivilizations cannot self-destruct or retrogress. According to these principles, there must exist in space megastructures of great size, emitting a lot of energy and information, and existing for billions of years, while being compact enough to rapidly exchange large amounts of data between them. A supercivilization would thus create a technological structure of cosmic dimensions. As an example, Kardashev cites Freeman Dyson's megastructure, in the form of a sphere of several astronomical units in diameter. Other phenomena may indicate highly technological activities, such as artificially exploding stars or the changing of stellar orbits to store mass and energy. Giant molecular clouds also hold great potential for astroengineering. Kardashev even raises the possibility of a supercivilization reshaping the entire galaxy.[6][7]

Then he evokes the theoretical and mathematical possibility of the existence of a megastructure in the form of a disk rotating on itself at a constant angular velocity. According to him, the search for intelligent signals should be directed to the detection of such megastructures at the characteristic radiation (20 μm). Quasars or galactic centers can be excellent candidates to testify to the existence of a supercivilization since they emit strong infrared radiation, which indicates a solid structure. The astronomer advises to look for these objects in a wavelength range from a few microns to a few millimeters. Large intelligent structures can also be detected by the fact that they screen or reflect the surrounding radiation.[6]

Possible scenarios for the evolution of supercivilizations

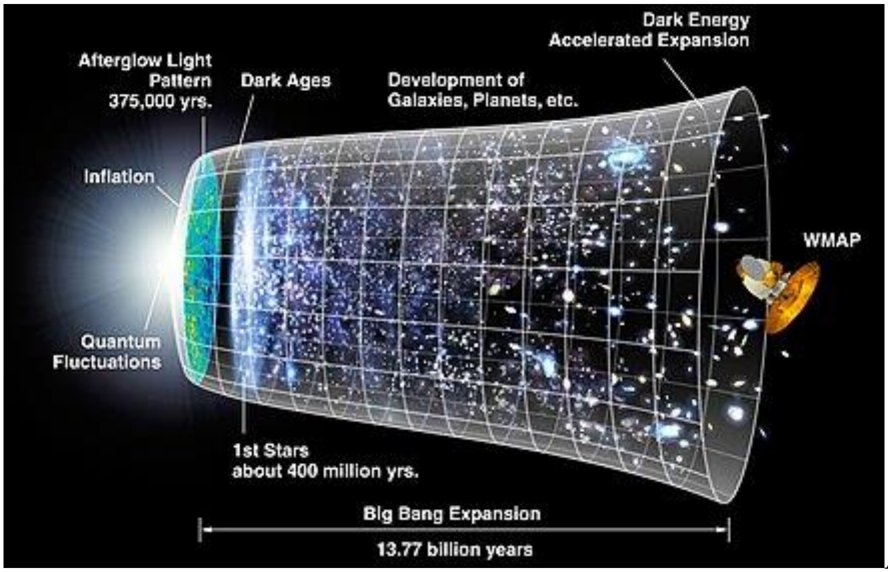
See also: Potential cultural impact of extraterrestrial contact

Kardashev believes that it is very likely that a supercivilization has already detected and observed humanity through cosmic-sized telescopes. He discusses this in a 1997 article on the subject, entitled *Radioastron – a Radio Telescope Much Greater than the Earth*.[13] For this supercivilization, the science of "cosmic ethnography" must be highly developed. However, the fact that no contact has been made so far could be explained by ethical considerations of these civilizations. Based on this principle, Kardashev sees only two possible evolutionary scenarios for a supercivilization: natural evolution and evolution after contact with other extraterrestrial civilizations. He considers more likely the scenario based on contact between two civilizations highly developed technologically and culturally advanced civilizations; this scenario, which he calls the "Urbanization Hypothesis", would result in the regrouping and unification of several civilizations within a few compact regions of the Universe.[6]

Kardashev lists, in the form of investigative tools, six possible scenarios (summarized in a table at the end of his 1997 article)[13] that explain the evolution of a civilization. Each of the scenarios corresponds to a probability, one or more objects to be observed, an adapted procedure, and, finally the possible consequences for our civilization:[6]

1. The scenario of a large unification of civilizations over an extent of one to ten billion light-years with concentration in a certain region has a probability of 60%. These civilizations are to be searched for in the most powerful quasars and in the galactic bulge, at a radiation level higher than 10^{38} watts, in the wavelengths from 10 μm to 1 cm, as well as in the other regions of the spectrum. This is to detect megastructures or signals with a wavelength of 1.5 mm[14] and omnidirectional emission up to 21 cm. In the event of contact, humanity would see progress in all areas of society in order to join this supercivilization; it is also expected that an ethnographic conservatory would be created on Earth.
2. The scenario of a unification on the scale of the galactic cluster has only a 20% probability of realization. Kardashev advises to observe the Virgo cluster (especially M87) and other clusters in a similar way as in the first scenario. The consequences for humanity are the same as in the first scenario.
3. The scenario of a unification on the scale of galaxies has only a 10% probability. To confirm it, we must study the galactic centers, both of the Milky Way and of neighboring galaxies (such as M31, M33), according to a procedure similar to that of the first scenario. The consequences for humanity are the same as in the first scenario.
4. The scenario of a complete colonization of space has no probability of being realized according to Kardashev because if it were realizable then "they" would already be on Earth; yet this is not the case. However, in the case of a contact, the consequences on humanity are the same as in the first scenario.
5. This scenario assumes that all civilizations would have destroyed themselves before any contact. Kardashev estimates the probability of this to be 10%. Humanity should be able to detect ancient megastructures in the vicinity of the nearest stars. As a result, no contact with humanity can take place.
6. The last scenario suggests that we are the first or the only ones in the Universe. Kardashev estimates its probability at 10%.
   Only exobiology can confirm or falsify such a scenario. We can imagine a potential contact in the distant future, and then the consequences would be similar to those of the other five scenarios.

Fourth publication (1997)



According to the standard model describing the expansion of the Universe since the Big Bang, there may be planets older than the Earth, capable of harboring supercivilizations.

In the article *Cosmology and Civilizations* published in 1997, Kardashev reiterates the need to carefully observe astronomical objects with strong radiation in order to detect supercivilizations. However, the discovery of a civilization at a stage of development similar to ours is unlikely. The existence of such supercivilizations is made possible by the fact that life on Earth is recent compared to the age of the Universe (8×10^9 years before the formation of the Solar System). He then examines the conditions for the appearance of life on cosmological time scales. Assuming the rate of evolution of life on Earth and considering the age of the Universe, it is reasonable to assume that a civilization could have reached our level of technological development in 6×10^9 years. Such civilizations can be observed in nearby regions, since the farther away we observe, the younger the objects are. Recent discoveries of sources of intense radiation deadly to life show that life could have flourished under cover for the time necessary for its appearance and maintenance. Another argument for the possibility of a very old supercivilization is that most of the objects that could be megastructures have not yet been discovered and mapped. In addition, 95% of the matter remains invisible or can only be inferred by the gravitational influence it produces.[7]

According to Kardashev, it is essential to focus our search tools on new objects radiating at a wavelength of a few microns to a few millimeters, and at a temperature of 3 to 300 K, which is characteristic of large structures of solid matter.[15] It would then be possible to detect structures belonging to Type II in our galaxy or in those nearby. Type III structures can also be observed at large cosmological distances. Kardashev recalls that a study was conducted on 3000 sources of the IRAS catalog from the four directions of the sky. Two temperature bands were targeted: from 110 to 120 K and from 280 to 290 K. The analysis showed that the 110–120 K sources are clustered in the Galactic plane and in its center. Kardashev explains that only more powerful observations in the infrared and submillimeter range can reveal possible artificial sources of radiation. He then refers to projects that he has proposed, in particular that of putting into orbit a cryogenic space telescope (the *Millimetron Project*).[7][16]

According to Kardashev, these results, combined with those of other research on the age of certain cosmic objects, suggest that civilizations dating from 6 to 8 billion years ago may exist in our galaxy. It is likely that they have long since discovered our own civilization, a hypothesis that could answer the question posed by Enrico Fermi when he formulated his paradox: "Where are they?". Without the discovery of artificial sources, however, Shklovsky's theory that civilizations self-destruct as a result of large-scale social conflicts would be proven. Kardashev mentions another hypothesis that, in his opinion, is capable of explaining the dynamics of the supercivilizations: the "feedback effect" (theorized by Sebastian von Hoerner in 1975),[17] which is based on the hypothesis that at a high technological level, civilizations tend to converge rather than to isolate themselves. The distance between supercivilizations could then be determined by half the time of the technological evolution of the oldest civilization, which would be about 3 to 4 billion years. On the other hand, this supercivilization may not have been present in our galaxy for a long time. Kardashev concludes by saying that since the expansion of the Universe is infinite, the number and lifetime of such supercivilizations are also infinite.[7]

Categories defined by Kardashev

The hypothetical classification, known as the Kardashev scale, distinguishes three stages in the evolution of civilizations according to the dual criteria of access and energy consumption.[18][19] The purpose of this classification is to guide the search for extraterrestrial civilizations, particularly within SETI, in which Kardashev participated,[20] and this on the assumption that a fraction of the energy used by each type is intended for communication with other civilizations. To make this scale more understandable, Lemarchand compares the speed at which a volume of information equivalent to 100,000 average-sized books can be transmitted across the galaxy. A Type II civilization can send this data using a transmission beam that lasts for only 100 seconds. A similar amount of information can be sent across intergalactic distances of about ten million light years, with a transmission time of several weeks. A Type III civilization can send the same amount of data to the entire observable universe with a transmission time of 3 seconds.[18][21]

Kardashev's classification is based on the assumption of a growth rate of 1% per year. Kardashev believed that it would take humanity 3,200 years to reach Type II, and 5,800 years to reach Type III.[3] However, Dr. Michio Kaku believes that humanity must increase its energy consumption by 3% per year to reach Type I in 100–200 years.[22] These types are thus separated from each other by a growth rate of several billion.[3]

Type I

A civilization "close to the level currently achieved on Earth, with an energy consumption of $\approx 4\times10^{19}$ erg/sec" (4×10^{12} watts).[2] A Type I civilization is usually defined as one that can harness all the energy that reaches its home planet from its parent star (for Earth, this value is about 2×10^{17} watts), which is about four orders of magnitude higher than the amount currently achieved on Earth, with an energy consumption of $\approx 2\times10^{13}$ watts by 2020. The astronomer Guillermo A. Lemarchand defined Type I as a level close to today's terrestrial civilization, with an energy capacity equivalent to Earth's solar irradiance, between 10^{16} and 10^{17} watts.[23]

Type II

A civilization capable of harnessing the energy radiated by its own large star – for example, by successfully completing a Dyson sphere or Matrioshka brain – with an energy consumption of $\approx 4\times10^{33}$ erg/sec.[2] Lemarchand defined such civilizations as being able to harness and channel the entire radiation output of their star. The energy consumption would then be comparable to the luminosity of the Sun, about 4×10^{33} erg/sec (4×10^{26} watts).[23]

Type III

A civilization with energy on the scale of its own galaxy, with an energy consumption of $\approx 4\times10^{44}$ erg/sec.[2] Lemarchand defined civilizations of this type as having access to energy comparable to the luminosity of the entire Milky Way galaxy, about 4×10^{44} erg/sec (4×10^{37} watts).[23]

In accordance with the data available at the time, Kardashev did not go beyond a Type III civilization. However, new types (0, IV, V, and VI) have been proposed.

Reassessments of the Kardashev scale

Sagan's finer classification

In 1973, Carl Sagan discovered Kardashev's work on the classification of civilizations.[24] He found that the differences between the types Kardashev identified were so great that they did not allow for the best possible modeling of the evolution of civilizations.[11] Consequently, Sagan proposes a more refined classification, still based on Kardashev's types, but integrating intermediate levels using the following logarithmic interpolation formula:[25]

Where *K* is the Kardashev type of a civilization and *W* is the amount of power it uses, in watts. Thus, a *Type 1.1* civilization would be defined by a power of 10^{17} watts, while a *Type 2.3* civilization would be able to harness 10^{29} watts.

Moreover, the above formula could be used to extrapolate beyond Kardashev's original types. For example, a ***Type 0*** civilization, not defined by Kardashev, would control about 1 MW of power (equivalent to having around 100 campfires burning at any given time); on Earth, the emergence of Type 0 civilizations is roughly concurrent with the rise of civilization in a general sense.[26]

Sagan estimated that, according to this revised scale, 1970s humanity would be Type 0.7 (about 10 terawatts),[27] equivalent to 0.16% of the power available on Earth.[28] This level is characterized, according to him, by the ability to self-destruct, which he calls "technological adolescence".[21] In 2021, the total world energy consumption was 595.15 exajoules (165,319 TWh),[29] equivalent to an average power consumption of 18.87 TW or a Kardashev rating of 0.73 (to 2 s.f.).[30]

Sagan also suggests that, for completeness, an alphabetical scale should be added to indicate the level of social development, expressed in the amount of information available to the civilization. Thus, a Class A civilization would be based on 10^6 bits of information (less than any recorded human culture), a Class B on 10^7, a Class C on 10^8, and so on. Humanity in 1973 would belong to the "0.7 H" class.[31] According to Sagan, the first civilization with which humanity would come into contact could be between "1.5 J" and "1.8 K"; a galactic supercivilization would be at the "3 Q" stage, while a federation of galaxies could be at the "4 Z" stage.[21] The information and energy axes are not strictly interdependent, so even a level Z civilization would not have to be Kardashev Type III.[31] Sagan believed that no civilization had yet reached level Z, speculating that so much unique information would exceed that of all the intelligent species in a galactic supercluster, and observing that the universe is not old enough to exchange information effectively over large distances.

In 2017, the total amount of information generated on the internet was 26 zettabytes (with an estimated 120 zettabytes in 2023),[32] equivalent to 0.73 R/S on Sagan's combined scale.

Kaku and the knowledge economy

In *Physics of the Future* (2011), American physicist Michio Kaku examines the conditions for humanity to converge on a Type I planetary civilization. This convergence is based primarily on the knowledge economy. Kaku uses the Kardashev scale, but develops it by adding an additional stage: a Type IV civilization would be able to draw the energy it needs from extragalactic radiation. By studying the evolution of technologies that have changed history (paper, the integrated circuit), Kaku believes that humanity is moving toward a civilization of planetary dimensions, the "starting point" of which is the Internet.[33]

A Type I civilization consumes power on the order of thousands to millions of times our current planetary output, about 100 trillion trillion watts. It would have enough energy to manipulate the occurrence of certain natural phenomena, such as earthquakes or volcanoes, and could build cities on the oceans. We can see the beginnings of a Type I civilization in the fact that a global language is developing (English), a global communication system is emerging (the Internet), a global economic system is in the making (the establishment of the European Union), and even a globalized culture is standardizing humanity (mass media, television, rock music, and Hollywood movies).[3] To achieve Type I, humanity must be able to communicate with the rest of the world and to focus on several areas: building infrastructure to facilitate communication and cooperation, education, research and development, and innovation, as well as building strong ties between diasporas and their countries of origin, and between migrants and non-migrants.[33] If development fails, it is likely that the world will not be able to achieve Type II. If these areas do not develop, Kaku predicts that humanity will sink into the "abyss":[33] an advanced civilization must grow faster than the frequency of occurrence of extinction-level cosmic catastrophes, such as comet or asteroid impacts. A Type I civilization should also be able to master space travel to deflect threatening objects. It would also have to anticipate the onset of ice ages and modify the climate long before they occur to avoid them.[3]

In addition, in his books *Hyperspace* and *Parallel Worlds*, Michio Kaku has discussed a Type IV civilization that could harness "extragalactic" energy sources such as dark energy.[34]

Zubrin's planet mastery

In *Entering Space: Creating a Spacefaring Civilization*, Robert Zubrin suggests another form: his definition of a Type I civilization is described as one that has achieved full mastery of the resources of its planet (global), a Type II of its solar system (interplanetary), and a Type III would have unleashed the full potential of the galaxy (starfaring civilization). Metrics other than pure energy consumption have also been proposed.[4]

He ponders the possibility of a Type IV civilization, one that would dominate the universe, noting that there are limits to how minds can connect and interact on a galactic or intergalactic basis. As an example, he mentions that communication from the center of our galaxy to its edge would take about 50,000 years (since nothing can travel faster than light, according to our understanding of physics).[35][4]

Barrow's microdimensional mastering

The astronomer John D. Barrow of the University of Sussex has hypothesized that there are other stages beyond Type III. These Type IV, V, or even VI civilizations would be able to manipulate cosmic structures (galaxies, galactic clusters, superclusters) and even escape the Big Crunch through holes in space.[3]

Barrow also proposes an "anti-Kardashev scale": he observes that humans have found it more cost effective to extend their ability to manipulate their environment to smaller and smaller scales rather than to larger and larger ones. He, therefore, proposes a reverse classification, from Type I-minus to Type Omega-minus:

- **Type I-minus** is capable of manipulating objects on the scale of itself: building structures, mining, joining and breaking solids;
- **Type II-minus** is capable of manipulating genes and altering the development of living things, transplanting or replacing parts of themselves, reading and manipulating their genetic code;
- **Type III-minus** is capable of manipulating molecules and molecular bonds, creating new materials;

- **Type IV-minus** is capable of manipulating individual atoms, creating nanotechnology at the atomic level, and creating complex forms of artificial life;
- **Type V-minus** is capable of manipulating the atomic nucleus and engineering the nucleons that compose it;
- **Type VI-minus** is capable of manipulating the most elementary particles of matter (quarks and leptons) to create organized complexity among populations of elementary particles;
- **Type Omega-minus** is capable of manipulating the fundamental structure of space and time.[36]

In Impossibility: The Limits of Science and the Science of Limits (1998), Barrow proposes a scale ranging from "BI" to "BVI", with an ultimate stage he calls "BΩ", the former characterized by the possibility of manipulating one's environment, while the latter allows for the modification of spacetime.[37]

Galántai's miniaturization and resilience to catastrophes

For Zoltan Galántai, a scale classifying civilizations should be based on their ability to survive catastrophes, particularly those of cosmic origin, such as an asteroid impact.

Zoltan Galántai recognizes the important role that Kardashev's classification has played in the SETI program, but he believes that another scale is possible, without using energy consumption, by resorting to miniaturization. The hypothesis of Donald Tarter, researcher at SETI, is that a civilization based on nanotechnology would not need an ever-increasing amount of energy. A Type I civilization that masters local space travel could colonize its planetary system and even the Oort cloud without needing an amount of energy that would make it Type II.[24] This scale loses its meaning beyond Type II, since it is impossible to predict the evolution of civilizations over long distances in a galactic colonization process. Finally, the Kardashev scale is the product of an era of insufficient scientific knowledge, which considered the possibility of stellar object CTA-102 as an artificial Type III source, whereas today we know that it is a galactic nucleus.[24]

In another article, Zoltan Galántai suggests considering another scale, no longer based on energy consumption, but on a civilization's ability to survive natural and cosmic disasters. Type I would describe a civilization capable of surviving a local natural disaster, like the Anasazi. A Type II civilization would have the means to withstand a regional or continental disaster, and finally Type III could face a global disaster such as an asteroid's impact, a supervolcano's eruption, or an ice age. Beyond the first three types are civilizations that have scattered throughout the galaxy. The Type IV civilization would still be vulnerable to some cosmic threats, while the Type V civilization would be technically immortal, as no cosmic catastrophe could reach it.[24] The Kardashev scale can be a relevant tool for preventing catastrophes, whether human or natural, according to Richard Wilson, who relates this scale to the power of destruction, in TNT. A Type I civilization would use 25 megatons of equivalent TNT per second, a Type II civilization 4×10^9 times more (4 billion hydrogen bombs per second), while a Type III civilization would use 10^{11} times more.[28]

Progression through the types

Further information: World energy supply and consumption

Towards type I

According to Carl Sagan, Type I should be reached around 2100.[33]

Physicist and futurist Michio Kaku has suggested that, if humans increase their energy consumption at an average rate of 3 percent per year, they could reach Type I status in 100–200 years, Type II status in a few thousand years, and Type III status in 100,000 to a million years.[38]

Physicist Freeman Dyson has calculated that Type I should be reached in about 200 years,[39] while Richard Carrigan has estimated that the Earth is just four-tenths of the way to Type I on the Sagan scale. If Type I is reached soon (in the year 3000 for Richard Wilson),[40] it would be accompanied by profound social upheavals, but also by a significant risk of self-destruction.[40]

According to Per Calissendorff, energy consumption cannot be the main parameter to explain the transition from one type to another. Civilizations must have the means to maintain their growth rate despite climatic conditions and major natural disasters, even on the cosmic scale. A civilization moving towards Type II must have mastered space travel, interplanetary communication, stellar engineering, and climate. It must also have developed a planetary communication system, such as the Internet.[19] For Michio Kaku, the only serious threat to a Type II civilization would be the explosion of a nearby supernova, while no known cosmic catastrophe would be capable of wiping out a Type III civilization.[3]

According to Philip T. Metzger, humanity has reached Type I, but faces an energy challenge. In his 2011 paper *Nature's Way of Making Audacious Space Projects Viable*, he states that the Earth's non-renewable energy sources are nearly exhausted; natural gas will be depleted by 2020–2030, coal by 2035, uranium by 2056, while oil production peaked in 2006–2008.[41] Nuclear energy cannot fully meet the world's energy needs (it represented only 6% in 2011). In addition, renewable energy cannot meet the growing demand for energy. Most of the minerals used by humans are in danger of becoming scarce; 11 minerals are already classified as having passed their peak production. For Metzger, humanity must therefore undertake a "100-year project" aimed at building a spacecraft ("100 Year Starship") capable of accessing the vast energy resources of the Solar System.[41] For Metzger, it is even probable that if extraterrestrials coveted the energy resources of our Solar System, they would not look for them on Earth, but on the various asteroids and planetoids. Robotics is the only way to access so many dispersed resources, and humanity should embark on a second long-term project, which Metzger calls the "robotsphere", that would begin with the energetic exploitation of the Moon (estimated at 2.3×10^{13} J/year). This first step would make it possible to reach Type II in 53 years. Then the robotsphere (self-replicating and self-learning automated probes) would extend to the rest of the Solar System. Current advances in artificial intelligence suggest that the foundations of a robotsphere could be reached early in the next century, beginning in 2100. Metzger sees eight benefits for humanity in building the 100 Year Starship, including zero launch costs because the spacecraft will be built in space by robots that can do so with little human assistance (drastically reducing manufacturing costs), the creation of a Solar System-wide economy, and the use of resources from celestial objects and possibly terraforming them.[41]

Towards type II

Viorel Badescu and Richard B. Cathcart have studied the possibility that a Type II civilization could use a 450 million kilometer device to direct solar radiation and thus be able to impart a kinetic motion to its star that deviates it from its usual trajectory by about 35 to 40 parsecs,[42] allowing it, among other things, to capture its energy and navigate the galaxy.[43][42]

For Claude Semay, "a Type II civilization could be detected at great distances (by what is called "astro-technical leakage"),[verification needed] provided that it is not located in a region of the galaxy that is too distant from us, or that it does not occupy a location that is obscured from us by clouds of gas or dust".[44]

Towards type III

Artist's view of quasar GB1508. According to Russian astronomer Kardashev, a highly evolved civilization, known as "Type III" in his theoretical classification, would be able to draw its energy from such a source.

A Type III civilization should be detectable because of the large amount of radiation captured on a galaxy-wide scale. Calissendorff suggests using 75% of the total light emitted by a galaxy to determine that a Type III civilization uses many Dyson spheres. If only three or four of these spheres occupy the galaxy, it does not necessarily mean that the civilization has reached Type III; it may still be in transition.[19]

However, such civilizations may remain beyond the reach of our understanding and instruments. Sagan believes that the nearest Type III civilization is at an average distance of 10,000 light-years from us, but that it is not interested in classical radio transmissions, being of a different technological level. Only small, low-level civilizations could communicate with us.[27]

However, "a Type III civilization should not be confused with what science fiction writers call a 'galactic empire'", Semay notes, knowing that it can only exist if interstellar travel is achieved. Semay argues that there is no evidence that this will ever be possible.[44] Based on Dyson's calculations, Semay believes that such a journey would take three centuries, with an average distance between stars of about 7 light years. Overall, the speed of the colonization front, which ranges from 4×10^{-4} to 5×10^{-3} light-years per year, would result in humanity spreading throughout the galaxy in a period of 16 to 200 million years.[44] "A Type III civilization, having thus "domesticated" its galaxy by building a large number of Dyson spheres, would be detectable over intergalactic distances of several million light-years."[44]

A Type III civilization could theoretically live inside a supermassive black hole, in a stable periodic orbit, which would make it completely undetectable, according to V. I. Dokuchaev.[45]

Towards type IV

Zoltan Galántai notes that neither Kardashev nor Sagan thought to extend the scale and define a Type IV (which would use the energy of an entire Universe). They simply did not envision a civilization capable of manipulating its environment on the largest possible scale (about 14 billion parsecs).[11] The concept of a Type IV supercivilization approaches divine possibilities, enabling the creation of, and travel through, alternate Universes of such a civilization's own design,[11] although the latter possibility is reserved for a Type V civilization by Carrigan.[25] The fraction of energy captured by a civilization capable of powering itself on a black hole could also be used to classify civilizations.[46]

Possible scenarios

According to Kardashev, the most important parameters to define the existence of a civilization are three: the presence of very powerful energy sources, the use of non-standard technologies, and the transmission of significant amounts of information of various kinds through space.[47]

Energy sources

Kardashev's classification is based on the hypothesis that an advanced civilization uses significant energy, which implies that it must be de facto detectable over long distances, as summarized by Zoltan Galántai.[24] For Kardashev, the limit of a civilization's energy consumption is originally located in the region of the electromagnetic spectrum from 10^6 to 10^8 Hz, which allows two observations related to thermodynamics. First, all the energy consumed is inevitably converted into heat. Second, this energy can only be dissipated in the form of radiation scattered in space. These two findings are the pillars of Kardashev's theory that cosmic objects with strong radiation could be artificial sources.[47] He also considered the possibility of detecting an artificial source by emphasizing the spectral line of hydrogen in its use for nuclear fusion.[48]

Dutil and Dumas consider several physical limits to continuous energy production, such as photosynthesis (about 10 TW), climate (about 127 TW), and solar flux (174,000 TW).

The only inexhaustible source of energy that can sustain a civilization for over several billion years, is deuterium (used in nuclear fusion).[49] The sustainability of a civilization must therefore involve "strict control of the exploitation of available resources"; this difficulty in exceeding energy limits may explain the fact that the vast majority of civilizations fail to engage in a space colonization project.[49]

Astrophysicist Makoto Inoue and economist Hiromitsu Yokoo have explored the possibility that a Type III civilization could extract energy from a supermassive black hole (SMBH). The captured energy could meet the extraordinary needs of a civilization that requires about 4×10^{44} erg/s.[46] The energy would be captured in the form of radiation emitted by the matter rushing into the star, by means of collectors located within the accretion disk. These collectors are similar to Dyson spheres. The overflow, as well as the waste of the civilization, would be redirected towards the black hole. A fraction of this energy, directed as a high-powered beam, could be useful for space travel. A galactic club of civilizations could transmit the energy through networks within the galaxy. Within the various central power stations that make up the network, power transmission is periodically switched between transmitter and receiver, according to the galactic rotation. To be efficient, this network should be located at the center of the galaxy.[46]

The technology

Further information: Stellar engineering and Megastructure

This parameter is one of the most undetectable in the Universe due to the fact that solid matter structures are at low temperatures and emit weak radiation. Their luminosity, which is difficult to observe, also makes it impossible to observe them with telescopes. Likewise, we cannot detect them by their gravitational effects.[47] On the other hand their existence can be detected by analyzing the wavelengths between 8 and 13 microns, corresponding to surface temperatures of 300 K. A hypothetical Dyson sphere could thus be detected,[25] provided that the observation is made from space. Locally, the significant dip in luminosity that would result from a giant Dyson sphere (or "Fermi bubble") would allow the detection of a Type III civilization.[25]

A megastructure like a Dyson sphere could be the result of a technology based on self-replicating probes, as those imagined by von Neumann. A Type III civilization would indeed have the means to disperse a significant number of these spheres throughout the galaxy, which would have the effect of attenuating the light emitted by the galaxy.[19] Kaku also considers this to be the most efficient method of colonizing space. For example, a galaxy 100,000 light years in diameter would be explored in half a million years.[3] Paul Davies has suggested that a civilization could colonize the galaxy by scattering miniature probes, no larger than the palm of a hand, using nanotechnology. This thesis is realistic, he explains, because it is obvious that the technology is becoming increasingly miniaturized and proportionally less expensive.[3]

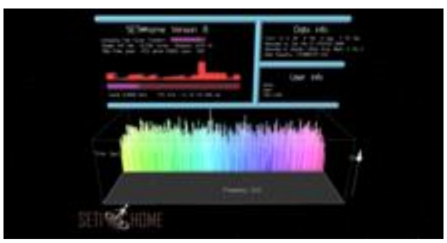
Type II megastructures would be easier to detect. This would be the case of a Dyson sphere used as a "stellar engine",[50] as well as the contribution of heavy elements.[25] Similarly, "Shkadov thrusters", which would produce a lateral thrust of

4.4 parsecs on their star by reflecting solar radiation through a structure made of mirrors, would be observable objects. This device would break the symmetry of solar radiation and counteract gravitational forces, allowing a Type II civilization to move its home solar system through space.[51][50] Drake and Shklovski have also considered the possibility of "seeding" a star (Stellar salting) by artificially adding extremely rare elements such as technetium or promethium. Such an intervention in a star's composition would be detectable.[25]

It is still possible that humanity could discover traces of lost Type I, II, or III civilizations. The search for material traces of such civilizations (e.g. Dyson spheres or stellar engines), an "interesting alternative" to the conventional SETI program, lays the foundation for a "cosmic archaeology" according to Richard A. Carrigan. Efforts to detect intelligence markers in the atmospheres of exoplanets (such as freon, oxygen, or even ozone, residues of biotic activity according to James Lovelock's research)[25] are one of the most promising avenues. A civilization watching its star die (as a red giant, for example) could have tried to prolong its existence through megastructures that should be detectable.[25] The possible traces could be nuclear remnants, to be sought within the spectral types going from A5 to F2 according to Whitmire and Wright.[52] It could also be a change in the isotopic ratio, due to a stellar engine, or an unusual spectral modulation in the composition of the star.[25]

The interstellar transmission of information

Further information: Interstellar communication



Screenshot of the SETI@home computer program

According to Kardashev, the transmissions of an extraterrestrial civilization (what SERENDIP is looking for) can be divided into two types. On the one hand, there can be an exchange of information between highly developed civilizations or civilizations at similar stages of evolution. On the other hand, the transmission of information can be aimed at raising the level of other less developed civilizations. If supercivilizations do exist, the transmissions of the first type must remain inaccessible to our observation because they must be unidirectional and not be directed toward the Solar System. Conversely, those of the second type must be easily detectable by our listening devices.[47] A signal of artificial origin should contain more than 10 and less than 100 bits. The latter would be of two types: transient and stable. Several criteria allow us to distinguish a signal of artificial origin from others. First, the optimal region of the spectrum to host artificial signals is the one where the temperature of the cosmic microwave background is the lowest.[47] Second, artificial sources must have a minimum angular size. Finally, the presence of suspicious data in other regions of the spectrum (such as circular polarization, radio and optical frequencies,[53] or X-ray emissions) can confirm that it is an intelligent transmission. Two sources among those studied have parameters close to those expected: 1934-63 and 3C 273B.[47]

For L. M. Gindilis, there are two criteria for a signal to be called artificial: one related to the artificial nature of the source and the other related to a particular radiation, intentionally designed to ensure communication and facilitate detection.[54] Only Type II or III civilizations can communicate using isotropic transmissions that allow omnidirectional reception. In a 1 MHz band (which requires about 10^{24} watts), detection of signals from a Type II civilization is possible up to 1,000 light-years away, while signals from a Type III civilization are detectable virtually throughout the observable Universe.[54] However, building an omnidirectional transmitter powerful enough to transmit over a range of 1,000 light years would take several million years. According to V.S. Troitsky, the energy required and the limitations in its production would be two obstacles to completing this project in a reasonable time.[55]

For Zoltan Galántai, we would not be able to distinguish between an intelligent extraterrestrial signal and a signal of natural origin. Therefore, he does not believe that Type II, III or even IV civilizations can be detected. Even if humanity reaches Type IV, it will not be able to detect another supercivilization of a similar level, and we will consider their changes in the universe to be the result of natural causes. Thus, there may be many Type IV civilizations in the universe, but none of them will be able to detect the others. Moreover, the dimensions of the universe make these supercivilizations like islands far from the others, which Dyson defines as a "Carroll Universe".[11]

For Alexander L. Zaitsev, the radio transmission of interstellar messages (IRM) is the most likely method used by civilizations. Planetary radio telescopes and those installed on asteroids would make it possible to listen to the many messages that could be sent to us.[56] In 2007, the SETI program analyzed the only television frequencies sent by a Type 0 civilization, notes Michio Kaku. Therefore, our galaxy may have communications from Type II and III civilizations, but our listening devices can only detect Type 0 messages.[3]

Search and detection of civilizations

The Byurakan Conference (1964)

From 1962, Kardashev was a member of a SETI research group at the Sternberg Astronomical Institute in Moscow. In 1964, he organized the first Soviet conference on the possibility of extraterrestrial civilizations, which was held at the Byurakan astrophysical observatory in Armenia.[1] This national conference was held in response to the American seminar known as the *Green Bank conference* of 1961, which was held at the Green Bank observatory in the United States.[57] It brought together radio astronomers with the aim of "finding rational technical and linguistic solutions to the problem of communication with an extraterrestrial civilization that is more advanced than the Earth's civilization". Kardashev presented his classification, while Troitskii announced that it was possible to detect signals from other galaxies.[58]

For Kardashev, "in the next 5 to 10 years, all the sources of radiation with the largest observable flux, in all the regions of the electromagnetic spectrum, will have been discovered and studied", the sensitivity of the listening devices having indeed reached their technical limits. According to him, the entire electromagnetic spectrum will be known and, consequently, the list of the objects that could be artificial sources could thus be extended. The search for artificial signals will then have to concentrate on objects of maximum luminosity or radiation belonging to a certain region of the spectrum, but also on objects of significant mass, and on those that represent the essence of matter in the Universe. As early as 1971, Kardashev considered that this observation requires the preparation of a plan of listening and analysis, which will allow the success of the search for extraterrestrial civilizations. Humanity will then be able to solve the "main dilemma", as it was stated by Enrico Fermi.[47] This dilemma is, according to the Soviet astronomer, is certainly connected with our lack of information and knowledge.[47][59]

Kardashev believes that a research project like Ozma is incapable of detecting a Type I civilization (an idea also promoted by Kaplan in 1971),[60] and that SETI should instead focus on searching for intense radio signals that could emanate from active Type II or III civilizations.[24] To prove the effectiveness of this approach, Kardashev therefore turned his attention to two radio sources discovered by the California Institute of Technology, nicknamed CTA-21 and CTA-102. Subsequently, Gennadii Borisovich Sholomitskii then used the Russian astronomical research station to study the data from CTA-102.[57] He found that this radio source is characterized by its variability. Kardashev then considered that this could be an indication of an artificial emission source, albeit of rather short life span.[1]

Towards a "physical eschatology"

The knowledge of these hypothetical supercivilizations must fit into a wide range of physical laws that contain the entirety of our current knowledge, since the technical and scientific developments of mankind can be considered as an inevitable and necessary stage in the process of the evolution of a civilization. Based on this principle, Kardashev proposes to define several concepts applicable to extraterrestrial civilizations.[47] The physical laws, which are universal, can be used as a common basis for understanding other civilizations and, in particular, allow us to develop an objective research program.[47] Michio Kaku also believes that the evolution of civilizations obeys the "iron laws of physics" and in particular the laws of thermodynamics, those of stable matter (baryonic matter) and those of planetary evolution (probability of occurrence of natural or cosmic catastrophes).[3] The anthropic principle also makes it possible to predict the sociological characteristics at the basis of any civilization.[61]

However, these universal laws are not the only parameters to consider. Zoltan Galántai explains that "it is impossible to calculate the future of the Universe over long periods of time without including the effects of life and intelligence", a position close to that of Freeman Dyson.[20] Taking into account these two phenomena, the universal physical laws and the intelligence resulting from life, defines a "physical eschatology", as Galántai puts it. This approach began in the 1970s with the work of Kardashev, and then physical eschatology gradually interested a number of scientists and thinkers, notes Dyson.[20]

A functional definition of civilization

Galaxy M87 has an active galactic nucleus, providing a strong source of radiation in all wavelengths. This type of radiation was considered by Kardashev to be one of the possible signals of an advanced civilization.

Observation of the development of living organisms shows that they are characterized by the tendency to store a maximum amount of information, both about the environment and about themselves. This information then leads to an abstract analysis, which plays an important role in the development of life forms. Thus, Kardashev defines civilization from a functional perspective as "a state of very stable matter capable of acquiring, abstractly analyzing and applying information in order to extract data about the environment and itself, in order to develop survival reactions ".[47] However, this functional definition of civilization implies that it cannot have a goal or end, since it is based on the principle of accumulating more and more information. Taking up von Hoerner's categories, Kardashev sees four possible scenarios for the development of civilizations:

1. Total destruction of life.
2. Destruction of only intelligent life.
3. Degeneration.
4. Loss of interest.

However, he refuses to see these as inevitable ends. But the assumption that the only limit to the development of a civilization can be the existence of a finite amount of information, in all areas, is also false, since it is highly improbable that information in the Universe is infinite.[47] Given these two hypotheses, Kardashev argues that there is no universal civilization (supercivilization) because highly developed civilizations lose interest in space exploration. In any case, and despite the problem of the end of civilizations, he concludes, in the light of his functional definition of the advanced civilization, that the latter must use mass and energy on fantastic scales. According to him, there is no reason to denounce the hypothesis that the expansion of the Universe would not be an effect of the intelligent activity of a supercivilization.[47]

Human civilization: a model for extrapolation

Kardashev poses the following question: "Is it possible to describe the development of a civilization in general terms over large cosmological periods?" Now many of the fundamental parameters that characterize the development of civilization on Earth are growing exponentially. In the field of energy, astronomer Don Goldsmith estimated that the Earth receives about one billionth of the Sun's energy, and that humans use about one millionth of it.[3] So we consume about one millionth of a billionth of the Sun's total energy. Since human expansion is exponential, we can determine how long it will take for humanity to go from Type II to Type III according to Michio Kaku.[3] Thus, the rate of development of our own world remains the only criterion for extrapolating the state of civilizations older than humanity.[47] The same is true for social values and basic needs according to Ashkenazi.[62] Therefore, the time to double technical knowledge is about ten years, and to double energy output, available reserves, and population is about 25 years. Two scenarios are then possible: spatial expansion or energy stagnation, the latter being possible only for 125 years, according to Kardashev, using

the following relationship : where is the number of years, is a parameter that

increases annually as a function of and of according to and a

growth rate. If , then humanity's energy consumption will exceed the incident solar power (1,742 × 10^{17} W) after 240 years, the total power of the Sun (3,826 × 10^{26} W) after 800 years, and that of the Galaxy (7,29 × 10^{36} W) after 1,500 years.[note 1][47] Based on this calculation, Zuckerman estimates the number of civilizations that could exist in our galaxy at 10,000.[63] Kardashev concludes that the current exponential growth is a transitional phase in the development of a civilization, and that it is inevitably limited by natural factors. In fact, he believes that the required mass and energy will continue to grow exponentially for another 1,000 years.[47] Civilization is thus defined by an exponential rate of increase. Humanity as a model for thinking about the development of extraterrestrial civilizations has its limitations, which can be truly overcome by a multidisciplinary approach according to the work of Kathryn Denning.[64]

Research conducted

In 1963, Nikolai Kardashev and Gennady Borissovich Sholomitskii studied the CTA 102 radio source on the 920 MHz band from the *Crimea Deep Space Station*, looking for signs of a Type III civilization.[65] CTA 102 had been discovered by Sholomitskii a year earlier, and Kardashev quickly saw it as a possible artificial source to study in order to validate his classification. The observation lasted until February 1965, and on April 12, Sholomitskii announced to the press (via the Russian ITAR-TASS) that Soviet astronomers had discovered a signal that could be of extraterrestrial origin. On April 14, he gave a conference in Moscow where he repeated his announcement; but by November 1964, two American astronomers had identified CTA 102 as a quasar, and their publication definitively closed the "CTA 102 case".[66] It was the study of this source that had led to the Byurakan conference in 1964.[67]

In 1975 and 1976, the American astronomers Frank Drake and Carl Sagan searched at Arecibo for signs of Type II civilizations in four galaxies of the Local Group: M33, M49, Leo I and Leo II.[68][69] The year before, the two men had sent mankind's first message to M13.[70] The results were published as "The Search for Extraterrestrial Intelligence" in *Scientific American* in May 1975.[71]

In 1976, Kardashev, Troitskii, and Gindilis used the RATAN-600 radio telescope in the North Caucasus to search for signals from Type II or III civilizations in the Milky Way and other nearby galaxies.[69] The radio telescope was built in 1966 under the supervision of Gindilis to listen at centimeter wavelengths.[67]

In 1987, Tarter, Kardashev, and Slysh used the VLA to detect possible infrared sources near the galactic center from the IRAS telescope catalog. All three were looking for evidence of hypothetical Dyson spheres. The objects turn out to be OH/IR type stars.[69][72]

A small-scale search for possible Type III sources was conducted by James Annis in 1999 and published in the *Journal of the British Interplanetary Society* under the title "Placing a limit on star-fed Kardashev type III civilizations".[73] An astrophysicist at Fermilab (US), Annis studied a sample of 31 galaxies, both spiral and elliptical, using the Tully-Fisher diagram, in which the absolute magnitude is a function of the galaxies' rotational speed. Annis suggested that 75% of the least luminous objects (i.e., those with a decrease in absolute magnitude of 1.5 compared to the diagram) could be considered as possible candidates. However, no object with this characteristic is observed in his survey.[19][44] On the other hand, Annis uses the available astronomical data to estimate the probability that a Type III civilization could exist. He shows that the average time that could allow for the emergence of such a civilization is 300 billion years, so none can exist in our present Universe.[74]

Per Calissendorff conducted a study on a sample of spiral galaxies from two databases: 4,861 from the *Spiral Field I-band* (SFI++ catalog compiled by Springob et al. in 2005) and 95 from that of Reyes et al. in 2011.[19] The same procedure was followed as in Annis, but the sample of galaxies used is 80 times larger than that used in the Annis study.[19] Some sources were classified as "lopsided": they appear asymmetric in shape, meaning that one side of the galactic disc is more massive and less luminous than the other. This characteristic, according to Calissendorff, could be an indication that the galaxy is home to a civilization that has placed Dyson spheres in its main part. This can be explained by the fact that the colonization starts from one side of the galactic disk, making it appear darker and leading a distant observer to believe that the core has moved to that same side.[19] On the other hand, a galaxy hosting Dyson spheres should be characterized by a significant source of far-infrared radiation.[19] The fact remains that a Type III civilization can consume energy through a Dyson sphere without surrounding a star. Indeed, such megastructures could also extract energy from a black hole, according to the study by Inoue and Yokoo (2011). However, such a structure would not reduce the luminosity of an observed galaxy.[19] Calissendorff's study concludes that 11 of the sources analyzed (out of a catalog of 2,411 galaxies, or 0.46%) show possible evidence of a Type III civilization. Searching for objects that obscure 90% of the light leaves only one source remains that meets the criteria.[19] These positive sources show a low redshift (so they are old, about 100 million years), which is consistent with possible Type III civilizations, that could have flourished only in the early past.[19] To have a better chance of detecting Type III artificial sources, Calissendorff suggests taking several photographs in a row, fast enough to fix the movement of turbulence in the atmosphere, applying different photometric filters and looking for dark areas (the case of a Dyson sphere being assembled by a Type II civilization), or analyzing the infrared spectrum of galaxies. A much larger sample of objects should be studied.[19]

Observational evidence

In 2015, a study of galactic mid-infrared emissions concluded that "Kardashev Type III civilizations are either very rare or do not exist in the local Universe".[75]

In 2016, Paul Gilster, author of the Centauri Dreams website, described a signal apparently coming from the star HD 164595 as requiring the power of a Type I or Type II civilization, if produced by extraterrestrial lifeforms.[76] In August 2016, however, it was discovered that the origin of the signal was most likely a military satellite orbiting the Earth.[77]

Kardashev's point of view

According to Kardashev, our ignorance of the physical possibilities of communication through space is great.[47] We know only a negligible fraction of the electromagnetic spectrum and, therefore, of the existing sources of information in the Universe.[47] Thus, of the 89% of information that we lack, 42% concerns the range from 10^9 to 10^{14} Hz (centimetric, millimetric, submillimetric and infrared waves) and 25% concerns the range from 10^{15} to 10^{18} Hz (ultraviolet radiation and X-rays).[47] Kardashev distinguishes two categories of listening areas: objects emitting in a broad frequency spectrum and objects emitting on the contrary in a narrow spectral line, the second category posing much more theoretical problems than the first, while being central, both for astrophysics and for the search for extraterrestrial civilizations.[47] Despite advances in astrophysics, the available information is still insufficient to prove the absence of supercivilizations, based on the inability to observe signs of activity. However, because of the possibility that planetary systems are much older than our own, and considering that cosmic objects such as quasars could be products of supercivilization activity, a detailed program of listening and searching for intelligent signs remains valid. This program includes:[47]

- Monitoring the sky at 3, 10, 30, 100 and 300 microns, especially at 1, 3, and 10 mm, in order to identify one hundred of the most powerful sources among those observed and at each frequency;
- Study in detail the properties of quasars and other unusual objects;
- Search for monochromatic anomalies among the most powerful radio sources (such as a hydroxyl emission line), in the decimeter band;
- Search for periodic signals (pulsars) of interstellar origin, in the same band;
- Searches for monochromatic signals of different frequencies, always in the same band.

According to Kardashev, only a radio interferometer with a base, either of the order of or larger than the diameter of the Earth, placed in orbital space, would allow listening to centimetric and decimetric frequencies.[47] Once a set of unusual sources has been selected, the next step is to look for significant content in the radiations from these objects.[47] In 1998, Nikolai Kardashev, S. F. Likhachev, and V. I. Zhuravlev proposed two SETI space projects to detect artificial sources: the *Millimetron* project (an orbiting observatory with a 10-meter diameter mirror) and the *VLBI optical telescope* (for interferometric synthesis of ultraviolet, optical, and infrared images).[78]

Other leads

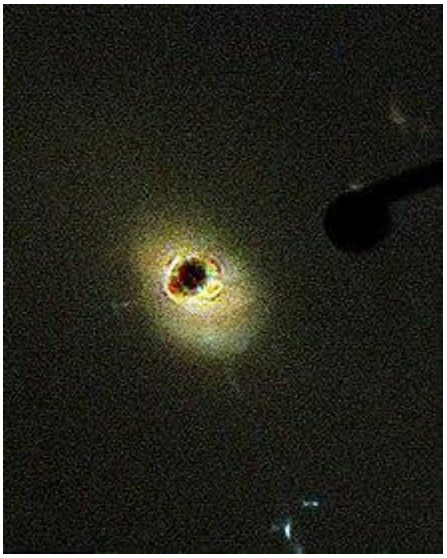
For Samuil Aronovich Kaplan, "the most reliable criterion" remains the small angular diameter of the radio source. The wavelength of 21 cm, privileged since 1959, according to the study of Cocconi and Morrison, is not the only listening region. Kaplan, in 1971, also mentioned the radio region of the spectrum, characterized by the hydroxyl radical (OH). For Livio, the means of detection should focus on globular clusters, the regions most likely to harbor planets similar to the Earth.[25]

For Guillermo A. Lemarchand, extraterrestrial civilizations should not use an omnidirectional transmitter. Instead, they should look for signals of weak information, intermittent and unidirectional. They will certainly need to use interferometry to inspect solar systems where life might appear. From Earth, it would be possible to pick up such signals at distances of up to $35 + (t\_f - 2000) / 2$, where t_f is the observation date in years, knowing that $t\_f \geq 2000$.[21] However, there are many techniques for transmitting an interstellar message, ranging from bosons to particles and even antiparticles.[23]

An artificial source located in the accretion disk of a supermassive black hole would be undetectable by the beams used to transmit the collected energy. In fact, the probability of detecting a beam of one micron arc-second is less than 10^{-23}. Moreover, the energy emitted by the black hole would not allow detection of the energy used by the Type III civilization. On the other hand, the specular reflection system of the radiation could be detected by the shadow it casts on the accretion disk.[46]

A Type III civilization using a "Fermi bubble" would be detectable by the fact that it decreases the luminosity of a region of the galaxy. An infrared observation would make it possible to highlight it, especially in elliptical galaxies, Annis suggests.[25]

Unusual objects



Quasar 3C 273, the brightest ever observed

The quasar 3C 9 is cited by Kardashev as early as 1971.[47] The study of the quasar 3C 273 shows that it has a solid structure. Other quasars (3C 279, 3C 345, 3C 84) have properties close to those expected from an artificial source, especially since the emissions are powerful in the intermediate region of the spectrum (between radio and optical frequencies).[47] Quasars are potential artificial sources, especially since their age corresponds to the technical possibilities of supercivilizations. Radio sources at the center of galaxies can also be artificial sources, according to Kardashev, even if in 2013 they were proven to be supermassive black holes. In 1971, Kardashev believed that the objects most likely to be artificial sources could be discovered in the [then] next few years.[47]

The extraordinary periodicity of pulsar emissions was already considered an artificial source in 1968 by Antony Hewish, the discoverer of the first pulsar (CP 19019). The press of the time nicknamed this object "LGM-1" (for "little green men"), following the clumsiness of Hewish, who did not wait for the necessary verifications. Kaplan, in 1971, removed the pulsar from the list of objects that could be a source of artificial origin.[60]

In 2011, James and Dominic Benford examined the possibilities that exist to distinguish pulsars from possible artificial sources emitting intelligent signals, such as: bandwidth (signals of about 100 MHz could be artificial), pulse length (to reduce costs, the pulse should be short) and frequency (about 10 GHz, also for economic reasons). The radio source PSR J1928+15 (observed in 2005 near the Galactic disk, at a frequency of 1.44 GHz, at Arecibo) could be of extraterrestrial origin. James and Dominic Benford consider three scenarios in which the cost factor is taken into account. If the source is cost-optimized, it belongs to a civilization of Type 0.35 (the Earth being of Type 0.73).[note 2] If it is not cost-optimized and operates with a small antenna, the Type is 0.86. With a large antenna, it would be from a Type 0.66. Using this cost/efficiency method, it can be estimated that low-intensity sources may be the most prevalent, but also the most difficult to observe.[79]

Criticisms of the classification

William I. Newman and Carl Sagan believe that the growth of energy consumption alone cannot describe the evolution of civilizations; it is also necessary to consider population growth, and in particular the fact that it can be limited by the transport capacity of interplanetary means of travel. They conclude that there can be no ancient civilizations of galactic dimensions, nor galactic empires, although the possibility of networks of colonized worlds (of about 5 to 10 planets) is strong.[80]

The scale theorized by Kardashev was born in the geopolitical context of the Cold War, in which energy had supreme value.[28] According to Guillermo A. Lemarchand, a physicist at the University of Buenos Aires, there are four arguments against Kardashev's classification:[21]

1. Long range omnidirectional transmitters would be very energy intensive. Using directional or intermittent devices, each pointing in a different direction, would require much less energy. Type II or III civilizations might therefore be defined by something other than exponential energy consumption.
2. The assumption of exponential energy consumption is certainly wrong, because if we analyze per capita energy consumption throughout human history, it forms a series of logistic curves with a saturation point for each

technological innovation. Therefore, a steady state or limited growth is more likely.

3. According to the principle of mediocrity, applied to the search for extraterrestrial civilizations by Sagan and Shklovskii in 1966 on the basis of John Richard Gott's calculations,[81] civilizations more important than ours must be so rare that they do not have the possibility to dominate and be visible.
4. Finally, research and listening programs in Harvard University and Buenos Aires (Horowitz and Sagan in 1993 or Lemarchand et al. in 1997) have not provided any scientific proof of the existence of artificial sources, neither in the Milky Way nor in nearby galaxies (M33, M81, the Whirlpool Galaxy or Centaurus A), or even in the Virgo cluster.

For the British meteorologist Lewis Fry Richardson, author of a statistical study on mortality (published in *Statistics of Deadly Quarrels*, 1960), man's aggressiveness does not allow us to predict a life span that will allow humanity to reach more evolved stages. He estimates that man's violent impulses will destroy the social order over a period of 1000 years. Moreover, mankind will probably be destroyed with weapons of mass destruction within a few centuries at the most.[21]

Transhumanists Paul Hughes and John Smart explain the absence of signals from a Type III civilization with two hypotheses: either it has self-destructed or it has not followed the trajectory described by Kardashev.[24] The growth of energy consumption should lead to a climate crisis, which Yvan Dutil and Stéphane Dumas set at 1 W/m^2 of the Earth or 127 TW for the entire planet. At a growth rate of 2% per year, an industrial civilization should stop growing quite early in its history (after a few centuries).[49] In summary, the impossibility of sustainably securing energy resources may explain the absence of Type II and III civilizations.[49]

For Zoltan Galántai, it is not possible to imagine a civilization project that spans centuries (like a Dyson sphere) or even millions of years, unless one imagines a thought and an ethic different from ours, within the reach of an ancestral civilization. He therefore proposes to classify civilizations according to their ability to carry out large-scale civilization projects over the long term.[24]

Finally, for Freeman Dyson, communication and life can continue forever in an open Universe with a finite amount of energy; intelligence is therefore the only fundamental parameter for a civilization to survive in the very long term, and energy is then no longer what defines it, a thesis he develops in his article "Time Without End: Physics and Biology in an Open Universe".[82]

Energy development

Type I civilization methods

- Large-scale application of fusion power: In terms of mass–energy equivalence, Type I implies the conversion of about 2 kg of matter to energy per second. An equivalent energy release could theoretically be achieved by fusing about 280 kg of hydrogen into helium per second,[83] a rate roughly equivalent to 8.9×10^9 kg/year. One cubic kilometer of water contains about 10^{11} kg of hydrogen, and the Earth's oceans contain about 1.3×10^9 cubic kilometers of water, meaning that humans on Earth could sustain this rate of consumption over geological time scales, in terms of available hydrogen.

- Antimatter in large quantities would provide a mechanism to produce power on a scale several orders of magnitude beyond the current level of technology.[citation needed] In antimatter-matter collisions, all of the rest mass of the particles is converted to radiant energy. Their energy density (energy released per mass) is about four orders of magnitude greater than that from using nuclear fission, and about two orders of magnitude greater than the best possible yield from fusion.[84] The reaction of 1 kg of antimatter with 1 kg of matter would produce 1.8×10^{17} J (180 petajoules) of energy.[85] Although antimatter is sometimes proposed as a source of energy,[86] this does not seem feasible. Artificially producing antimatter – according to current understanding of the laws of physics – involves first converting energy into mass, which yields no net energy. Artificially created antimatter is usable only as an energy storage medium, not as an energy source, unless future technological developments (contrary to the conservation of the baryon number, such as a CP violation in favor of antimatter) allow the conversion of ordinary matter into anti-matter. Theoretically, humans may be able to cultivate and harvest a number of naturally occurring sources of antimatter in the future.[87][88][89]
- Renewable energy by converting sunlight into electricity – either directly through solar cells and concentrating solar power, or indirectly through biofuels, wind, and hydroelectric power: There is no known way for a human civilization to harness the equivalent of the Earth's total absorbed solar energy without completely covering the surface with man-made structures, which is not feasible with current technology. However, if a civilization constructed very large space-based solar power satellites, Type I power levels might become achievable—these could convert sunlight to microwave power and beam it to collectors on Earth.

Type II civilization methods

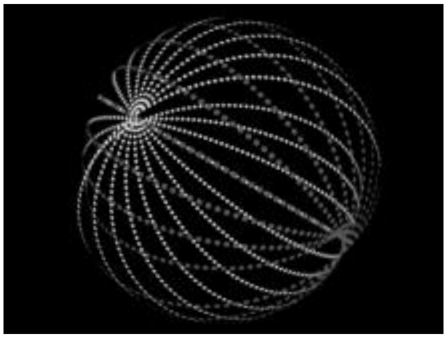


Figure of a Dyson swarm surrounding a star

- Type II civilizations could use the same techniques as a Type I civilization, but applied to a large number of planets in a large number of star systems.

- A Dyson sphere or Dyson swarm and similar constructs are hypothetical megastructures originally described by Freeman Dyson as a system of orbiting solar power satellites designed to completely encircle a star and capture most or all of its energy output.[90]
- Another means of generating usable energy would be to feed a stellar mass into a black hole, and collect the photons emitted by the accretion disk.[91][92] A less exotic means would be to simply capture photons already escaping from the accretion disk, thereby reducing a black hole's angular momentum; this is known as the Penrose process. However, this may only be possible for a Type III civilization.
- Star lifting is a process by which an advanced civilization could remove a substantial portion of a star's matter in a controlled manner for other uses.
- Antimatter is likely to be produced as an industrial byproduct of a number of megascale engineering processes (such as the aforementioned star lifting), and could therefore be recycled.[citation needed]
- In multiple star systems with a sufficiently large number of stars: absorbing a small but significant fraction of the output of each individual star.
- Stellar engines can be used to move stars.

Type III civilization methods

- Type III civilizations might use the same techniques as a Type II civilization, but applied individually to all possible stars in one or more galaxies.[6]
- They may also be able to tap into the energy released by the supermassive black holes believed to exist at the center of most galaxies.[93]
- White holes could theoretically provide large amounts of energy by collecting the matter ejected outward.
- Capturing the energy of gamma-ray bursts is another theoretically possible power source for an advanced civilization.
- The emissions from quasars are comparable to those from small active galaxies and could be a massive power source if they could be collected.

Civilization implications

There are many historical examples of human civilization undergoing large-scale transitions, such as the Industrial Revolution. The transitions between Kardashev scale levels could potentially represent similarly dramatic periods of social upheaval, as they involve exceeding the hard limits of the resources available within a civilization's existing territory. A common speculation[94] is that the transition from Type 0 to Type I could carry a strong risk of self-destruction, since in some scenarios there would be no room for further expansion on the civilization's home planet, as in a Malthusian catastrophe.

For example, excessive energy consumption without adequate heat removal could plausibly render the planet of a Type I approaching civilization unsuitable for the biology of the dominant life forms and their food sources. Using Earth as an example, ocean temperatures above 95 °F (35 °C) would endanger marine life and make it difficult, if not impossible, for mammals to cool to temperatures suitable for their metabolism. Of course, these theoretical speculations may not become problems, possibly through the application of future engineering and technology. Also, by the time a civilization reaches Type I, it may have colonized other planets or established O'Neill-type colonies, so that waste heat could be distributed throughout the star system.

The limitations of biological life forms and the evolution of computer technology may lead to the transformation of the civilization through mind uploading and artificial general intelligence in general during the transition from Type I to Type II, leading to a digitized civilization.

1. ^ " If the growth rate a = 1.04 is maintained after the critical period, the human power output will exceed the quantity of incident solar radiation after 240 years, after 800 years the total energy radiated by the Sun will be exceeded, and after 1500 years we will exceed the total radiation output of the entire Galaxy'."
2. ^ According to Sagan's interpolated Kardashev scale, as of 2021

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Further reading

Library resources about
Kardashev scale

- Resources in your library
- Resources in other libraries

- Dyson, Freeman J. *Energy in the Universe* Article in September 1971 *Scientific American* magazine (Special September Issue on *Energy*)
- Wind Powering America Archived 2005-04-21 at the Wayback Machine
- Clean Energy for Planetary Survival: International Development Research Centre
- LBL Scientists Research Global Warming Archived 2021-01-28 at the Wayback Machine
- E³ Handbook
- Clarke H2 energy systems
- Holdren, John P.; Kaysen, Carl (2003). "Environmental Change and the Human Condition" (PDF). Bulletin Fall. pp. 24–31. Archived from the original (PDF) on 2006-07-14. Retrieved 2006-08-10.
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- *Supercivilizations as Possible Products of the Progressive Evolution of Matter*: also by Kardashev
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- *The Radio Search For Intelligent Extraterrestrial Life*, by Frank Drake
- Freitas Jr., Robert A. *Energy and Culture* (chapter 15).
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External links

[edit]

- Kardashev civilizations
- Flash Animation on Civilizations
- What's the Kardashev Scale? by Universe Today.
- Description of civilization types from Dr. Michio Kaku.
- The Kardashev scale: Classifying alien civilizations by Space.com.
- Detectability of Extraterrestrial Technological Activities
- Astrobiology: The Living Universe at the Wayback Machine (archived 2013-05-14)
- After Kardashev: Farewell to Super Civilizations at the Wayback Machine (archived 2007-01-08)
- Exotic Civilizations: Beyond Kardashev at the Wayback Machine (archived 2009-02-20)
- Search for Type III civilizations at the Wayback Machine (archived 2015-05-25)
- What Do Alien Civilizations Look Like? The Kardashev Scale on YouTube by Kurzgesagt, explaining and visualizing the topic.
- Kardashev Scale, the big picture on space civilizations, an audio podcast
- by SciFi Thoughts.

Theories on life after death (ONLY ONES THAT MATTER)

Do you believe in some form of existence after death? If the idea of an absolute end worries you, have a look at some of these various beliefs about the afterlife.

The biocentrism theory

According to some quantum physicists, life creates the universe and not the opposite. In this conception of the world, bodies die, but consciousness continues to exist.

The Buddhist theory

One of six destinies awaits Buddhists when they pass away. They may be reincarnated as gods, demi-gods, humans, animals, or hungry ghosts, or sent to the realm of hells. If you were a good person, chances are you'll be reborn in one of the first three categories.

The Hindu theory

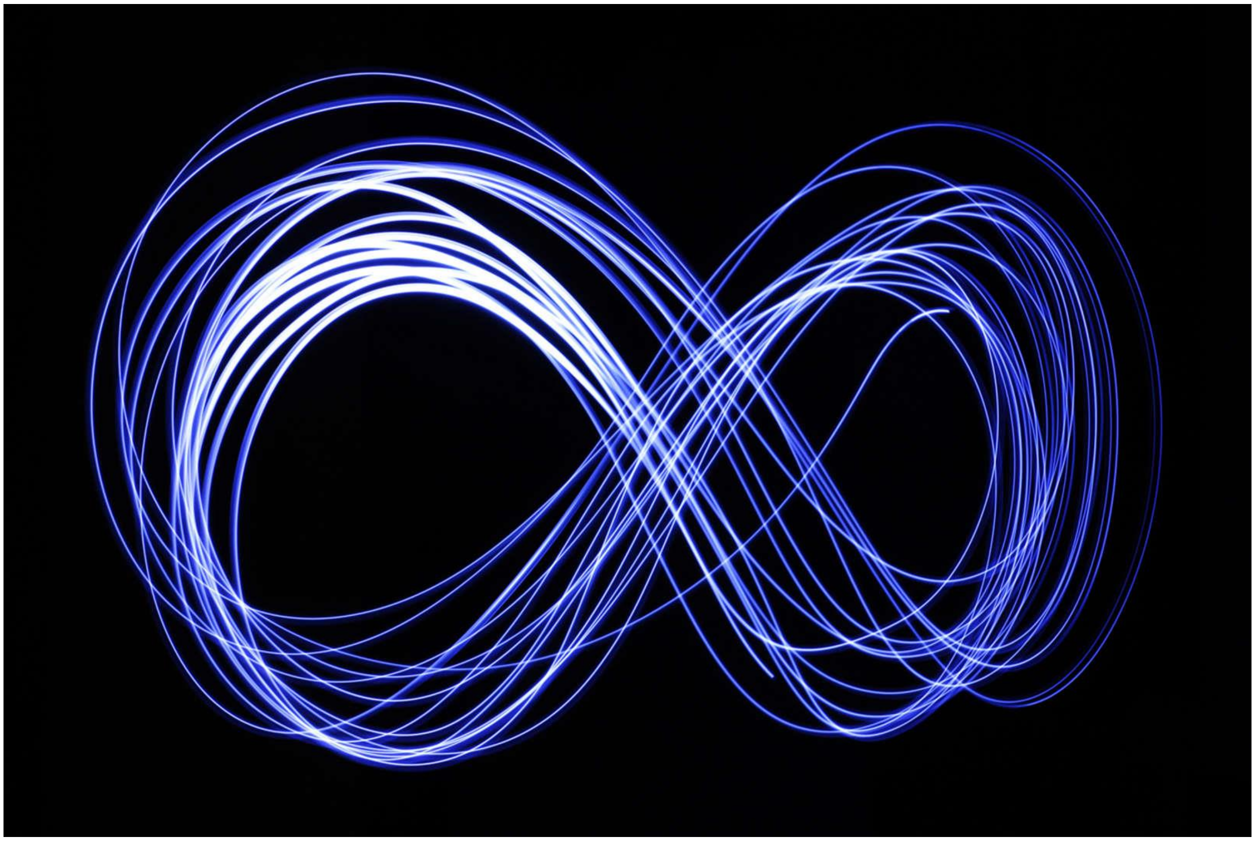
Hindus believe in reincarnation. According to them, you will be reincarnated 52 million times – as a plant, animal, etc. – before returning to human form.

The egocentric theory

According to proponents of solipsism, you are the only person who exists, and the entire universe is but the fruit of your imagination. Thus, when you die, logically, the universe will no longer exist.

The theory of being reborn

According to some, life starts over immediately after death, like rewinding a cassette tape. This theory would explain the various feelings of déjà-vu we experience throughout our lifetime.



The Rastas' theory

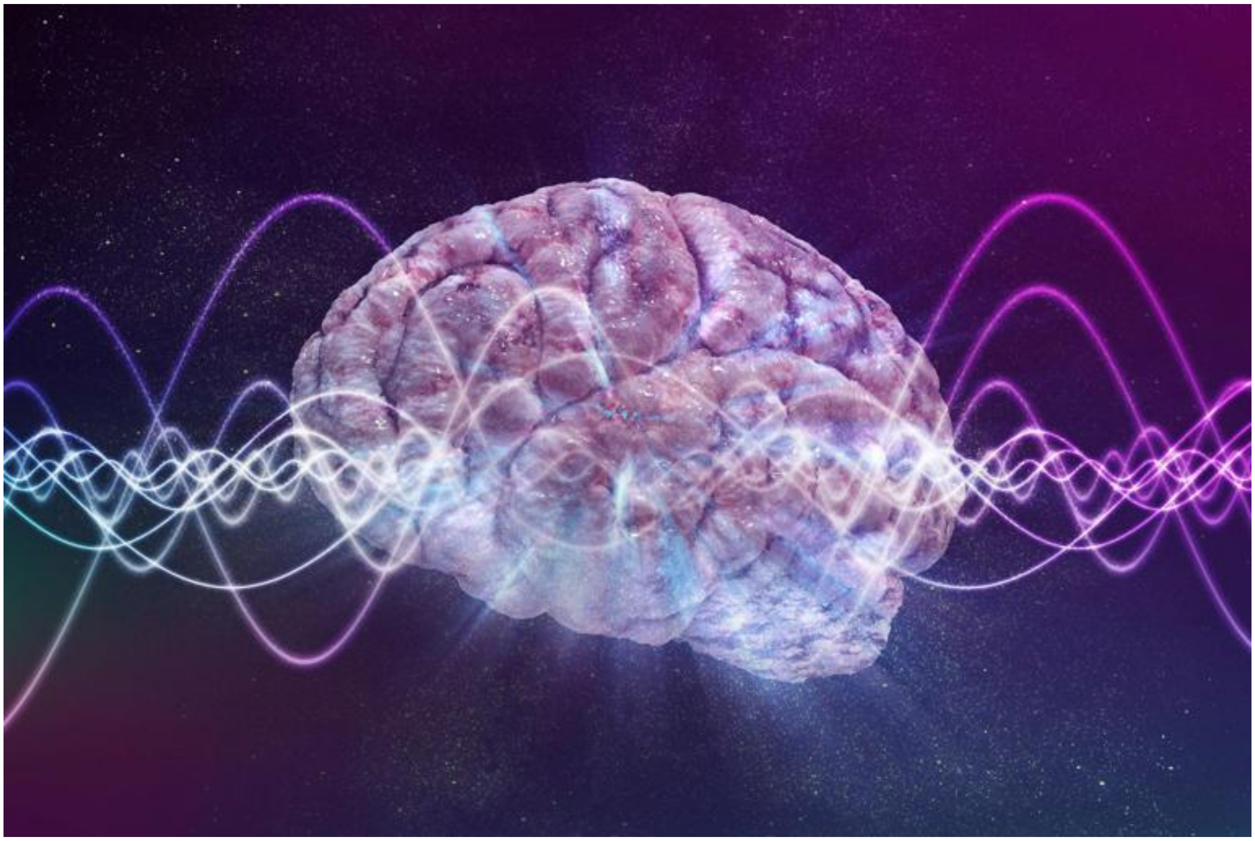
Rastas have perhaps the strangest conception of heaven. For them, heaven corresponds to Ethiopia. In other words, if you were a good person, when you die, you will find yourself in a third-world country where the infant mortality rate is 68%.

Scientists can't decide if consciousness is real or fake

What if everything in our world has a soul and mind? What if every desk, chair, and potted plant has a conscious stream of thoughts? That's the basic idea behind Panpsychism, a theory first put forward in the late 16th century by Francesco Patrizi. It's been a hundred years or so since science won out about this theory in the 1920s, but now it's regaining momentum.

To understand why this theory is regaining popularity requires us to look at one of the most difficult conundrums that human scientists have ever faced: where consciousness comes from. Scientists have been trying to solve this hard problem for over a hundred years, and while developments in neuroscience, psychology, and quantum physics have come far, we still don't have a definitive answer.

The argument is regaining momentum, though, thanks in part to the work of Italian neuroscientist and psychiatrist Giulio Tononi, who proposed the idea that there is widespread consciousness even found in the simplest of systems. Tononi and American neuroscientist Christof Koch argued that consciousness will follow where there are organized lumps of matter. Some even believe that the stars may be conscious.



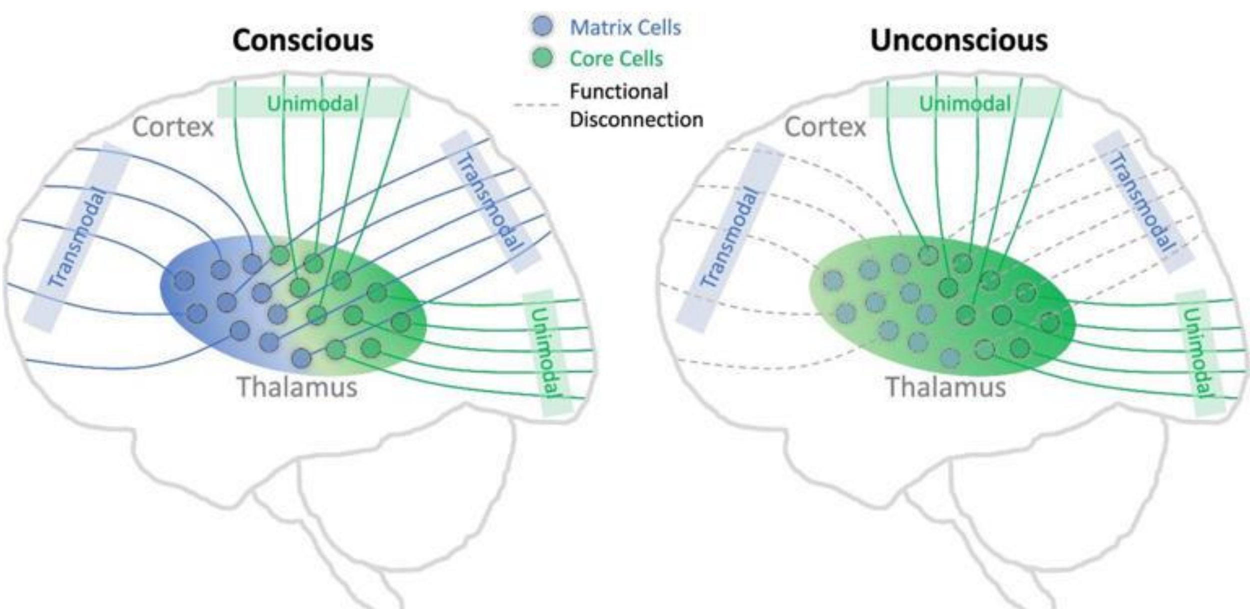
This basic idea, then, seems to suggest that grouped lumps of matter, like the very chair you're sitting in right now, may have a stream of consciousness. Of course, not everyone agrees with this. Many still take the stance that this is just an attempt to grasp at straws, if you will, in a bid to understand consciousness and how it comes to be.
The main idea behind Panpsychism seems to rely on the belief that if brains are not required for consciousness, then anything can be conscious of its existence, and thus, everything has different experiences. But there are more than just the

believers and unbelievers here. There are actually some who believe that consciousness is all an illusion, which raises even more questions.

Keith Frankish, an honorary professor of philosophy at the University of Sheffield, told *Popular Mechanics* that he believes that consciousness is just an illusion of our own minds. Whether or not the very stars are conscious has yet to be proven, of course. And we're still a long way from understanding the brain and how it correlates to different things within our world.

This is still an area of science that draws a lot of big question marks from scientists. All you can really say for sure is what you believe. Are you conscious? Or is consciousness just an illusion that your brain has conjured up? It is certainly an interesting thought.

How the brain's inner chamber governs our state of consciousness



Schematic illustration of the primary conclusion. Credit: Nature Communications (2024). DOI: 10.1038/s41467-024-51837-1

In hospital operating rooms and intensive care units, propofol is a drug of choice, widely used to sedate patients for their comfort or render them fully unconscious for invasive procedures.

Propofol works quickly and is tolerated well by most patients when administered by an anesthesiologist. But what is happening inside the brain when patients are put under and what does this reveal about consciousness itself?

Investigators at U-M who are studying the nature of consciousness have successfully used the drug to identify the intricate brain geometry behind the unconscious state, offering an unprecedented look at brain structures that have traditionally been difficult to study.

"Consciousness has been the subject of study from various perspectives and understanding the neurobiological foundations of consciousness carries major implications of multiple medical disciplines such as neurology, psychiatry and anesthesiology," said Zirui Huang, Ph.D., Research Assistant Professor in the Department of Anesthesiology at U-M Medical School.

To date, researchers have debated about how anesthetics suppress consciousness. Specifically, whether the site of action lies primarily in the thalamus, an egg-shaped structure deep within the brain, which receives information from what we see, touch and hear, or in the cerebral cortex, which processes that information in complex ways.

A study published in the journal *Nature Communications* and led by Huang, George Mashour, M.D., Ph.D. and Anthony G. Hudetz, Ph.D., of the U-M Center for Consciousness Science, outlines for the first time in humans how the connections among brain cells within those two important areas are modified by propofol. The paper is titled "Propofol Disrupts the Functional Core-Matrix Architecture of the Thalamus in Humans."

In healthy volunteers, they mapped changes in the brain's architecture before, during and after propofol sedation, guided by functional magnetic resonance imaging (fMRI). This enabled them to monitor blood flow to areas of the brain as the study participants entered and exited an unconscious state.

At baseline, explained Huang, the thalamus has a balanced level of activity of both specific nuclei (clusters of brain cells) that send sensory information to highly defined areas of the cortex—known as unimodal processing—and nonspecific nuclei that send information more diffusely throughout a higher layer of the cortex, known as transmodal processing.

The team found that, under deep sedation, the thalamus showed a drastic reduction in activity in clusters of brain cells responsible for transmodal processing, leading to a dominant unimodal pattern—suggesting that while sensory inputs are still received, there is no integration of those inputs.

"The field has been focusing on anesthetic effects in the thalamus and cortex for more than two decades—I believe this study significantly advances the neurobiology," said George Mashour, M.D., Ph.D., Professor of Anesthesiology and Pharmacology, and founder of the U-M Center for Consciousness Science.

Next, they discovered the specific cell types that played a role in the shift to an unconscious state and their relationship to the change in thalamic processing. The thalamus contains at least two distinct cell types, said Huang, core cells and matrix cells.

"We now have compelling evidence that the widespread connections of thalamic matrix cells with higher order cortex are critical for consciousness," says Hudetz, Professor of Anesthesiology at U-M and current director of the Center for Consciousness Science.

Imagining that the cortex is layered like an onion, core cells connect to lower layers while matrix cells connect to higher layers in a more spread-out manner.

By measuring mRNA expression signatures—like I.D. badges for the cells—they were able to see that a disruption in the activity of matrix cells played a greater role in the transition to unconsciousness than core cells. An additional surprise was that GABA, a major inhibitory transmitter in the brain usually thought to be key to propofol's actions, did not appear to play as prominent a role as expected.

"The results suggest that loss of consciousness during deep sedation is primarily associated with the functional disruption of matrix cells distributed throughout the thalamus," said Huang.

More information: Huang, Z., et al. Propofol disrupts the functional core-matrix architecture of the thalamus in humans. *Nature Communications* (2024). DOI: 10.1038/s41467-024-51837-1

Provided by University of Michigan

The Hunt For The Laws Of Physics Behind Memory And Thought

The Hunt For The Laws Of Physics Behind Memory And Thought

One of the curious features of the laws of physics is that many of them seem to be the result of the bulk behavior of many much smaller components. The atoms and molecules in a gas, for example, move at a huge range of velocities.

When constrained in a container, these particles continually strike the surface creating a force.

But it is not necessary to know the velocities of all the particles to determine this force. Instead, their influence averages out into a predictable and measurable bulk property called pressure.

This and other bulk properties like temperature, density and elasticity, are hugely useful because of the laws of physics that govern them. Over one hundred years ago, physicists like Willard Gibbs and others determined the mathematical character of these laws and the statistical shorthand that physicists and engineers now use routinely in everything from laboratory experiments to large scale industrial processes.

The success of so-called statistical physics raises the possibility that other systems that consist of enormous numbers of similar entities might also have their own "laws of physics". In particular, physicists have long hoped that the bulk properties of neurons might be amenable to this kind of approach.

Neural Physics

The behavior of single neurons is well understood. But put them together into networks and much more significant behaviors emerge, such as sensory perception, memories and thought. The hope is that a statistical or mathematical approach to these systems could reveal the laws of neural physics that describe the bulk behavior of nervous systems and brains.

"It is an old dream of the physics community to provide a statistical mechanics description for these and other emergent phenomena of life," say Leenoy Meshulam at the University of Washington and William Bialek at Princeton University, who have reviewed progress in this area.

"These aspirations appear in a new light because of developments in our ability to measure the electrical activity of the brain, sampling thousands of individual neurons simultaneously over hours or days."

The nature of these laws is, of course, fundamentally different to the nature of conventional statistical physics. At the heart of the difference is that neurons link together to form complex networks in which the behavior of one neuron can be closely correlated with the behavior of its neighbors.

It is relatively straightforward to formulate a set of equations that capture this behavior. But it quickly becomes apparent that these equations cannot be easily solved in anything other than trivial circumstances.

Instead, physicists must consider the correlations between all possible pairs of neurons and then use experimental evidence to constrain what correlations are possible.

The problem, of course, is that the number of pairs increases exponentially with the number of neurons. That raises the question of how much more data must be gathered to constrain the model as the number of neurons increases.

One standard system in which this has been well measured is the retina. This consists of a network of light sensitive neurons in which activity between neighbors is known to be corelated. So if one neuron is activated there is a strong possibility that its neighbor will be too. (This is the reason for the gently evolving, coral-like patterns in vision that people sometimes notice when they first wake up.)

Experiments in this area began by monitoring the behavior of a handful of neurons, then a few dozen, a few hundred and now approach thousands (but not millions). It turns out that the data helps constrain the model to the point where they give remarkably accurate predictions of neural behavior when asked, for example, to predict how many neurons are active out of any given set of them.

That suggests the system of equations accurately captures the behavior of retinal networks. In other words, "the models really are the solutions to the mathematical problem that we set out to solve," say Meshulam and Bialek.

Of course, the retina is a highly specialized part of the nervous system so an important question is whether similar techniques can generalize to the higher cognitive tasks that take place in other parts of the brain.

Emergent Behavior

One challenge here is that networks can demonstrate emergent behavior. This is not the result of random correlations or even weak correlations. Instead, the correlations can be remarkably strong and can spread through a network like an avalanche.

Networks that demonstrate this property are said to be in a state of criticality and are connected in a special way that allows this behavior. This criticality turns out to be common in nature and suggests networks can tune themselves in a special way to achieve it.

"Self-organized criticality" has been widely studied in the last two decades and there has been some success in describing it mathematically. But exactly how this self-tuning works is the focus of much ongoing research.

Just how powerful these approaches will become is not yet clear. Meshulam and Bialek take heart from the observation that some natural behaviors are amenable to the kind of analysis that physicists are good at. "All the birds in a flock agreeing to fly in the same direction is like the alignment of spins in a magnet," they say.

The fact that this is merely a metaphor concerns them - metaphors can help understanding but the real behavior of these system is often much more complex and subtle.

But there are reasons to think that mathematical models can go further. "The explosion of data on networks of real neurons offers the opportunity to move beyond metaphor," they say, adding that the data from millions of neurons should soon help to inform this debate.

"Our experimentalist friends will continue to move the frontier, combining tools from physics and biology to make more and more of the brain accessible in this way," conclude Meshulam and Bialek. "The outlook for theory is bright."

Ref: Statistical mechanics for networks of real neurons : arxiv.org/abs/2409.00412

Scientists restore monkey's vision with a patch made from human stem cells

Scientists have fixed a hole in a monkey's retina with a patch derived from human stem cells.

This feat — described in a study published Oct. 3 in the journal Stem Cell Reports — is a step forward in retinal transplantation. The retina is the layer of light-detecting cells in the back of the eye, and damage and disease to the tissue can cause vision loss and blindness. Such conditions can be difficult to treat. Sometimes doctors can move part of the patient's own retina from its outer edges to the center, but this inevitably leads to blind spots in the periphery.

The new study focused on repairing a macular hole. In this rare condition, a hole develops in the very center of the retina, at the "fovea," which is needed for central vision and sharp focus. Macular holes often occur when the jelly-like substance inside the eye pulls away from the retina, causing tears. About 90% of such cases can be surgically treated, but the remaining 10% can leave patients with blurred vision or blind spots.

Dr. Michiko Mandai, director of the research center at the Kobe Eye Hospital in Japan, has been working for years on developing miniature, lab-grown versions of retinas from stem cells. These retinal "organoids" are sheets of light-detecting cells, derived from stem cells that can be nudged to develop into any tissue in the body.

Related: Scientists develop 'crying' model of human eye tissue

In 2019, Mandai had an opportunity to test these sheets on macular holes: Another lab studying how the eyes and brain process images found that one of their Japanese macaques (*Macaca fuscata*) could not complete visual tasks. It turned out that the monkey had a macular hole. The lab then transferred the animal to Mandai's lab for surgery.

Mandai and her team grew a retinal sheet from human stem cells and used it to surgically patch the monkey's retina — sort of like applying a patch to torn clothing. The transplant was safe and effective, and the monkey's performance on visual tests improved post-surgery, they reported.

The only complication of the procedure was a mild rejection of the patch, seen four months after the surgery, Mandai told Live Science. Rejection involves the immune system attacking the transplanted tissue, and in this case, the team resolved the problem with steroid injections that suppressed that immune response.

The rejection may have been due to the cross-species nature of the transplant, Mandai said. "Transplantation of human tissue to a human would have less risk of immune response," she suggested.

Six months after the surgery, the researchers surgically removed the monkey's eye to examine the patch. They found that new visual cells — rods, which primarily handle night vision, and cones, which are key to color vision — had developed. However, the team could not confirm that connections had formed between the transplanted cells and the monkey's original cells.

With macular hole, the improvement in vision arises from the eye recovering its structural organization and function after that hole is closed up, Mandai said. "Whether grafted retinal cells can also contribute to visual function is not known yet, but that part is not mandatory," she said. In other words, vision improves by virtue of the hole being closed, not the grafted cells actually helping with visual processing.

Mandai's team is moving forward on using their retinal organoids to treat other conditions. Last year, the researchers reported results from a clinical trial that used the sheets in human patients with retinitis pigmentosa, a genetic condition that causes progressive vision loss. After two years, the grafts had safely integrated into the patients' retinas, and their vision loss progressed more slowly than that of patients who hadn't been treated.

The team is also studying the function of transplanted retinal tissue in animals to learn whether the transplants can host working cells.

14 of the Most Baffling Mysteries About the Universe

Observations by the NASA/ESA Hubble Space Telescope have taken advantage of gravitational lensing to reveal the largest sample of the faintest and earliest known galaxies in the universe. Some of these galaxies formed just 600 million years after the big bang and are fainter than any other galaxy yet uncovered by Hubble. The team has determined for the first time with some confidence that these small galaxies were vital to creating the universe that we see today. An international team of astronomers, led by Hakim Atek of the Ecole Polytechnique Fédérale de Lausanne, Switzerland, has discovered over 250 tiny galaxies that existed only 600-900 million years after the big bang— one of the largest samples of dwarf galaxies yet to be discovered at these epochs. The light from these galaxies took over 12 billion years to reach the telescope, allowing the astronomers to look back in time when the universe was still very young.

What came before the Big Bang?

If the universe began billions of years ago with the Big Bang, what preceded it?

According to renowned physicist Stephen William Hawking, PhD: Nothing. However, no one can know for sure; any events that happened before the universe came into existence are without "observational consequence," as Hawking put it, and therefore, we "may as well cut them out of the theory, and say that time began at the Big Bang."

What is dark matter?

Everything and everyone is made up of "baryonic matter:" protons, neutrons, and electrons. Until about 30 years ago, astronomers thought that the universe followed the same rules—it was entirely baryonic matter. Over the last few decades, however, scientists have found that only *5 percent* of the universe is composed of baryonic matter—and they can't even detect the other 95 percent. Scientists believe that some 25 percent consists of dark matter—but nobody can say definitively what dark matter actually is or what it's made of yet. Don't miss these other science mysteries no one has figured out yet.

This new NASA/ESA Hubble Space Telescope image shows a beautiful spiral galaxy known as PGC 54493, located in the constellation of Serpens (The Serpent). This galaxy is part of a galaxy cluster that has been studied by astronomers exploring an intriguing phenomenon known as weak gravitational lensing. This effect, caused by the uneven distribution of matter (including dark matter) throughout the Universe, has been explored via surveys such as the Hubble Medium Deep Survey. Dark matter is one of the great mysteries in cosmology. It behaves very differently from ordinary matter as it does not emit or absorb light or other forms of electromagnetic energy — hence the term

What is dark energy?

The other 70 percent of the universe is thought to be comprised of dark energy. What scientists do know about dark energy is that it has a gravitationally repulsive effect (which is to say, the *opposite* of gravitational pull) and that it's responsible for the expansion of the universe. But what exactly *is* dark energy continues to elude scientists, leaving NASA scratching their heads and wondering if Einstein got his theory of gravity wrong. One thing Albert Einstein definitely got right was the secret to happiness—and it's genius.

The crew of STS-45 is already training for its March 1992 mission, including stints on the KC-135 zero-gravity-simulating aircraft. Shown with an inflatable globe are, clockwise from the top, C. Michael Foale, mission specialist; Dirk Frimout, payload specialist; Brian Duffy, pilot; Charles R. (Rick) Chappell, backup payload specialist; Charles F. Bolden, mission commander; Byron K. Lichtenberg, payload specialist; and Kathryn D. Sullivan, payload commander.

How can gravity be so strong and yet so weak?

Gravity poses a vexing paradox that can be summed up with this question: Why can a mere refrigerator magnet defy an entire planet's gravitational pull? Some scientists believe that gravity may well be as strong as the other fundamental forces (such as electromagnetism and the force that holds the nucleus together), but its influence is dissipated because it leaks into extra dimensions. That explanation will have to do until they come up something better.

The dwarf galaxy NGC 4214 is ablaze with young stars and gas clouds. Located around 10 million light-years away in the constellation of Canes Venatici (The Hunting Dogs), the galaxy's close proximity, combined with the wide variety of evolutionary stages among the stars, make it an ideal laboratory to research the triggers of star formation and evolution. Intricate patterns of glowing hydrogen formed during the star-birthing process, cavities blown clear of gas by stellar winds, and bright stellar clusters of NGC 4214 can be seen in this optical and near-infrared image. Observations of this dwarf galaxy have also revealed clusters of much older red supergiant stars. Additional older stars can be seen dotted all across the galaxy. The variety of stars at different stages in their evolution indicates that the recent and ongoing starburst periods are not the first, and the galaxy's abundant supply of hydrogen means that star formation will continue into the future. This color image was taken using the Wide Field Camera 3 in December 2009.

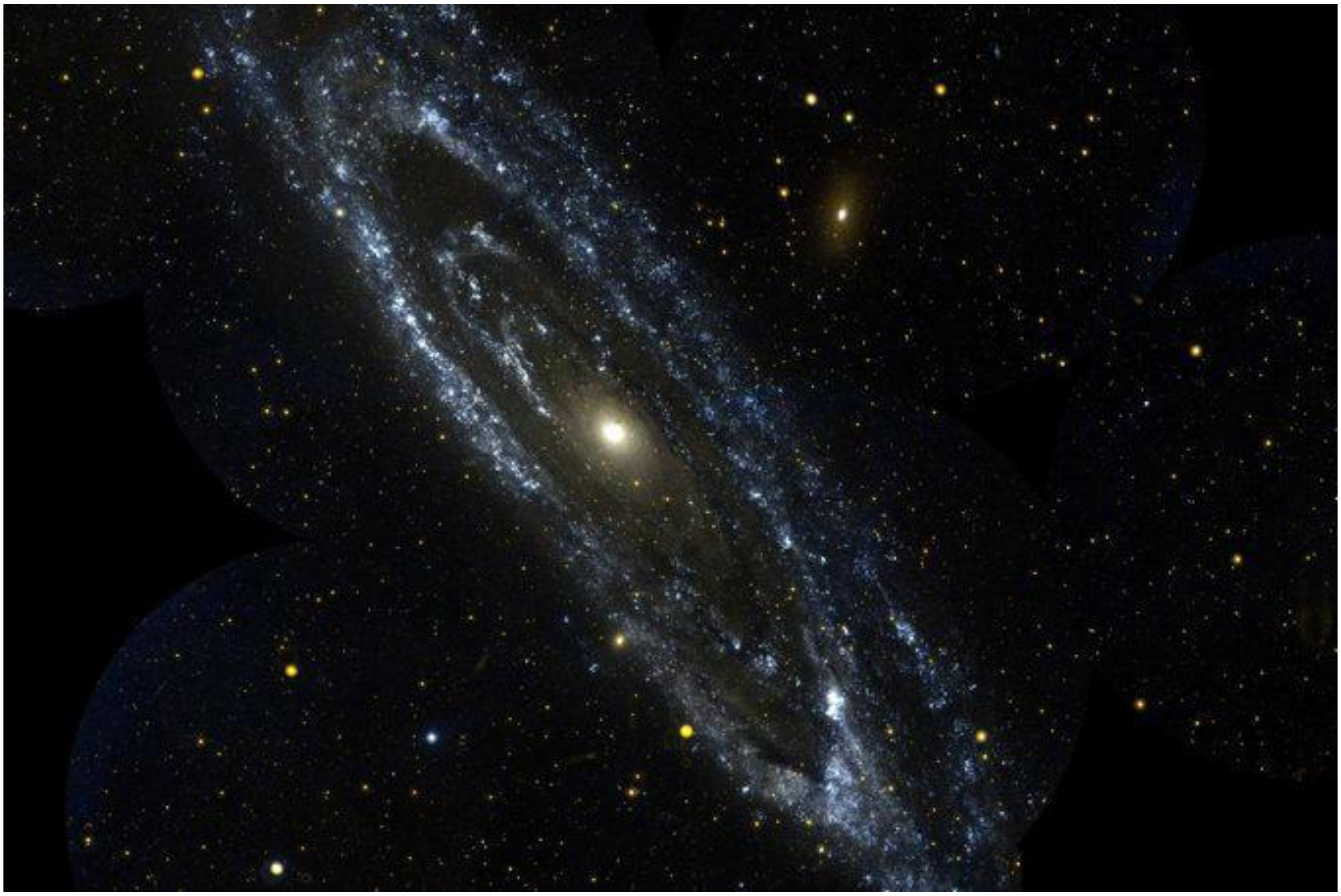
How big is the universe?

If scientists know that the universe is expanding, then they must be able to hazard a guess at how big it is, right? Unfortunately, scientists can't pin a number on it. They would have to know the universe's shape and rate of expansion, among other things—and those are mysteries as well.

NASA's Hubble Space Telescope has helped astronomers find the final piece of a celestial puzzle by nabbing a third runaway star. As British royal families fought the War of the Roses in the 1400s for control of England's throne, a grouping of stars was waging its own contentious skirmish — a star war far away in the Orion Nebula. The stars were battling each other in a gravitational tussle, which ended with the system breaking apart and at least three stars being ejected in different directions. The speedy, wayward stars went unnoticed for hundreds of years until, over the past few decades, two of them were spotted in infrared and radio observations, which could penetrate the thick dust in the Orion Nebula.

What is the shape of the universe?

Scientists have a number of theories about the shape of the universe. But according to NASA, the leading theory is that the universe is flat, which leads them to believe that it's infinite in size. However, since the universe has a known beginning, and perhaps an expected endpoint, we can only observe a *finite* volume of it. As NASA says, "All we can truly conclude is that the universe is much larger than the volume we can directly observe."



This image is from NASA Galaxy Evolution Explorer is an observation of the large galaxy in Andromeda, Messier 31. The Andromeda galaxy is the most massive in the local group of galaxies that includes our Milky Way.

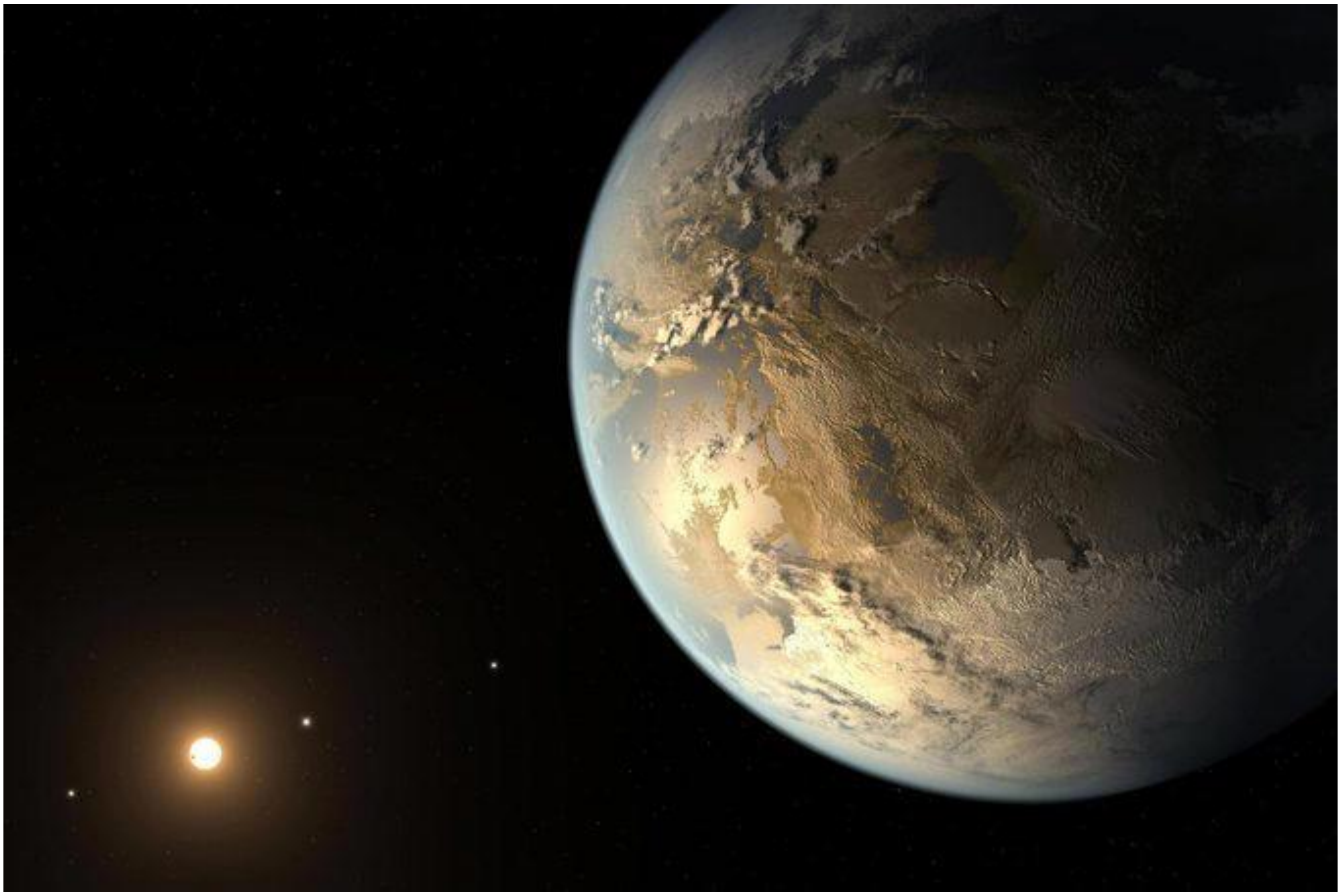
How fast is the universe expanding?

For the past six years, the Hubble Space Telescope has been calculating the speed at which the universe is expanding and recently came up with what is accepted as the most precise measurement to date—except that the rate stands in direct conflict with independent (and supposedly precise) measurements of the *early* universe's expansion. That's unsettling for astrophysicists because it means we know even less about our universe and its ways than we thought. "The community is really grappling with understanding the meaning of this discrepancy," said the lead researcher, Adam Riess, a Nobel Laureate and Bloomberg Distinguished Professor at Johns Hopkins University. Find out the 17 scientific facts that turned out not to be true.

Parallel universe science theory

Is the universe actually a multiverse?

"Our universe could be just one of an infinite number of universes making up a 'multiverse,'" according to astronomy news site space.com, and as bizarre as that may seem, there's actual science behind it. Because there are only a finite number of ways particles can be arranged in space and time (and remember the universe is flat and infinite), then the universe would have to start repeating at some point. Which leads to the question…


This artist concept depicts Kepler-186f, the first validated Earth-size planet to orbit a distant star in the habitable zone, a range of distance from a star where liquid water might pool on the planet surface.

Could there be another you?

If the universe is compelled to repeat itself—to be part of a multiverse—could there be another version (or multiple versions) of *you*? "If you look far enough, you would encounter another version of you—in fact, infinite versions of you," according to space.com. "Some of these twins will be doing exactly what you're doing right now, while others will have worn a different sweater this morning, and still others will have made vastly different career and life choices." This counts as one of the mysteries we're unlikely to ever get an answer for, but it's intriguing nonetheless. (Maybe the other version of you isn't hopelessly addicted to Girl Scout cookies.) The experts say that this theory would require additional dimensions, and if so…


Futuristic timetravel or space warp. 3D rendering

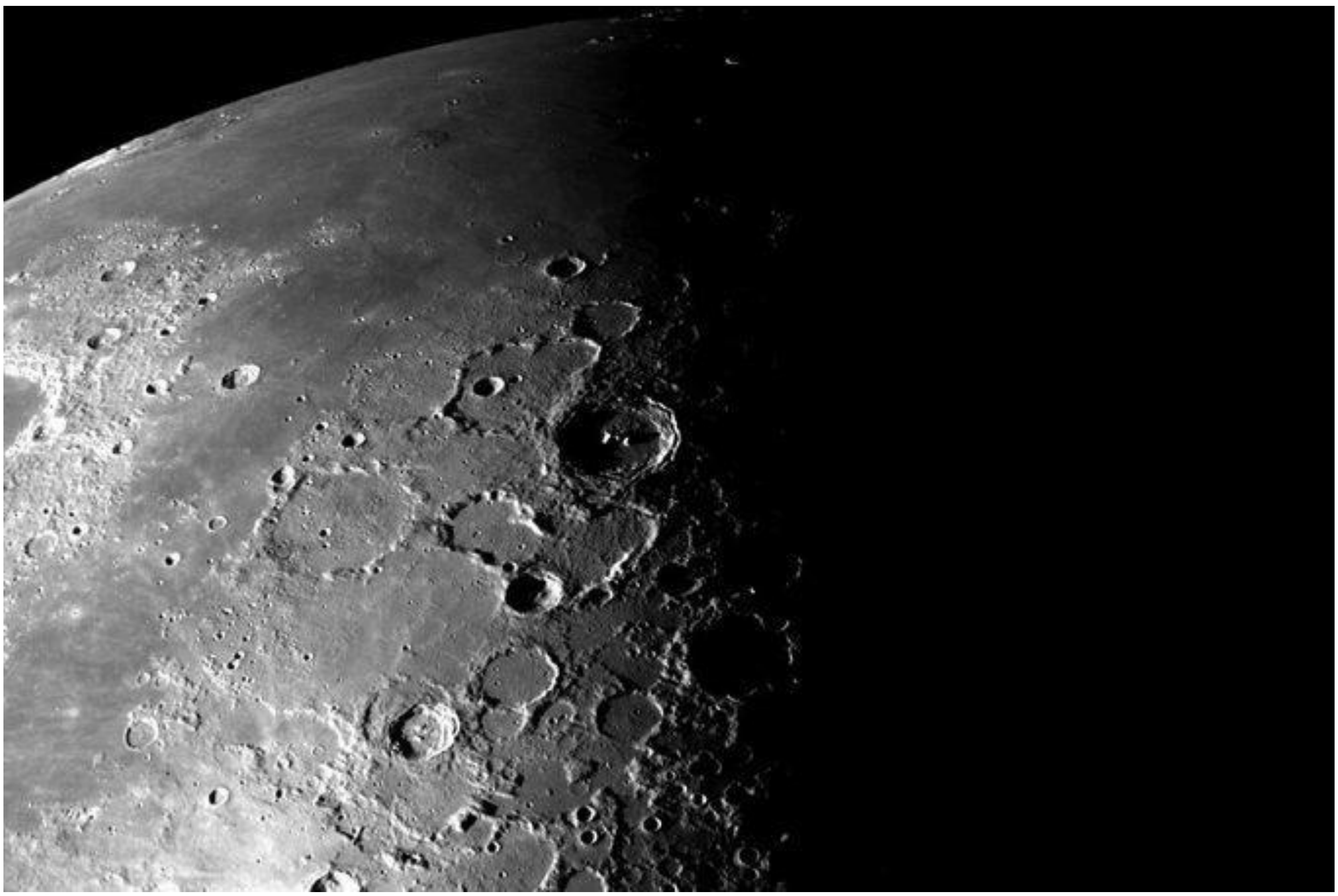
How many dimensions are there really?

The three dimensions of which we can be certain pertain to what we can perceive: length, width, and depth. Scientists also point to the fourth dimension of time. But according to Phys.org, while still a mystery, some potential dimensions include:

- Fifth: In which we can see a world slightly different from our own (which would give us the means of gauging similarities and differences between it and ours).
- Sixth: We can see all possible universes that have begun the same as our own

- Seventh: We can perceive all possible universes that began differently than our own.
- Eighth: We see all possible universes. Period.
- Ninth: We are aware of all possible laws of physics and universe beginnings.
- Tenth: We can see all things possible and imaginable.

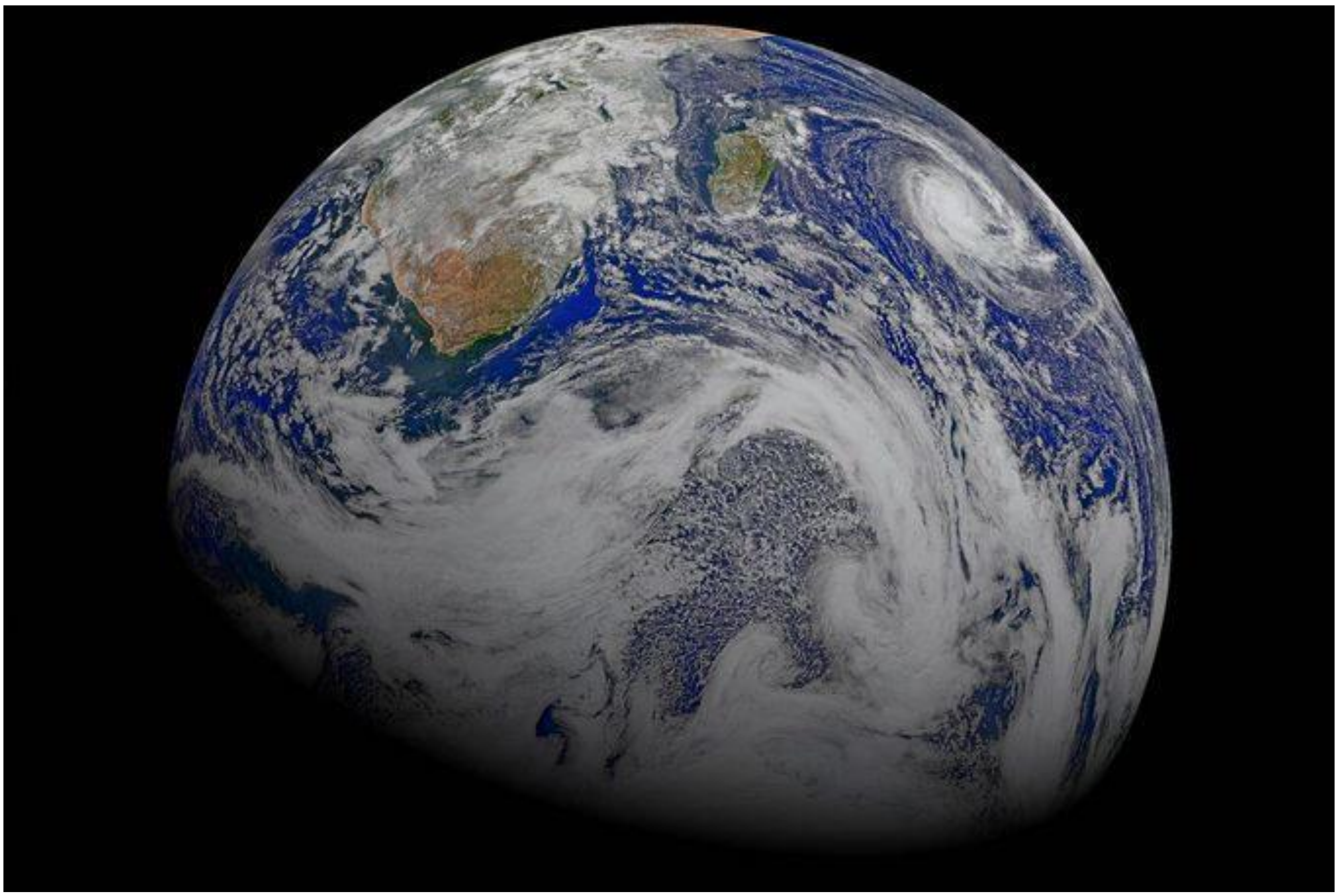
If you're looking for more science fun, don't miss these 18 science facts you never learned in school.



This view of the north polar region of the Moon was obtained by NASA's Galileo camera during the spacecraft flyby of the Earth-Moon system on December 7 and 8, 1992.

How did the moon form?

The moon's gravitational pull is responsible for the rise and fall of the ocean tides, but how did the moon come to be? After all, it took a *hundred million years* after the solar system and its planets began to form before the moon actually sprang into existence. Several theories exist, none of which is close to being proven. Meanwhile, one potential key to figuring out how we got a moon is to understand why Venus doesn't have one, according to Dave Stevenson, a professor of planetary science at the California Institute of Technology. We still haven't figured that one out, either.



This composite image of southern Africa and the surrounding oceans was captured by six orbits of the NASA/NOAA Suomi National Polar-orbiting Partnership spacecraft on April 9, 2015, by the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument. Tropical Cyclone Joalane can be seen over the Indian Ocean. Winds, tides and density differences constantly stir the oceans while phytoplankton continually grow and die. Orbiting radiometers such as VIIRS allows scientists to track this variability over time and contribute to better understanding of ocean processes that are beneficial to human survival on Earth.

Did life originate on Earth?

We take it for granted that life on Earth actually began here—but that's not actually accurate. [Scientists are finding evidence that life on Earth may have come from Mars] and was brought to this planet by a meteorite. The trouble is that scientists can't even agree on which area of science will provide the answer, let alone whether science is even where we should look.


3D UFO over the sea and waves

Is there alien life?

Since the early 1960s, scientists have theorized that it's [extremely likely that intelligent life exists outside of Earth]. The trouble is that we have zero scientific evidence. In fact, we have no hard scientific evidence that any life exists outside of earth, at least so far. But the time may be drawing closer when science confirms that there is life elsewhere in our solar system, or the galaxy, or at least somewhere in the universe.

Also, check out the most chilling UFO sightings ever recorded.

Sun beams or rays breaking through the dark clouds at sunset. Hope, prayer, God's mercy and grace. Beautiful spectacular conceptual meditation background.

Who’s in charge here?

Does someone or something start the whole process that led to you reading these words on an electronic screen? Or is everything that’s happened in the history of ever simply the result of a process guided by laws of science? While many notable scientific thinkers say God is a myth, not all scientists are atheists. This is one we’re unlikely to solve—at least during our lifetime..

Research explores cell-based theory of consciousness and what it entails

Story by Science X staff

• 10mo • 3 min read

Credit: Pixabay/CC0 Public Domain© Provided by Phys.org

Humans and other animals with brains perhaps aren't the only beings on the planet to experience consciousness, says a study in the journal *EMBO Reports*.

Consciousness instead underpins all life forms, from the smallest cells to the most complex organisms. Far from being limited to creatures like ourselves, the cell-based theory of consciousness frames the phenomenon a fundamental part of life itself.

Conventional thinking about consciousness—called the standard model of consciousness—focuses on the brain, supposing only complex organisms like humans and animals have it. But the new cell-based theory argues that consciousness started with the very first cells that emerged about 3.8 billion years ago and plants, bacteria and even amoebas have it.

The standard idea of consciousness has attracted rising criticism from scientists who think it's not completely wrong, but doesn't paint the full picture.

That approach is limiting, says Brunel University London's Dr. Predrag Slijepcevic. "When you look at the entire biosphere, brains are fairly rare. That's less than 1% of the biosphere where plants make up 75% of the biomass. Bacteria make up 20%. So bacteria and plants are 95% of the biosphere. When you put all animals together, it's probably 1% or less. And humans are just one species in the animal kingdom. Our cell-based consciousness theory is that life and consciousness were simultaneous. So they're one and the same."

The team, which includes The University of British Columbia, Bioverse Foundation and University of Bonn, delves into sentience, the ability to "feel" or sense and react to the world. People call their "feeling" emotions and sensations. But even very simple single-celled organisms like amoebas show they too can "feel" by reacting to the environment.

When they feel something is wrong in the environment, some amoebas build a protective calcium carbonate shell or house around themselves. The iconic White Cliffs of Dover show just that—they're made of trillions of shells made by living things. When amoebas die, their shells calcify, and over about 100 million years, amoeba shells piled up to form the symbolic landmark.

This is how the cell-based consciousness theory intertwines consciousness with evolution. It started with bacteria and the very first forms of life, which over billions of years evolved into more complex life forms.

The implications of this theory, based on two dozen research papers published in the last four years, stretch way beyond consciousness. The cell-based theory could potentially reframe how we view life, intelligence, and even artificial intelligence, challenging what we already think about existence.

"Obviously, there are people who would disagree," said Dr. Slijepcevic, "that's the nature of science. But we think people should focus on cell-based consciousness. Whether that will be accepted by the mainstream, we don't know, but we say cell-base consciousness has the capacity to perhaps provide a new, more useful understanding of consciousness. It basically boils down to interpreting what life is what life is all about. Life is about consciousness. We look forward to a paradigm shift in evolutionary biology."

More information: Arthur S. Reber et al, The CBC theory and its entailments: Why current models of the origin of consciousness fail, *EMBO Reports* (2023). DOI: 10.1038/s44319-023-00004-6. www.embopress.org/doi/full/10. ... 8/s44319-023-00004-6

Provided by Brunel University

Our brains trick us into thinking consciousness can reside outside the body, research argues

Psychology professor Iris Berent says perceiving minds and bodies as separate has evolutionary roots. Credit: Matthew Modoono/Northeastern University© Provided by Medical Xpress

The origins of consciousness have been debated by philosophers for centuries. Each conscious person has a sense of "being me," which invariably gives rise to the question of where that sense originated—from within or outside the body, says Northeastern University psychology professor Iris Berent.

"How do human brains give rise to this experience? That's the big mystery, right?" she says.

Influential philosopher David Chalmers famously won a bet in 2023 for claiming consciousness exists beyond the merely physical, Berent says.

But she says the question of where consciousness exists is a false one—and she has a new paper that presents her position.

In an article published in the *Neuroscience of Consciousness*, she argues that the debate stems from the delusional—albeit natural—biases in the way humans think about the separation, or lack thereof, between body and mind.

"One of the biases is dualism, intuitive dualism—the fact that we perceive minds as separate from our bodies."

"The extent to which we look at consciousness and think that it is this really mysterious thing could very well arise from how we see it rather from what consciousness really is," Berent says.

"Consciousness isn't hard. Psychology is," she says.

Mary and the zombie

Berent points to an experiment in perception she conducted in her lab that used the well-known Mary and the zombie hypothetical exercise, but with a twist.

According to the experiment, when people are asked to think of a zombie twin of themselves, they describe a creature with their physical features but without their thoughts or feelings.

"They intuit that the mind, consciousness included, is really separate from the physical," Berent says.

In the other thought experiment, Mary is a neuroscientist who knows everything about color and how the brain perceives color, even though she lives in a black-and-white world.

When Mary sees a red rose for the first time, people participating in the experiment say she learns something outside the bounds of physical, scientific explanation.

Berent says she decided to challenge these conclusions with two additional questions.

"The first question is kind of a reality check question, which is do they think Mary's case is significant? Is it transformative? And everybody said, 'Sure, it's super transformative,'" Berent says.

"We also asked how likely is it that this experience will actually show up in her brain? If we scan her brain, will it light up? And it turns out that that's exactly what people said. It will significantly register in the brain."

"The point being, in the condition of the zombie people say, 'no,' (consciousness) is not physical," Berent says. "And in Mary's condition, people say it's physical."

"If people change their mind in this way, it can't possibly be that in reality consciousness has changed. It must be that there is something within the human psyche that colors how we see consciousness."

"For me, this means that we need to be really careful before we assume that there is any real mystery going on."

The evolutionary roots of dualism

Berent blames what she calls "delusional attitudes about bodies and minds" to "the same old psychological biases that I've been studying in my lab for years."

She calls the separation of mind and body dualism Previous research by Berent shows that autistic people are less dualistic than neurotypical people and that males are less dualistic than females.

Evolution is responsible for the fact people hold two different systems of perception in their mind, Berent says.

"Animals have an evolutionary advantage to be able to perceive objects, say, the bodies of their mothers," she says.

It's also important to be able to perceive objects that have agency as separate from other objects, Berent says. "You want to follow the mother and not a body that is inanimate" to receive nurturance and protection.

This type of dualism, she says, "primes us to think about people and their minds and bodies as separate from each other. That's one reason we think about consciousness as this ethereal thing separate from the body."

"The point is that our perception of consciousness changes depending on the situation. And if that's the case, there's no way that we can trust it to reflect what our consciousness really is. It must be that our brain plays tricks on us."

An intimate understanding of who we are

"Every psychology student that has ever come into my class asks if we're going to talk about consciousness," Berent says.

"This is considered to be super important. This is our intimate understanding of who we are."

Berent says the thought experiment outlined in her paper provides "the smoking gun" that intuitions about consciousness existing outside the body are manufactured by humans' dualistically inclined brains.

Consciousness likely comes down to electrochemical functions in the brain, she says. "It's hard for psychological reasons."

More information: Iris Berent, Consciousness isn't "hard"—it's human psychology that makes it so!, *Neuroscience of Consciousness* (2024). DOI: 10.1093/nc/niae016

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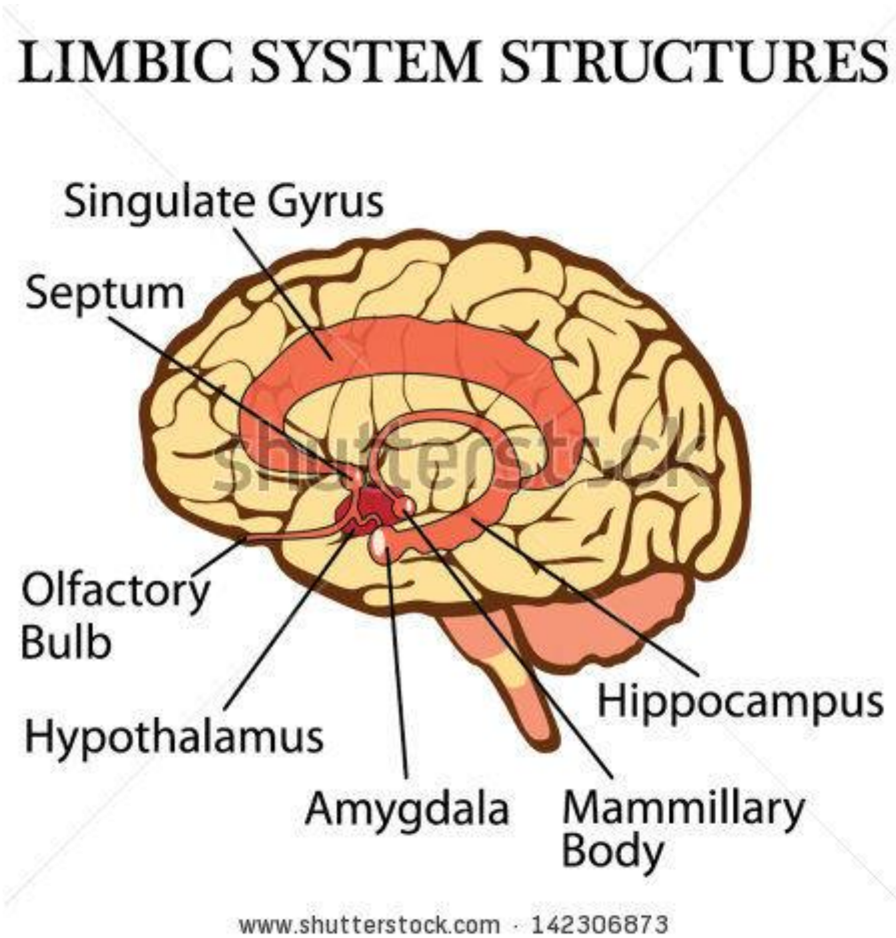
A Unified Field Theory of Consciousness

A new paradigm.



A theory of consciousness has to correspond to the actualities of human nature. It has to be consonant with the living of a human life. Its design has to reflect the productions it creates. My view through the looking glass came from many years of psychiatric practice, the long term, intensive psychotherapy of character. This provided me an unusual circumstance where I had a considerable sampling of the vast array of human character. I saw the whole range of symptoms and human suffering. Since I was allowed into the inner sanctum of my patients' stories, I was privy to how each one evolved, the story behind the story. I was let into the truth of each formative family life. And I became familiar with the discreet array of my patients' different temperaments. This uncommon experience gave me a working and in-depth knowledge of character, psychiatric symptoms, human suffering, and recovery. As a therapist I have also had the unusual experience of hearing thousands of dreams. The trance state of REM sleep creates dreams composed of characters, feelings, scenarios, set designs, and landscape. Each and every one of them had comprehensible meaning through which a patient digested an issue of the day in the context of a characteristic and discernible inner play. Consciousness creates these dreams as well. In addition to character and dreams, a theory of consciousness has to be a unified field theory that encompasses myths, the imagination, art, culture, and religion.

None of the prevailing theories of consciousness seem to account for the full scope of human nature. Psychiatric theories don't correspond to human actuality, never mind the English language. Child development theories also seem to miss the boat as they squeeze reality into their boxes, rather than the other way around. Medical neurology is fascinating and illuminating, but it evolved as a kind of piecemeal understanding of the brain from diseases and pathology and doesn't lend itself to an overall grasp of consciousness or how that relates to personality and the living of a life. Modular centers, genetic unfolding, epigenetic influences do not account for the productions in the brain of consciousness. Neuroscience has been taking off as a discipline and is intriguing. But it too seems to be prone to ungrounded theories which get established as dogma. And finally the pharmaceutical-psychiatric complex promoted the bogus idea that neurotransmitters and brain chemistry are the key to consciousness and psychiatry. They have gained ascendancy through financial and scientific corruption. They have invented so called evidence-based psychiatry which is neither scientific nor evidence based, which has pre-empted real scientific inquiry. See "No, It's not the Neurotransmitters, Depression is not a biological disease caused by an imbalance of serotonin".

A theory of consciousness must not only account for human nature, but its organization in the brain-body must reflect the actual brain-body in its development and organization, as well as evolution. The key to consciousness is that it is created by the limbic-cortical mappings of experience. These high end maps are grounded in the limbic system and generate the organization of consciousness as a play, with a cast of characters, feeling relatedness between them, scenarios, plots, landscape and set designs. This play is written from the actuality of one's formative life experience - responsiveness, abuse, and deprivation - as it is digested by one's specific, genetic temperament. Each and every person has a unique play which is manifest as his character.

I have traced the function of the limbic system which begins in utero in "Ray Kurzweil's presentation of hybrid thinking does not grasp the biological operations of the brain". Consciousness coalesces at six weeks old when the limbic-cortex is sufficiently mapped to create a non-representational formless feeling of our self. This results from the history of limbic-cortical mappings of the fetus and infant of his 'self' relating to its maternal environment. I call this the Authentic Being, the brain's creation of sentience which is grounded in limbic feeling. Over the next three years, the child's extensive mapping of experience of self and other and their relatedness matures to achieve a high enough state of order that it creates symbolic form. At this point we have representational consciousness. Representational consciousness creates images and the image-ination. The Authentic Being gets supplanted, but its mappings remain and it is the source of authenticity, loving, consciousness and creativity for the rest of our lives. Both the Authentic Being and our conventional sense of self are synthetic illusions created by the brain. See "How did Captain Hook Get Into Eddie's Closet?"

Once established, these high end limbic-cortical brain maps operate via cortical top down processing, the brain's short cut for the living of a life. These high end brain maps utilize the various brain centers all throughout the architecture of the cortex. But consciousness is not located in any one center. None of the various brain centers exist for their own sake, but only to serve the overall organization of limbic-cortical brain mappings.

The presence of developmental abuse and neglect writes a limbic-cortical play of sado-masochism. As such the serotonin in the synapses of its mappings gets consumed by the ongoing attacks of the established internal drama. Eventually, later in life, the ongoing play of sado-masochism will over consume its neurotransmitter supplies and generate psychiatric symptoms.

Typically, one can change learned cortical mappings by disuse of the activated circuit. Then one can establish a new set of circuits through new experience that isn't controlled by old de-activated top down processed maps. When the cortical circuits are limbic, then the process of disuse is called mourning. This is precisely the way psychotherapy changes the internal character play. Mourning the play itself allows us to deactivate old top down limbic circuits and write new ones through new experience. I proceeded as a therapist by paying attention to the feeling communications of my patient, within the boundaries and emotional holding of psychotherapy. This led to a patient mourning his pain in the context of his internal story. When he relinquishes his original play, he writes a new one grounded in love and responsiveness. The old pathways of circuits cease to be activated and new ones get established. As the sado-masochism (often masked) of the old plays ceases to be operative, the symptoms and suffering disappear.

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The Unity of Consciousness

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Human consciousness usually displays a striking unity. When one experiences a noise and, say, a pain, one is not conscious of the noise and then, separately, of the pain. One is conscious of the noise and pain together, as aspects of a single conscious experience. Since at least the time of Immanuel Kant (1781/7), this phenomenon has been called the *unity of consciousness*. More generally, it is consciousness not of *A* and, separately, of *B* and, separately, of *C*, but of *A*-and-*B*-and-*C* together, as the contents of a single conscious state.

Historically, the notion of the unity of consciousness has played a very large role in thought about the mind. Indeed, as we will see, it figured centrally in some of the most influential arguments about the mind from the time of Descartes to the 20th century. In the early part of the 20th century, the notion largely disappeared for a time, but since the 1960s, analytic philosophers and others have begun to pay attention to it again.

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1. History

The unity of consciousness was a main concern of most philosophers in what is often called the ‘classical modern era’ (roughly, 1600 to 1900), including Descartes, Leibniz, Kant, Hume (in a way; see below), Reid, Brentano, and James.

Consider a classical argument of Descartes’ for mind-body dualism. It starts like this:

When I consider the mind, that is to say, myself inasmuch as I am only a thinking thing, I cannot distinguish in myself any parts, but apprehend myself to be clearly one and entire. [Descartes 1641: 196]

Descartes then asserts that if the mind is not made of parts, it cannot be made of matter because anything material has parts. He adds that this by itself would be enough to prove dualism, had he not already proven it elsewhere. Notice where it is that I cannot distinguish any parts. It is in “myself inasmuch as I am only a thinking thing” (ibid.); that is, in myself as a whole—which requires unified consciousness of myself as a whole. The claim is that this subject, the target of this unified consciousness, is not a composite of parts.

In Kant (1781/7), the notion that consciousness is unified is central to his ‘transcendental deduction of the categories’ (see the entry on Kant’s view of the mind and consciousness of self for a fuller treatment of Kant). There Kant claims that in order to tie various objects of experience together into a single unified conscious experience of the world, we must be able to apply certain concepts to the items in question. In particular, we have to apply concepts from each of four fundamental categories of concept: quantitative, qualitative, relational, and what he called ‘modal’ concepts. Kant’s attempt to link the unity of consciousness to the structure of knowledge continues to capture the imaginations of philosophers: Arguments of this form can be found in P. F. Strawson (1966), Cassam (1996), Hurley (1994, 1998) and Revonsuo (2003), and are examined critically in Section 7.3 and in Brook (2005).

Kant was familiar with arguments of the kind that we just saw Descartes mount (chiefly from similar reasoning in Leibniz and Mendelssohn) but he was not impressed. For Kant, that consciousness is unified tells us nothing about what sorts of entity minds are, including whether or not they are made out of matter (1781, chapter on the Paralogisms of Pure Reason). He argues that the achievement of unified consciousness by a system of components acting together would be no more or less mysterious than its being achieved by something that is simple, i.e., has no components (1781: A352).

Leibniz, Hume, Reid, Brentano, and James held a variety of positions on unity. Briefly, for Leibniz (see the entry on Leibniz’s philosophy of mind) unified consciousness and the noncompositeness, the indivisibility that he took to be required for it seem to have served as his model of a monad, the building block of all reality. With Hume (1739), things are more complicated. It should have followed from his atomism that there is no unified consciousness, just “a bundle of different perceptions” ([1739] 1962: 252). Yet, in a famous appendix, he says that there is something he cannot render consistent with his atomism (p. 636). He never tells us what it is but it may have been that consciousness strongly appears to be more than a bundle of independent ‘perceptions’. Reid (1785), almost an exact contemporary of Kant’s, made extensive use of the unity of consciousness, among other things to run Descartes’ argument from unity to indivisibility the other way around. Brentano (1874) argued that all the conscious states of a person at a time will and perhaps must be unified with one another. (He combined this view with another strong thesis, that all mental states are conscious.) Finally, late in the 19th century James developed a detailed treatment of synchronic (or ‘at a time’) unity of consciousness. We will discuss his view later (see also entries on David Hume, Thomas Reid, Franz Brentano, and William James).

Early in the 20th century, the unity of consciousness almost disappeared from the research agenda. Logical atomism in philosophy and behaviourism in psychology had little to say about the notion. Logical atomism focussed on the atomic elements of cognition (sense data, simple propositional judgments, protocol sentences, etc.), rather than on how these elements are tied together to form a mind. Behaviourism urged that we focus on behaviour, the mind being either a myth or at least something that we cannot and do not need to study in a science of the human person.

One partial exception to this pattern of neglect was Gestalt psychology. Indeed, Gestalt psychology was sufficiently influential in its time that some positivists tried to make their systems compatible with it (Smith 1994: 23). For instance, Carnap chose to avoid any commitment to atoms of experience as the elements of his system, opting instead for ‘total experiences’. As we will see, a notion similar to his concept of irreducible experiential wholes can be fruitful (Section 7.4). However, Carnap seems to have had something rather different in mind from what philosophers now have in mind when they speak of the unity of consciousness. Gestalt unity is a unity in a structure of which one is conscious, where the way in which each part appears is derived from the structure of the whole (Tye 2003: 11–5; Bayne & Chalmers 2003: 27). This is distinct from unity in *one’s consciousness of* objects, objects that need not themselves exhibit the qualities of gestalt structures.

After decades of neglect, the last third of the 20th century saw a resurgence of interest in unified consciousness among analytic philosophers. It began with influential commentaries on Kant in the 1960s (Strawson 1966; Bennett 1966, see also his 1974), as well as discussions by Nagel (1971) and Parfit (1971, 1984). More recently, quite a number of philosophers and a few psychologists have written on the subject, including Marks (1981), Trevarthen (1984), Lockwood (1989, 1994), Hill (1991), Brook (1994), Marcel (1994), Hurley (1994, 1998), Shoemaker (1996, 2003), O’Brien and Opie (1998). The first decades of the 21st century have seen a lot of important new work on the subject: Dainton (2000), Stevenson (2000), Bayne and Chalmers (2003), Hurley (2003), Kennett and Matthews (2003), Rosenthal (2003), Radden (2003), Tye (2003), Zeki (2003), Nikolinakos (2004), Brook and Raymont (2006), LaRock (2007), and Bayne (2008, 2010, the latter a book-length study). Cleeremans (2003) is an excellent collection containing papers by philosophers such as Bayne, Chalmers, Hurley, Shoemaker, Cotterill, and Thompson and psychologists such as Triesman, Humphreys, Engel, Diennes, Perner, and Varela. Blackmore (2004, especially ch.

17) is a good, scientifically-oriented introduction. The section on the unity of consciousness in PhilPapers has 391 entries (as of April 2017), the vast majority from the last twenty years (see Other Internet Resources).

2. Characterizations and Taxonomies

2.1 Characterizations

What characterizes the unity of consciousness? Note that this question can be asked and answered whether *or not* there is any such thing as unified consciousness. Indeed, we need to know what the unity of consciousness is like even to address the question of its existence. (For ease of exposition, we will write as though there is unified consciousness, even though the question really remains open until the next section.)

That said, it should also be noted that it is difficult to say much about the unity of consciousness that is both non-question-begging and more than a thinly disguised synonym, a point that Dainton (2000) emphasizes. Even as great a theorist of the subject as Immanuel Kant threw up his hands. He observed that this unity is “not the category of unity” (B131), that is to say, is not just a matter of being numerically one—and said no more.

Underlying the various attempts to identify what is characteristic about the unity of consciousness are two opposing views of the structure of a unified conscious experience. On what we will call the experiential parts view (EP), a unified conscious experience is a composite of other experiences. The no experiential parts view (NEP) denies this, asserting that while a unified conscious experience will have a complex object or content, it has no experiential parts. On this view, when the objects of particular experiences get incorporated into a ‘bigger’ unified experience, the new experience replaces the particular experiences rather than containing them as parts. It would be premature to discuss the two views here (see Sections 7.1 and 7.2) but we need to know about them to understand the attempts that have been made to characterize unity. The first two ways of characterizing the unity of consciousness that we will examine are within the experiential parts approach.

2.1.1 Subsumption

One increasingly prominent attempt to characterize the unity of consciousness holds that in unified consciousness, particular experiences are subsumed in a more complex experience. For example, Bayne and Chalmers (2003) say that when particular experiences are unified, they are “aspects of a single encompassing state of consciousness” (see also Bayne 2010: 20, 31). More precisely, two experiences are what they call ‘subsumptively unified’ “when they are both subsumed by a single state of consciousness” (2010: 27). This yields a distinctive phenomenology. Two subsumptively unified states will have what they call a conjoint phenomenology: a phenomenology of having both states at once that subsumes the phenomenology of the individual states: “there is something it is like for the subject to be in [two conscious] states simultaneously” (2010: 32).

One feature of subsumption is that it requires there to be experiential parts. Thus, those who favour NEP or even wish a characterization of unified consciousness to be neutral on this issue will look for a different account.

2.1.2 Co-Consciousness

A second attempt to characterize unified consciousness claims that a relation among local conscious states is the crucial element, a relation usually called co-consciousness. As James put it, in synchronic unified consciousness, we are co-conscious of *A*, *B*, and *C* (1909: 221). Others who centre their analysis on the notion include Parfit (1984) and Hurley (1998). These theorists seldom try to define the term 'co-consciousness'. They treat the notion as being intuitively clear and let it function as a primitive in their analysis.

Like subsumption, most versions of co-consciousness require experiential parts (James, who accepted NEP and thus had an unusual conception of co-consciousness, is an exception). In addition to a problem of lack of neutrality, this requirement faces the problem that some forms of unified consciousness do not seem to involve multiplicity of items, unified consciousness of self for example. If there is no multiplicity of items, there is nothing to enter into a 'co'-relationship.

A number of theorists combine the two approaches. Many of the people who use the term 'co-consciousness' in fact seem to have subsumption in mind as the underlying notion. Dainton, for example, embraces the language of co-consciousness and relates the notion to"being experienced together" [subsumption] (2000: 236) but urges in the end that co-consciousness is a better primitive than subsumption (Dainton 2005: 258–259). Or Lockwood (1989: 88): co-consciousness is "the relation in which two experiences stand, when there is an experience of which they are both parts". Similarly Shoemaker (2003: 65): "The experiences are co-conscious … by virtue of the fact that they are components of a single state of consciousness … ".

2.1.3 Joint Consciousness

There are at least two approaches to what characterizes unified consciousness that are compatible with NEP. One we find in Tye. In unified conscious states, the things that we experience are "experienced together", "enter into the same *phenomenal content*" (2003: 36, his emphasis)—which phenomenal content could be the content of a single non-composite experience.

Another has been advanced by Brook and Raymont (Brook 1994: 38; Brook 2000; Brook & Raymont 2006). The key idea is what they call joint consciousness. Joint consciousness is present when the following holds: If an experience that one is having provides consciousness of any item, then it provides consciousness of other items and of at least some of the items as a group. Likewise for consciousness of acts of experiencing.

This notion tries to capture what is distinctive about unified consciousness in a way that is neutral with respect to the EP/NEP debate. The notion is related to the phenomenal side of the Bayne/Chalmers notion of subsumption, there being something it is like to be in two conscious states simultaneously (Bayne & Chalmers 2003: 32), but in a way that is free of the non-neutral notion of subsumption. It is not clear whether joint consciousness is an alternative to Tye's notion of same phenomenal content or an attempt to say something about what yields such content.

2.2 Taxonomies

Most contemporary theorists agree that unified consciousness can take a number of forms. Many schemes for dividing it up exist in the literature. Tye (2003: 11–5), for example, distinguishes object unity, neurophysiological unity, spatial unity, subject unity, introspective unity, and, finally, phenomenal unity. The latter is the notion that he explicates in terms of contents being experienced together, entering into the same phenomenal content, and is the notion on which he focuses.

Similarly, Bayne and Chalmers (2003: 24–7) distinguish objectual unity (a matter of two conscious experiences of one object, so different from Tye's object unity), spatial unity, subject unity, and subsumptive unity, the last a matter of two or more conscious states becoming aspects of a single conscious state. Then within subsumptive unity, they distinguish between access unity and phenomenal unity. We just examined their definition of the latter. As is true of Tye, it is what mainly interests them. Two conscious states are phenomenally unified "if there is something it is like for the subject to be in both conscious states simultaneously".

Kant and philosophers in the Kantian tradition break phenomenal unity down. The division usually follows the traditional division of experience into subject, representation, and object or content, assigning to each its own form of unified consciousness. Thus there will be unified consciousness of individual objects, of multiples of objects, of acts of experiencing, and of oneself as the subject of such experiencing. (A fifth form can be distinguished, too, as we will see.) Few contemporary theorists break phenomenal unity down at all, so this division is of some interest.

The first three forms of unified consciousness in the Kantian tradition can be expressed in terms of the notion of joint consciousness just introduced. First, *unified consciousness of individual objects*. This is Tye's object unity; Bayne and Chalmers' objectual unity is at least a related notion. The process at work here is now commonly called binding (Hardcastle 1998; Revonsuo 1999). Binding is the process of tying various features of a visual scene such as colour, shape, edges, and contours, features detected in various places in the visual cortex, together into an experience of a unified, three-dimensional object. Binding may be necessary for consciousness of individual objects but it does not seem to be sufficient. We must, it seems, also be jointly conscious of the various elements to have unified consciousness of an object.

Next, *unified consciousness of contents*. In unified consciousness of contents, if an experience that one is having provides consciousness of any object or content, then it provides consciousness of other objects or contents and of at least some of the items as a group. Here 'object' and 'item' cover objects, properties, events—anything of which one can be conscious. (We speak of experiences rather than representations in deference to those who doubt that we experience in representations, or need do so: we wish to be neutral on this issue.)

This distinction between unified consciousness of individual objects and of multiples of objects corresponds closely to two kinds of synthesis distinguished by Kant (1781/7, First Division, Book 1, Chapter 2). Kant distinguishes between the kind of acts of synthesis needed to attain consciousness of individual objects and the kind of acts of synthesis needed to attain consciousness of a number of objects at the same time as a single array of objects experienced by a single subject (Brook 1994: 123). He builds his argument for necessary causal connectedness on the latter.

Unified consciousness of contents appears to be central to our kind of consciousness. For example, suppose that one is conscious of one's computer and also of the car sitting in one's driveway. If consciousness of these two items were not unified, an important, indeed probably the most important, way of comparing them would not be available. One could not answer questions such as, Is the car the same colour as the WordPerfect icon?, or even, Is the car to the left or to the right of the computer? That is what unified consciousness does for us: it allows us to make such comparisons. Since relating item to item in this and related ways is fundamental to our kind of cognition, unified consciousness is fundamental to our kind of cognition. As we will see in Section 4.1, there are disorders of consciousness in which this ability to compare seems to be lost. These disorders leave people with a massive cognitive impairment.

Most theorists outside of philosophy and many within accept that there is a second form of conscious unity related to unified consciousness of contents, namely, *unified consciousness of acts of experiencing*. It is present when, for the current acts of experiencing that one is doing, consciousness of one act of experiencing (consciousness of how one is experiencing something, for example seeing it, imagining it, …) provides consciousness of other acts of experiencing. (This explication is structured to be neutral as to whether unified conscious states include a multiplicity of conscious states. We speak of 'consciousness of acts of experiencing' rather than 'consciousness of *an* experience' for the same reason.)

Not all theorists accept that this second form of unified consciousness exists. Those who promote the so-called transparency thesis, the claim that we are not directly conscious of our own experiencings, deny that we have any such form of consciousness (Dretske 1995; Tye 2003). Tye, for example, says that when we hear something, we are not conscious of the auditory experience, just what it represents. If one tries to be conscious of the experience, at best one is aware only of "the auditory qualities that the experience represents" (2003: 33).

Many theorists have also had a fourth thing in mind when they speak of the unity of consciousness, namely, *unified consciousness of oneself*, the thing that has the experiences. Here, one is or certainly seems to be (see the discussion of Rosenthal in Section 3.1) conscious of oneself not just as subject but, in Kant's words (A350), as the 'single common subject' of many or all the aspects of the unified experience that one is now having and of a number of similar experiences past and, in anticipation, still to come. (*Mutatis mutandis*, the same holds for the single common agent of various bits of deliberation and action.) One has unified consciousness of self when one is conscious of oneself as the single common subject of experiences of many items in many acts of experiencing.

The unified consciousness here seems not to be a matter of joint consciousness. When one is conscious of oneself as the common subject of one's current unified acts of experiencing and of unified acts of experiencing past and to come, one is not conscious of *a number* of objects, nor a number of acts of experiencing either. (Indeed, if Kant is right, when one is conscious of oneself as subject, one need not be conscious of oneself as an *object* at all (A382, A402, B429).) However, something similar might be at work. One seems to be conscious of one and the same thing as one and the same thing, namely, oneself, via *a number of acts of experiencing*.

Unified consciousness of self has been argued to have some very special properties, for example that the reference to oneself as oneself by which one achieves consciousness of oneself as subject must be indexical and cannot make use of 'identification' (Castañeda 1966; Shoemaker 1968; Perry 1979). Generalizing the latter notion, it has been claimed that reference to self does not proceed by way of attribution of properties or features to oneself at all (Brook 2001). One argument for this view is that one is or could be conscious of oneself in the same way as the subject of each and every one of one's conscious experiences. If so, one would not be conscious of oneself as one kind of thing rather than another. As Bennett (1974: 80) once put it, consciousness of self would not be 'experience-dividing'—statements expressing it would have "no direct implications of the form 'I shall experience *C* rather than *D*'". And if that is so, one's consciousness of self might not be gained via being conscious of features of oneself at all

Some theorists especially in the empirical literature hold that a fifth form of phenomenal experience should attract the label, 'unified consciousness'. We might call it *unity of focal attention*. It differs from the other forms of unified consciousness that we have delineated. In the others, consciousness ranges over either many experienced items (unified consciousness of contents), experiencings of many objects (unified consciousness of experiencing), or multiple acts of access to oneself as subject of many experiencings (unified consciousness of self). Unity of focus picks out something within these unified 'fields'. Wilhelm Wundt captured what we have in mind in his distinction between the field of consciousness (*Blickfeld*) and the focus of consciousness (*Blickpunkt*; Wundt [1874] 1893: Vol. II, 67). The consciousness of a single item on which one is focussing is unified because one is conscious of many *aspects* of the item in one state or act of consciousness (especially relational aspects, e.g., any dangers it poses, how it relates to one's goals, etc.), and of many different considerations with respect to that item (one's goals, how well one is achieving them with respect to this object, etc.), in the same state or act of consciousness. In unified focal attention, one integrates a number of cognitive *abilities* and applies them to an object. Bayne and Chalmers' objectual unity is a related notion (2003: 24–25). Note that, if there are forms of unified consciousness different from focal attention, then, contrary to Posner (1994) and others, attention is not a component of all forms of consciousness (Hardcastle 1997).

All five of the forms of phenomenal unity can, to one degree or another, be attributed to Kant. The first four are clearly Kantian but there is a connection to him even with respect to the fifth. He didn't speak of attention very often but he did speak of it. See, for example, B156n.

Since Hume ([1739] 1962: 252) and Rosenthal (2003) deny that we have such unified consciousness of self and Dennett (1991, 1992) says at minimum that we have much less of it than we think, it is perhaps pertinent to say again that in this section we are merely trying to say what the various forms of unity would be like if they exist. Whether they do exist is the topic of Section 3.

2.3 Other Forms of Mental Unity

We will close this section by noting that the forms of unified consciousness distinguished above are not the only kinds of mental unity. Earlier we mentioned *Gestalt unity*. There is also unity in the exercise of our cognitive capacities, unity that consists of integration of motivating factors, perceptions, beliefs, etc., and there is unity in the outputs, unity that consists of integration of behaviour.

Human beings bring a strikingly wide range of factors to bear on a cognitive task such as seeking to characterize something or trying to reach a decision about what to do about something. For example, we can bring to bear: what we want; what we believe; our attitudes to self, situation, and context; input from each of our various senses; information about the situation, other people, others' beliefs, desires, attitudes, etc.; the resources of however many languages we have available to us; various kinds of memory; bodily sensations; diverse problem-solving skills; and so on. Not only can we bring all these elements to bear, we can integrate them in a way that is highly structured and ingeniously appropriate to our goals and the situation(s) before us. This form of mental unity could appropriately be called *unity of cognition*.

It is plausible to hold that unity of cognition is required for unity of focal attention. However, there is at least some measure of unified cognition in many situations of which we are not conscious, as is attested by our ability to balance, control our posture, maneuver around obstacles while our consciousness is entirely absorbed with something else, and so on.

At the other end of the cognitive process, we find an equally interesting form of unity, what we might call *unity of behaviour*: our ability to coordinate our limbs, eyes, bodily attitude, etc. The precision and complexity of the behavioural coordination we can achieve would be difficult to exaggerate. Think of a concert pianist performing a complicated work. However, this capacity to unify behaviour, though doubtless a product of unified consciousness, does not figure in what unified consciousness is.

3. Is Consciousness Unified?

Now that we know what we are talking about when we talk about unified consciousness, the next question to ask is: Does it exist? *Does* consciousness have the properties that it would need to have to be unified? If this division of questions looks peculiar, notice that it can apply to Santa Claus, too. We can develop an account of what Santa Claus would be like without committing ourselves on the question of whether such a being exists. However, the division may look peculiar in another way: How could anyone *deny* that consciousness is unified? That it is seems just obvious. In fact, there has been a good deal of skepticism on the matter.

Some will urge that before we ask whether unified consciousness exists, we should first ask, Does *consciousness* exist? There now seems to be a wide consensus that the answer to this question is, Yes, there is in us something appropriately called 'consciousness'. Even those who hold that the long-standing idea that intentionality (see entry) is a matter of attitudes to propositions is false and ripe for elimination, Paul and Patricia Churchland for example, allow that consciousness exists, though they urge that the concept be trimmed a bit (see, for example, Patricia Churchland 1983). Some writers have taken Dennett (1991) to deny that consciousness exists, either directly or by implication. He himself has said repeatedly that consciousness *is* real, however (1995: 135, 146 are two examples). A few writers, Wilkes (1984) and Rey (1988) for example, have espoused true eliminativist about consciousness but they are a tiny minority.

3.1 Skepticism about Unity

Many philosophers have been sceptical about whether consciousness is unified. It is possible to be sceptical about whether all consciousness is unified, whether as many conscious states are unified as we might think, and, the strongest form of scepticism here, whether there is any unity of consciousness. Let us examine the three in reverse order.

Hume ([1739] 1962: 252) seems to have been an example of the strongest form of scepticism. He famously doubted, or tried to doubt, that we have unified consciousness even of the self, let alone of one's conscious states. Among recent writers, perhaps the most sceptical about consciousness being unified is Rosenthal. Rosenthal holds that all we have is a "*sense of* the unity of consciousness" (1986: 344, emphasis added). Why merely a sense? On his view,

Mental states are conscious, when they are, in virtue of their being accompanied by HOTs [higher-order thoughts] and each HOT represents its target as belonging to the individual who also thinks the HOT in question. (Rosenthal 2002: 15)

Across a range of such self-ascriptions, one develops a sense of being their common subject. However, this sense could be wrong. The experiences thus ascribed, says Rosenthal, could be supported by or located in a diversity of subjects. It is because of this possibility that Rosenthal asserts that all we have is a sense of consciousness being unified.

Even when theorists such as Hume and Rosenthal deny that consciousness is unified, sometimes unity of some sort still seems to be at work in their models. Rosenthal says, for example, "A mental state is conscious just in case it is accompanied by a … thought to the effect that *one is in the state in question"* (2003: 325, our emphasis). If so, in addition to a HOT being about another psychological state, it is also about oneself, the thing that has the state ('that *one* is in the state in question'). Now, this consciousness of oneself is not consciousness of any old object, it is consciousness of oneself, oneself as the bearer of conscious states. But this is consciousness of oneself as, to use Kant's phrase, the single common subject of one's experience (1781/7, A350). If so, Rosenthal allows that one kind of unified consciousness exists despite himself.

More recently, Nagel (1971), Davidson (1980), Dennett (1991, 1992), O'Brien and Opie (1998), and Rosenthal (2003) have all urged in one way or another that the mind's unity has been overstated. The point these people make is not just that the mind works mostly out of the sight and often out of the control of consciousness. Virtually everyone agrees on that and the point would in no way tell against there being a real unity of some kind in the part that does enter consciousness. Rather, they maintain that not even all conscious states are unified with other conscious states.

Note that the claim here is not just that we are conscious of less of the contents of our mind than we think, as Freud and the psychoanalytic tradition argue. The claim is that our consciousness of even many states of which we are conscious is not, or not fully, unified. That we act against what we clearly know to be our own most desired course of action or do things while telling ourselves that we must avoid doing them are advanced as reasons for holding the view but these are not obvious examples of lack of unity. A change blindness experiment might offer a more substantial example.

In this experiment, a subject sits in front of a computer screen wearing an eye tracker visor. There is a paragraph of text on the screen. The subject is asked to read the text. When subject's eyes are focused on a particular word or phrase, the bit of text is as it should be. However, everything around the word or phrase at fixation, everything above, below and on both sides, beyond about 5 degrees of arc is chaotic: gibberish, out of order words, shapes vaguely like words but obviously not words, and so on. Each time the subject's eyes shift to a new bit of text, it pops into correct form just before the eyes get to it and the word or phrase just left goes strange. What is remarkable about this experiment is that, while to observers all appears chaotic except for a succession of words or phrases—they are marching to a different saccadic drummer—the subject has no consciousness that anything in the paragraph is ever out of the ordinary. If the subject is one of those people who automatically reads any text in front of her, often she has no idea that the experiment has even started!

What this experiment shows, Dennett (1991: 361–362) thinks, is that we take only a tiny, central bit of the scene in front of us fully into unified consciousness. Yet subjects are conscious of the rest of the screen in some ways. They are aware of movement, for example. If so, this experiment would be an example of conscious states that are not fully taken up into unified consciousness. We would have unified consciousness of fewer of our conscious states than has been thought.

Note that the argument just examined is not an argument that unified consciousness does not exist. Even if we have conscious states that are not unified or fully unified in consciousness, the most that that could force us to do would be to shrink the range of states over which consciousness is unified or fully unified. From the fact that not all of one's conscious contents are unified, it does not follow that none is.

Indeed, those who hold that the extent to which consciousness is unified has been overstated owe us an account of *what* has been overstated. When theorists claim that a some conscious states are not in unified consciousness, we should ask: Not unified with what? One plausible answer would be: The unified conscious mind. Here is one way to view the matter. Once upon a time, some theorists held that all conscious states are unified and indeed that all mental states are conscious. As we saw, Brentano is an example. (We will return to this view in the next Section.) The main difference between this pre-twentieth century vision of unified consciousness as ranging over everything in the mind and view we just examined is that on the latter view, less of consciousness is unified than the earlier view held.

Dennett is interesting in this regard. As we saw, he can plausibly be read as rejecting the traditional picture of unified consciousness. Yet he can still invoke unity. He says, "What is it like to be an ant colony? Nothing, I submit … What is it like to be a brace of oxen? Nothing (even if it is like something to be a single ox)" (Dennett 2005). Why is the answer nothing? In such cases, "there is no functional unity …—no unity to distinguish an *I* from a *we*" (Dennett 2005).

To sum up the discussion of scepticism about unified consciousness so far, the argument that the unity of consciousness is real, indeed is a central feature of our kind of mind, seems to be strong.

3.2 Consciousness *Must* be Unified

That said, there are theorists who maintain not only that some conscious states in a subject are unified but that all conscious states *must* be unified. Bayne and Chalmers (2003: 24; Bayne 2010: ch. 1.4) call this the *unity thesis*: necessarily, any set of conscious states of a subject at a time is unified. As we saw, Brentano probably held this view. Hill (1991) does, too. Scepticism about this view would be weaker than either of the two kinds of scepticism about unified consciousness that we just examined.

Bayne and Chalmers express sympathy for the thesis on the grounds that,

It is difficult or impossible to imagine a subject having two phenomenal states simultaneously, without there being a conjoint phenomenology for both states. (2003: 37)

Merely *having* phenomenal states might seem too little but Bayne and Chalmers are talking about phenomenal states where, for them, to have the state is for the state to be like something. If we recast to make this element explicit, we get a claim of some real intuitive appeal: If *A* is like something to *S* and *B* is like something to *S*, it must be the case that the combination, *A* and *B*, is like something to *S*. Interestingly, Kant seems to have believed something similar: "[Experiences] can represent something to me only insofar as they belong with all others to one consciousness" (A116). *A* and *B* having conjoint phenomenology is exactly what unity consists in, according to Bayne and Chalmers. Put this way, the unity thesis has some real appeal.

Are there reasons to be sceptical of the unity thesis, presumptive counter-examples say? Spelled out as we have spelled it out, we do not know of any. Bayne and Chalmers consider brain bisection cases to be putative counter-examples because, on some concepts of the subject of experience, we can think of there still being one subject in these cases even though not all the conscious states are unified. There are at least three ways to respond. The simplest is just to deny that there is one subject, at least for the period of the split. A second would be to note that, however one counts subjects during the period of the split, there is evidence that many conscious experiences in that body are not like anything to some subject. If so, the apparent lack of *conjoint* consciousness of them will not be a problem. A third (advocated by Bayne & Chalmers 2003: 38–9; Bayne 2010: ch. 9) would be to urge that while there is clearly a breach in the unity of access consciousness (access to information for purposes of belief formation, behavioural control, and so on) during the period of the split, phenomenal unity may still extend across all the conscious experience. We will discuss the third response in more detail in Section 4.2 below.

The unity thesis is a very strong thesis. Theorists could hold both that consciousness is unified and that this unity is important and yet deny that the unity thesis is true.

4. Disorders of Unified Consciousness

One of the most interesting ways to study psychological phenomena is to see what happens when they take an abnormal form or break down. Phenomena that look simple and seamless when functioning smoothly often reveal all sorts of structure when they begin to malfunction. The unity of consciousness can be damaged and/or distorted in both naturally-occurring and experimental situations. What can we learn from these cases?

As a rough grouping tool, we will treat unified consciousness as breaking down in ways that fit a two-by-two matrix. The cases we will consider can be grouped according to whether unified consciousness appears to continue but in an unusual form, one instance of it splitting into two for example, and situations in which it appears to deteriorate more severely, to the point where it may even be said to have been destroyed. And we will find examples of both kinds that occur at a time and across time. Indeed, some of the disorders that we will examine are both at a time and across time.

At a time, situations of disorder in which unified consciousness is retained may take a number of forms. There are cases where consciousness seems to split within one brain and body. The much discussed commissurotomies (brain bisection operations) are the best known example. (Across time, the closest analogue may be dissociative identity disorder, about which more shortly.) There may be cases in which a single occurrence of unified consciousness spans two bodies; some have said this about some mirror twins. And there are cases in which the array of phenomena over which unified consciousness ranges becomes strangely circumscribed: hemi-neglect and anosognosia are two examples. (We will describe all these phenomena in more detail below.) What is interesting for our purposes is that in all these kinds of cases, those in which unified conscious seems to split, those (if any) in which it seems to span two bodies, and those in which its range seems to shrink, the unity itself seem to be intact. It has not been destroyed or even damaged. It is just housed in an unusual way.

The cases just introduced contrast with situations in which we have just one instance of consciousness of some kind ranging over the usual phenomena or some of them, but where the unity, to dramatize a bit, appears to have shattered, not split or expanded or shrunk. In these cases, the unity of consciousness is not just unusually housed. It has been seriously compromised.

4.1 Some Disorders

4.1.1 Brain Bisection Operations

No medical procedure to do with consciousness has received as much philosophical attention in recent times as commissurotomies, more commonly known as brain bisection operations. Nagel (1971) was perhaps the first philosopher to write on them; his paper continues to be influential. Since then, Puccetti (1973, 1981), Marks (1981), Hirsch (1991), Lockwood (1989), Hurley (1998), Bayne (2008, 2010), Schechter (2010) and many, many other philosophers have written on these operations. Indeed, the strange results of these operations in certain controlled conditions was one of the things that brought the unity of consciousness back onto the cognitive research agenda.

In these operations, the corpus callosum is cut. The corpus callosum is a large strand of about 200,000,000 neurons running from one hemisphere to the other. When present, it is the chief channel of communication between the hemispheres. These operations, done mainly in the 1960s but recently reintroduced in a somewhat modified form, are a last-ditch effort to control certain kinds of severe epilepsy by stopping the spread of seizures from one lobe of the cerebral cortex to the other. For details, see Sperry (1984), Zaidel et al. (1993), or Gazzaniga (2000).

In normal life, patients show little effect of the operation. In particular, their consciousness of their world and themselves appears to remain as unified as it was prior to the operation. How this can be has puzzled a lot of people (Hurley 1998). Even more interesting for our purposes, however, is that, under certain laboratory conditions, these patients seem to behave as though two 'centres of consciousness' have been created in them. The original unity seems to be gone and two centres of unified consciousness seem to have replaced it, each associated with one of the two cerebral hemispheres.

Here are a couple of examples of the kinds of behaviour that prompt that assessment. The human retina is split vertically in such a way that the left half of each retina is primarily hooked up to the left hemisphere of the brain and the right half of each retina is primarily hooked up to the right hemisphere of the brain. Now suppose that we flash the word TAXABLE on a screen in front of a brain bisected patient in such a way that the letters TAX hit the left side of the retina, the letters ABLE the right side, and we put measures in place to ensure that the information hitting each half of the retina goes only to one lobe and is not fed to the other. If such a patient is asked what word is being shown, the mouth, controlled usually by the left hemisphere, will say TAX while the hand controlled by the hemisphere that does not control the mouth (usually the left hand and the right hemisphere) will write ABLE. Or, if the hemisphere that controls a hand (usually the left hand) but not speech is asked to do arithmetic in a way that does not penetrate to the hemisphere that controls speech and the hands are shielded from the eyes, the mouth will insist that it is not doing arithmetic, has not even thought of arithmetic today, and so on—while the appropriate hand is busily doing arithmetic!

Recently, this standard assessment has been challenged. In his important 2010 book and other publications, Tim Bayne suggests that there are not two centres of consciousness. There is just one. What explains the appearance of duality is that this single centre of consciousness switches in the material of which it is consciousness from one hemisphere to the other. He calls this the switch model (2010: chs 8.4 and 9.5). To so much as get this approach off the ground, it is crucial that that there be little or no evidence of a centre of consciousness that is conscious of, say, *A*, *B*, and *C* but not *D*, *E*, and *F* and at the same time of a centre of consciousness that is conscious of *D*, *E*, and *F* but not *A*, *B*, *C*. What we just called the standard assessment starts from a belief that there is lots of such evidence. Bayne disagrees. We will return to Bayne's view in Section 4.2.

Because brain bisection operations have attracted so much attention outside of psychiatry and neurology, we have included references to some of the more important writings. We will not do so for the rest of the disorders we will introduce. For fuller accounts and references, consult a general textbook of psychiatry. Here we are interested in them only for the vicissitudes of unified consciousness that they display, or might be thought to display.

4.1.2 Mirror Twins

In addition to cases in which one body may have two centres of unified consciousness, there are cases in which one centre of unified consciousness may span two bodies. Mirror twins sometimes have such an appearance. Mirror twins are biologically identical twins where each body mirrors the other. They dress exactly the same, finish each other's sentences, do tasks together whenever possible (if an egg is being cooked, both right hands will hold the handle of the frying pan), and so on. Brain bisection cases are putative examples of the number of centres of consciousness not lining up with the number of brains and bodies from one direction. Mirror twins might be an example from the opposite direction. In connection with unified consciousness, this possibility is interesting.

The best-known case is the case of Greta and Freda Chaplin, who came to light in the U.K. in the 1970s. Two bodies were involved but the bodies acted in ways that would have been compatible, at least, with a single instance of unified consciousness spanning them. Each body could finish complicated and unpredictable sentences started by the other. The two did everything they could together. When separated by more than a few metres, they complained bitterly, each body reporting that it felt like a part of itself was being ripped out. And so on. No professional discussion of the case has been found, unfortunately, but it was widely reported in the press at the time, for example in *Time*, Apr. 6, 1981.

4.1.3 Hemi-neglect and Anosognosia

In hemi-neglect, one loses all sense of one side of one's body or sometimes one half (divided vertically) of everything spatial in one's experience. Whatever is going on in hemi-neglect, unified consciousness seems to remain. It is just that its 'range' has been bizarrely circumscribed. It encompasses an experience of only half the body or half of objects seen, not of the whole body or whole objects. Where we expect perception and proprioception of the whole body and whole objects, these patients perceive and propriocept only one-half of the body and/or objects in general. So hemi-neglect is another phenomenon in which there may be a major change in the phenomena over which unified consciousness without unified consciousness itself being degraded.

Another phenomena in which unified consciousness seems to remain but with a bizarrely circumscribed range is anosognosia. In this condition, a person who has suffered loss of function (often as a result of a stroke) is unaware of the deficits (Gennaro 2015a). Thus, a person now blind will insist that she can see—and will stumble about in a room bumping into things. A person whose limbs are now paralysed will insist that his limbs are moving—and will become furious when family and caregivers say that they are not. And so on.

4.1.4 Dissociative Identity Disorder

Another candidate phenomenon is what used to be called Multiple Personality Disorder, now, more neutrally, Dissociative Identity Disorder (DID). Everything about this phenomenon is controversial, including whether there is any real multiplicity *of consciousness* at all (Hacking 1995; Dennett 1998a). DID can take two forms. The more common form is often described as the units (persons, personalities, sides of a single personality, or whatever one decides to call them) 'taking turns', usually with pronounced changes in personality. When one is active, the other(s) usually is(are) not. Here the most prominent symptom is usually strange memory gaps (amnesias) in each 'unit' for periods when the body in question was clearly conscious and active. In the other, less common form, both 'units' are present at the same time. Here, for example, the unit in control of speech will report that another 'person' inside her is, say, giving her orders, these orders being experienced not from the standpoint of giving them but as coming from another person. This form of DID is called the co-conscious form in the literature but the term names something very different here from what James, Parfit and the like had in mind when they used the term. Among other things, me and the 'little person inside me' are not unified in one consciousness. In fact, sometimes the dissociation in both forms of DID is behaviourally as complete as it is in brain bisection patients in the lab.

4.1.5 Schizophrenia

In some particularly severe forms of schizophrenia, the victim seems to lose the ability to have an integrated, interrelated experience of his or her world and self altogether. The person speaks in 'word salads' that never get anywhere, indeed sometimes never become complete sentences. The person is unable to put together perceptions, beliefs and motives into even simple plans of action or act on such plans if formed, even plans to obtain sustenance, tend to bodily needs, escape painful irritants, and so on. Here, it is plausible to suggest that the unity of consciousness has shattered rather than split. The behaviour of these people seems to express what we might call mere experience-fragments, the contents of which are so narrow and unintegrated that the subject is unable to cope with daily life and interact with others in the ways that, for example, split brain subjects can.

4.1.6 Dysexecutive Syndrome

In schizophrenia of the severe sort just described, the shattering of consciousness is part of a general breakdown or deformation of mental functioning: affect, desire, belief, even memory all suffer massive distortions. In another kind of case, the normal unity of consciousness seems to be just as absent but there does not seem to be the same sort of general cognitive or affective disturbance. This is true of what some researchers call dysexecutive syndrome (Dawson, 1998: 215, for example). What indicates breakdown in the unity of consciousness is that these subjects are unable to consider two things together, even things directly related to one another. For example, such people cannot figure out whether a piece of a puzzle fits into a certain place even when the piece and the puzzle are both clearly visible and the piece obviously fits. They cannot crack an egg into a pan. And so on.

Trevarthen (1984) reports a similar syndrome in a few patients. In the cases he reports, commissurotomy patients are conscious of some object seen in the right side of the visual field by the left hemisphere (controlled so that the information is received by only that hemisphere) until an intention is formed to reach for it with the left hand, controlled by the right hemisphere. Somehow the intention to reach for it seems to obliterate consciousness of it in the hemisphere that controls speech, presumably the left hemisphere. However, if the object is slid over to the left visual field, then the speech-controlling hemisphere reports that it can see the object again—even though the object can now be seen only by the right hemisphere and the left still controls speech!

4.1.7 Simultagnosia

A disorder presenting similar symptoms is simultagnosia or Balint's syndrome (Balint was an early 20th century German neurologist). In this disorder, patients see only one object located at one 'place' in the visual field at a time. Outside of a few degrees of arc in the visual field, these patients say they see nothing but an "undifferentiated mess" and seem to be receiving no information about objects (Hardcastle 1997: 62).

What is common to dysexecutive disorder, Trevarthen's cases, and simultagnosia is that subjects seem not to be conscious of even two objects in a single conscious state. They cannot, for example, compare the objects (in Trevarthen's cases, the object of a perception with the object of an intention). Unlike commissurotomy cases, it is not the case that a conscious experience of the second item exists within another unified consciousness. If there is any experience of the second item at all, it is not conscious. Rather than consciousness being split into two discrete parcels, there is just one diminished parcel. The rest of the conscious experiencing that is typical of normal consciousness has disappeared.

There are of course many different theories about what is going on in the conditions we have just sketched, severe schizophrenia, dysexecutive syndrome, simultagnosia/Balint's syndrome. Some hold that the deficits are not in unified consciousness at all; they are in the capacity to process perceptual information. On this view, consciousness remains unified but patients can no longer can take in what is happening. Here we will explore only the idea that the problem is with unified consciousness. If it is even possible that this is where the problem is, we can learn interesting things about the unify of consciousness.

Many of the disorders that we have considered are fairly directly a result of changes to the brain. Cognitive neuroscience is the study of the relationship between the two. The best-known objects of such study in connection with unified consciousness are brain bisection operations (commissurotomies). Other neuroscientific studies relevant to unified consciousness have examined blindsight (Weiskrantz 1986), blindsight with visual agnosia (van Gulick 1994), hallucinations and thought insertion (Stephens & Graham 2000), and archaic hand syndrome and delusions of control in schizophrenia (Mylopoulos 2015).

4.2 Do the Conditions have a Common Structure?

Can a single structure account for what is going on in all these phenomena? The Kantian taxonomy of forms of unified consciousness considered in Section 2.2 can give us a way into this issue.

As we said earlier, one natural way to think of the conditions just sketched is to break them into two groups. In one group, however drastic the change in unified consciousness, unified consciousness remains in a largely complete form. Arguably, this group would include brain bisection cases, hemi-neglect, anosognosia, and DID. In the second group, schizophrenia of the severe kind we sketched, dysexecutive disorder, and simultagnosia, it is more natural to think that unified consciousness has been damaged or even destroyed.

Brain bisection cases first. On the standard way of conceptualizing these cases, the key evidence for a duality of some kind is that there appear to be situations in which whatever is conscious of some items being experienced in the body in question is not conscious of other items being experienced in that same body at the same time. We looked at two examples of the phenomenon in Section 4.1, the word TAXABLE and the doing of arithmetic. With respect to these experienced items, there is a significant and systematically extendable situation in which to be conscious of some of these items is *not* to be conscious of others of them in a single unified consciousness where we would expect such consciousness. If so, brain bisection patients fail to meet the conditions for unified consciousness of contents. This seems to be what motivates the judgment that these patients have two centres of consciousness.

Let us describe the case a bit more precisely. On the standard account, a brain bisection patient could be conscious that both TAX and ABLE are being seen. But nothing in the patient would be conscious that both items are being seen *on the basis of seeing them*. For at least one of the two items, one of the two centres of consciousness could have only the same kind of behavioural and other 'outside' evidence that any observer of the situation could have.

Indeed, the apparent split runs still deeper. Between the two hemispheres there seems to be a split in unified consciousness of *experiencing*, too: Consciousness of doing some experiencing goes with lack of consciousness of doing other experiencing that is going on in the same body. To use a useful metaphor first coined, so far as we know, by Shoemaker, something is not conscious of acts of experiencing going on in its body 'from the inside', i.e., on the basis of doing them, while something else *is* conscious of them on this basis. There seems to be a split in unified consciousness of *self*, too: Consciousness of oneself as subject on the basis of doing acts of experiencing in that body goes with lack of consciousness of oneself as subject on the basis of other acts of experiencing being done in that body. If so, for many conscious states in these patients, there two instances of joint consciousness (section 2.1.3), not the normal one.

To be sure, this assessment is not universally accepted. As we saw, Bayne and Chalmers (2003) and Bayne (2010: ch. 9) urge that while access unity is split in these patients, phenomenal unity need not be. Why not? Because there may be no duality of unified consciousness at any given time. Rather, a single instance of unified consciousness may be switching back and forth between the material in the two hemispheres. As Schechter (2012) has urged, evidence of a simultaneous duality of consciousness would be a major problem for this approach. We will not attempt to assess the relevant evidence here (see Brook 2015 for further discussion). Even if Bayne is right, that should not affect the prospects of a unified account of disorders of unified consciousness—what is going on in brain bisection cases would not be a disorder of unified consciousness!

Next, dissociative identity disorder (DID). (We will take up hemi-neglect and anosognosia shortly.) In cases of DID, a central feature is either some pattern of reciprocal amnesia or a strong sense that another is inside (and yet still separate). This again seems to be a situation in which being conscious of some experienced objects by having the experience goes with not being conscious of others in the same body in the same way. The main difference is that the breach seems to be at a time in brain bisection cases, but can be either across time or at a time in DID cases. If so, the breakdown in unity will again consist in breakdowns of joint consciousness. The amnesia in diachronic DID has this character, clearly (and, except for the amnesia, is in line with Bayne's (2010) switch model), but so does synchronic DID. The person and the 'little person inside' have no access from the inside to each other, so no common unified consciousness of experiencing, and the objects of their experience are not unified, so no common unified consciousness of contents.

Now the second group. For severe schizophrenia, dysexecutive syndrome, and simultagnosia/Balint's syndrome—the cases where consciousness seems to be more shattered than split—the distinction of Kant's that we introduced in Section 2.2 between two kinds of synthesis is useful. As we saw, Kant distinguishes between the synthesis that gives us consciousness of individual objects (Tye's object unity) and the synthesis that gives us consciousness of a number of objects at the same time.

This distinction seems to shed some interesting light on the three phenomena. The evidence suggests that the first kind of synthesis continues to be available to dysexecutive and simultagnosia patients: they continue to be conscious of individual objects, events, etc. The damage seems to be with respect to the second kind, being conscious of multiple objects in a single act of consciousness. These people seem to achieve some measure of unified focal attention with respect to individual objects but unified consciousness of multiple objects is either restricted or missing.

With the severe forms of schizophrenia that we sketched, patients may lack even the ability to perform the first kind of synthesis. In a different jargon, these people may lack even the capacity for object constancy.

On this analysis, hemi-neglect and anosognosia are a bit different from the other conditions. Here there is no apparent breach of joint consciousness. *Neither a split nor a breakdown* in unified consciousness is evident. Rather, in both conditions, there appears to be a shrinking of the array of phenomena over which otherwise intact joint consciousness can range. Half of one's body and/or half of all perceived objects are excluded in the first condition, the actual situation with respect to sight, limbs, etc., in the second.

To sum up, it appears that there is some prospect of placing all the conditions we have considered within a single structure of (Kantian) distinctions, first between unified consciousness of contents and unified consciousness of experiencing, then between conscious experience of individual objects and unified conscious experience of multiple objects. Thought insertion might pose a problem for this scheme. Patients experience thought insertion when they believe that some of their thoughts, experiences, emotions, and so on are not their own and have been 'inserted' into them from without. People suffering it are still aware of the 'alien' thoughts from the point of view of having them. The deficit is in something to do with thinking of these thoughts as unified with the rest of conscious life. Normally, we think of ourselves as the subject and agent of all our experiences. In thought insertion, the victim does not appear to himself to be either subject or agent of some of the experiences of which he is in fact the subject and agent (Mylopoulos 2015).

5. Unity Across Time

Unified consciousness at a given time (synchronic unity) has mainly been our topic so far. We now turn, more briefly, to unified consciousness over time (diachronic unity). As was noted as long ago as Kant, unity across time is required even for such rudimentary mental operations as counting (1781: A103); indeed, unity across time is crucial for virtually all cognition of any complexity. Now, unification *in consciousness* might not be the only way to unite earlier cognitive states (earlier thoughts, earlier experiences) with current ones but it is certainly a central way and the one best known to us.

5.1 Retention and Memory

In its synchronic form, we have suggested that a natural way to think of unified consciousness is in terms of joint consciousness. Diachronically, unified consciousness has an additional feature; it requires retention over time, specifically, retention of earlier experienced contents as one experienced them. What the retention crucial to diachronic unity consists in is a matter of some interest. It is tempting to assume that it is a kind of memory. However, as Husserl already told us, there is reason to be sceptical of this approach. There is a difference between *experiencing* a succession from time 1 to time 2 and merely *remembering* experiencing what happened at time 1 while experiencing something at time 2. Dainton captures Husserl's point by noting the difference between "immediate and represented experience—remembering or imagining hearing a tone is not the same as directly experiencing the tone" (Dainton 2005: 155; Dainton cites Husserl 1928).

Kelly (2005) raises a similar question. Suppose that one is listening to a melody. It has five notes and the final note is just being played. If one simply recollected the earlier notes, one should experience a chord, not five notes spread out and related to one another in time. Somehow, the earlier notes come 'date-stamped' but still available to be integrated with the current experience in a single, temporally-extended, unified experience. Whatever this process is like, it is clearly vital to our kind of unified consciousness. Without it, one could not hear any sequence as a sequence or so much as read a simple sentence. Though some theorists call this across-time process unity of consciousness, a more distinctive name for it would be the *continuity of consciousness*.

This sort of continuity of consciousness can span very short durations (such as the 'specious present'). Even a seemingly simple, current experience is in fact a continuous experience of more than one instant, and must be if one is to hear a sound or *perceive* (as opposed to remember) any temporally stretched phenomenon. How can one have a unified conscious experience (not just a memory) of duration?

Here again the debate that we mentioned earlier over whether a unified conscious experience is one experience or an assembly of many experiences rears its head. Dainton (2005: chs. 5–7) takes a continuous, unified experience to include co-conscious experiences as parts. Tye (2003: ch. 4) urges instead that a diachronically unified experience has multiple contents but no experiences as parts.

5.2 Unity and Personal Identity

In the history of European philosophy at least since Locke, diachronic unified consciousness has been closely linked to personal identity in the philosopher's sense, i.e., continuing to be a single person, one and the same person, across time. (The point of the restriction to philosophy is that clinical psychologists use the term quite differently, as the name for certain aspects of personality and 'self-conception'.) Whatever may be true of the kind of diachronic unity we just discussed, the kind of diachronic unity associated with personal identity is clearly a kind of memory, specifically, a kind of autobiographical memory. At least since Locke, philosophers have argued that as far back as unified consciousness *via the right kind of autobiographical memory* extends, there extends the person, one and the same person over all this time. The right kind of autobiographical memory is memory of the having, feeling, or doing of earlier experiences, emotions, actions, and so on. As Locke has it, being the same person just is having the '*same consciousness*'. We must be careful here. There is lots of autobiographical memory that is not memory from the point of view of experiencing. A person can remember that so-and-so happened to her without remembering the event, the experience of it, or anything else 'from the inside', to use Shoemaker's useful metaphor again. Memory theorists' standard categories are not fine-grained enough for our purposes here.

Some important philosophers have urged that memory-carried diachronic unity is not sufficient for being one person over time. Kant, for example, argued for a dissociation here, in his famous critique of the third paralogism. In Kant's view, continuity sufficient to "retain the thought of the previous subject and so hand it over to the subsequent subject" (1781: A363), continuity sufficient therefore for diachronic unity of consciousness, is quite compatible with the 'retained thoughts' being passed from one subject to another, compatible therefore with an utter absence of personal identity. If so, diachronic unity is not sufficient for personal identity (Brook 1994: ch. 8). (Note: Locke and Kant may be less far apart than this brief discussion would suggest. We are merely using them to illustrate the two positions, not discussing either of them fully.)

Phenomena relevant to identity in things other than persons can be a matter of degree. This is well illustrated by the famous ship of Theseus. Suppose that over the years, a certain ship was rebuilt, board by board, until every bit of it has been replaced. Is the ship at the end of the process the ship that started the process? Now suppose that we take all those rotten, replaced boards and reassemble them into a ship. Is *this* ship the original ship? It seems that there is no determinate answer to these questions. Say what you like, and what you like may vary depending on whether you are an insurance adjuster or a history buff. Many philosophers have insisted that such indeterminacy can never be the case for persons. Identity in persons is always completely unambiguous, not something that could ever be a matter of degree (Bishop Joseph Butler [1736] is a well-known example).

Brain bisection cases (described in Section 4.1) in which, some urge, unified consciousness splits in two may be relevant here (Parfit 1971, 1984). As Parfit argues, the possibility of persons (or at any rate minds) splitting and re-fusing puts real pressure on intuitions about our specialness. Perhaps the continuity of persons can be just as tangled and just as much a matter of degree as the continuity of any other middle-sized object.

Two final comments. Nagel (1971) argues that there can be indeterminacy in synchronic unity, too (see Section 6). One can sympathize with Parfit about diachronic unity and yet have reservations about Nagel on synchronic unity. Likewise, one should distinguish the question of whether diachronic unity can be intransitive from the question discussed in Section 6 of whether synchronic unity can be intransitive.

6. Two Philosophical Questions

Philosophers have made some fairly exotic claims about brain bisection cases and related conditions. Here we will consider two of them.

6.1 No Whole Number of Centres of Consciousness

The first is a claim that in brain bisection patients, there is no whole number of persons. So far, we have talked as though in brain bisection we always end up with some clear number of instances of unified consciousness. Nagel (1971), one of the early philosophers to write about these cases, rejects that view. For him, there is no whole number of 'centres of consciousness' in brain bisection patients: there is too much unity (for example in life outside the laboratory and even in behaviour within) to say "two", yet too much separation in the specially contrived laboratory situations to say "one".

Not being happy with so counterintuitive a result, philosophers have responded. A response favoured by many is this. For any *precise* 'one or two?' question, there will be a precise answer. Behavioural control system? One. Groups of experienced objects unified in consciousness? Two. And so on. If so, while the one's and the two's wouldn't line up as tidily as they do most of the time in people who have not had this operation, it is not obvious that the mixed answers support Nagel's conclusion that there may be no whole number of centres of consciousness in these patients.

6.2 Partial Unity is Possible

The 'in some respects one, in some respects two' possibility at the centre of Nagel's analysis is related to a question about transitivity. Is it possible, for a given instance of experienced objects *p*, *q*, and *r*, for there to be unified consciousness of *p* and *q*, unified consciousness of *q* and *r*, but no unified consciousness of *p* and *r*? (The parallel in brain bisection cases? Call the 'centres of consciousness' in the two cerebral lobes *A* and *C*, the older unilateral brain below them *B*. Is it possible for a mental state in *A* to be unified in consciousness with one in *B*, one in *B* with one in *C*, and yet the state in *A* not to be unified with the state in *C*?)

Hurley (1998) examines this question in detail, as does Bayne (2010: ch. 9.4). Hurley comes at the question of transitivity by considering some results reported by Sergent (1990). Since Sergent's work has not been replicable, let us look instead at how the research by Trevarthen that we mentioned in Section 4.1.6 throws up the same issue. In this research, as we said, brain bisection patients under certain conditions are conscious of some object seen by, say, the right hemisphere until the left hand, which is controlled by the right hemisphere, reaches for it. Somehow the act of reaching for it seems to obliterate the consciousness of it. Very strange—how can something pop into and disappear from unified consciousness in this way? This question leads Hurley to the notion of *partial unity*. Could two centres of consciousness, *A* and *C*, though not unified in consciousness with one another, nonetheless both be unified with some third thing, in this case the volitional system *B* (the system of intentions, desires, etc.)? If so, 'being unified with' is not a transitive relationship—*A* could be unified with *B*, and *C* could be unified with *B*, without *A* being unified with *C*. This idea is puzzling enough. Even more puzzling is how activation of the system *B*, with which both *A* and *C* are unified, could result in the loss of consciousness in *A* and/or *C* of an object aimed at by *B*.

Hurley never pronounces on the possibility of partial unity. Instead, she argues that none of the cases suspected of displaying it really do. She accepts that intention can obliterate consciousness—but then distinguishes time periods (1998: 216). In Trevarthen's cases, for example, the situation with respect to unity is clear at any given moment—one either is or is not conscious of the object. The picture over time does not conform to our usual expectations for diachronic singularity or transitivity of unity—but that is simply an artefact of the cases, not a problem.

Hurley considers another class of cases, what she calls Marcel's (1994) cases. Here subjects are asked to report the appearance of some item in consciousness in three ways at the same time—say, by blinking, pushing a button, and saying, 'I see it'. Remarkably, in different trials each of these three acts are done without doing the other two. And the question is, What does this imply for unified consciousness? In a case in which the subject pushes the button but neither blinks nor says anything, for example, is the hand-controller aware of the object while the blink-controller and the speech-controller are not? How could the conscious system become fragmented in such a way?

Hurley's suggestion? They can't. What induces the appearance of incoherence about unity is the short time scale. Suppose that it takes some time to achieve unified consciousness, perhaps because some complex feedback processes are involved. If so, then Marcel's cases have not got to a stable situation with respect to unity. The subjects were not given enough time (1998: 216).

Is partial unity possible? To date, this remains an unanswered question, though Bayne (2010: 209) leans towards a negative answer.

Hurley discusses more aspects of the unity of consciousness than partial unity. She argues, for example, that there is a normative dimension to unified consciousness—conscious states have to cohere semantically for unified consciousness to result (we will return to this issue in Section 7.3). She discusses most of the kinds of breakdown phenomena that we considered earlier, exploring the implications of a wide range of 'experiments of nature' and laboratory experiments for the presence or absence of unified consciousness. In particular, she considers acallosal people (people born without a corpus callosum). Even though the corpus callosum, when present, is the chief channel of communication between the hemispheres, acallosal people show all the behavioural signs of having fully unified consciousness. If so, then the neurological and behavioural basis of unified consciousness would be very different in different people. (We will return to this last topic in Section 8.)

7. Theories of Unity

In the literature, there is quite a range of theoretical claims about unified consciousness. We have looked at some of them. The first group concerned diverging models: the subsumption, co-consciousness, single phenomenal content, and joint consciousness models and related taxonomies. Then we looked at the unity thesis, claims about limits to and disorders of unified consciousness, claims about unity over time, and claims that there need not be a whole number of centres of consciousness and that partial unity is possible. In Section 2, we said that we'd return to the issue of whether unified experiences has or does not have experiential parts (EP vs. NEP), the issue that underlays subsumption. EP and NEP are the topics of Sections 7.1 and 7.2. Near the end of Section 4, we said that we would return to the claim that unified consciousness requires links among conscious contents. We will take up this issues in Section 7.3. Finally for this Section, we will examine a claim that we have not discussed so far, what is usually called the co-ownership thesis (Section 7.4)

7.1 The Experiential Parts Theory

How is unified conscious experience structured? As we mentioned in Section 2.1, two incompatible models have some currency at the moment. On the experiential parts view (EP), unified conscious experience includes simpler experiences as parts or something like parts; unified consciousness has a mereological aspect. On this view, when I have a unified experience of a pain and a noise, this unified experience includes an experience of just the pain, and an experience of just the noise. These simpler experiences are the relata of unified consciousness; they are joined as parts of the unified experience of the pain and noise together. Experiences *a* and *b* are united in a third experience, *c*, which is their joint occurrence. On the no experiential parts (NEP) account, the conscious mental act through which diverse contents are presented does not have other conscious states, experiences, as parts. On the first view, when I have unified consciousness of experiencing, I am conscious of many experiences. On the second view, I am conscious of just one experience.

To clarify the two, let us use the notation '$E(o^1)$' for an experience that is the conscious experience of just the intentional object o^1. A conscious experience of just o^2 is $E(o^2)$. What is the nature of an experience that takes the bigger content in which o^1 and o^2 are presented together? On NEP, it has the structure of $E(o^1,o^2)$, where this introduces a single experience that has both contents as its object. To be conscious of o^1 by means of this experience is to be conscious of it *with* o^2. (See the concept of joint consciousness introduced in Section 2.1.3.) According to NEP, this is what the subject's conscious unity at the time amounts to (if we oversimplify by supposing her to be conscious of nothing but o^1 and o^2). No 'smaller' or simpler conscious states figure as parts. This experience might be realized in a brain state that has parts, but these parts are not further conscious states. By contrast, in EP $E(o^1)$ and $E(o^2)$ persist as parts of an encompassing experience by means of which one is conscious of o^1 and o^2 together and unified consciousness would have the structure $E(E(o^1)E(o^2))$.
Proponents of EP include Lockwood, Dainton, Shoemaker, and Bayne and Chalmers, and Bayne by himself (in his 2010 book). As we saw in Section 2.2, theorists as otherwise different as Dainton, Lockwood, and Shoemaker use the term 'co-consciousness' as the name for the relationship that ties the experiential parts together. Not only are most versions of EP built on some notion of co-consciousness; most notions of co-consciousness assume EP and are incompatible with NEP.

EP faces a difficulty. James describes the problem in his example of the twelve-word sentence. Suppose each word in the sentence is known by just one of twelve people. It is hard to see, James says, how these twelve thoughts could be combined to yield a unified consciousness of the sentence. As he says,

Take a sentence of a dozen words, take twelve men, and to each one word. Then stand the men in a row or jam them in a bunch, and let each think of his word as intently as he will; nowhere will there be a consciousness of the whole sentence. (James 1890: 160)

What EP needs is a way of combining experiences that does not simply conjoin them into an experiential aggregate, for a mere combination of experiences is not the experience of a combination. EP needs, then, a way of putting together experiences that also puts together their contents. Without any specification of how this combining of contents is to be achieved, we are left with a mere aggregate of experiences, each member of which is oblivious to the contents of the other states in the aggregate. As James puts it, "Idea of *a* + idea of *b* is not identical with idea of $(a+b)$" (1890: 161).

Proponents of EP may reply that they never intended to give an *account* of conscious unity. Instead, EP should be taken to provide a *description* of the structure of unified conscious states. In other words, it is a characterization, not an explanation, of such states and how they are individuated. It may be held that the only good way to individuate conscious states is on the basis of contents. Hence, since one is aware of many contents via a conscious state, that state must itself consist of several simpler conscious states that have (somehow) come to be unified. At the very least, then, those who advocate NEP owe us an alternative basis for individuating conscious states. We will return to this issue in the next section.

As we saw, the notion of a unified experience subsuming simpler experiences is central to Bayne's and Chalmers' (2003; see Bayne 2010) account of the unity of consciousness. This may appear to be a version of EP and Tye treats it so (without using that label; 2003: 21). However, Bayne and Chalmers hedge their bet. While they do speak of the encompassing conscious state as involving "at least a conjunction of each of many more specific conscious states" (2003: 27), and of a "complex phenomenal state and a simpler state that is intuitively one of its 'components'" (2003: 40), they also caution that thinking here in terms of "a mereological part/whole relation among phenomenal states" should be regarded only as an "aid to intuition rather than as a serious ontological proposal" (2003: 40). So how their view stacks up with respect to EP is not entirely clear.

7.2 The No Experiential Parts Theory

Searle and Tye are leading current advocates of NEP. Searle ([2000] 2002: 56) ventures that "maybe it is wrong to think of consciousness as made up of parts at all". For one has a "single, unified, conscious field containing visual, auditory, and other aspects" and "there is no such thing as a separate visual consciousness" ([2000] 2002: 55). Do "visual experiences stand to the whole field of consciousness in the part-whole relation?" ([2000] 2002: 54). No, says Searle (though he may do some backsliding later in the article).

Tye offers a similar view, which he dubs the 'one-experience view' (Tye 2003: ch. 1). Considering the polymodal nature of our experience, he says, "There are not five different … experiences somehow combined together to produce a new unified experience". Instead, "there is just one experience here" (2003: 27).

Part of what is at stake in this dispute is how to individuate (how to count) experiences. EP theorists think that experiences go one to an object: if you experience two things, you have two experiences. Or even finer: if you experience one thing in two ways, you have had two experiences. NEP theorists hold that some experiences can be individuated differently; a unified act of conscious experiencing is a single experience, experientially non-composite, no matter how many objects it has.

So what are the arguments for the two views like? Theorists who accept EP usually just assert or even assume it (we saw some examples of this in Section 7.1). The idea just seems intuitively plausible to its adherents and they tend not to argue for it. NEP is not intuitively obvious—even people such as Searle who advocate it can find themselves sliding into EP—and its adherents do argue for it.

James was the first champion of NEP. He endorsed it in the course of repudiating the 'mind-stuff theory', according to which "our mental states are composite in structure, made up of smaller states conjoined" (1890: 145). Against this James says that, while our experience is complex, this complexity is not a matter of there being several *experiences* (or 'feelings') present in an encompassing experience. This is because "we cannot mix feelings as such, though we may mix the objects we feel, and from *their* mixture get new feelings" (1890: 157). If one's experience appears to become more complex, that is a matter of *a single experience's content* being more complex, and is not the addition of *more experiences* (of the diverse contents). Indeed, he says, "We cannot even … have two feelings in mind at once" (1890: 157).

Here is how this is supposed to work. If we say that experiences *a* and *b* are fused to form experience *c*, we should treat 'fused' as referring to a process in which *a* and *b* are superseded by *c*, not included in it. *A* and *b* have been replaced by *c*, in which their contents are connected, and they (*a* and *b*) no longer exist. As James put it, contrasting the unified consciousness of the whole alphabet with the several states involved in consciousness of each letter taken singly,

It is safer … to treat the consciousness of the alphabet as a twenty-seventh fact, *the substitute and not the sum* of the twenty-six simpler consciousnesses. (1909: 189)

This view clearly avoids the problem of how to combine experiences that faces EP.

Since James had a concept of co-consciousness and we have linked co-consciousness closely to EP, we should say a word about his concept. It is not the same as the concept that we find in Parfit, Lockwood, Hurley, Shoemaker et al. For James, co-consciousness relates only to a multiplicity of items of which one is conscious. In unified conscious experience of them, there is no multiplicity of conscious states to enter into a 'co'-relationship. Indeed, the contents are made co-conscious by being presented together in a single, noncomposite experience.

We will close this discussion with two notes about the relationship of the dispute between EP and NEP to the transparency thesis that we discussed earlier. This is the thesis that we are not directly conscious of our own experiences. ('Transparent' here means that while I am conscious *via* conscious states, I am not conscious *of* them. I 'see through' them, as it were; hence 'transparency'.) First, all claims for both EP and NEP that we have considered would seem to go through even if the transparency thesis were true. So transparency would not undermine this debate. Secondly, even Tye (2003), who accepts both NEP and transparency, also accepts that NEP does not *require or entail* transparency. Rather, he seems to think that the transparency thesis is true and, since it is true, this constrains what could be unified in phenomenal unit. Accepting the constraint, he has to say that, "Phenomenal unity is a relation between qualities *represented* in experience, not between qualities *of* experiences" (Tye 2003: 36), however unintuitive this claim may be. Certainly there are approaches that can both accept NEP and reject transparency. That is true, for example, of those who hold that conscious states are self-representing states, states of which one becomes conscious just by having them. These theorists will hold that one *can* be directly conscious of one's own conscious states, yet they could still hold that states of unified consciousness have an NEP structure.

7.3 The Internal Links Theory

Now we turn to the idea that unified consciousness of contents and experiencing requires some kind of phenomenally evident relation among the contents of the unified conscious state (in addition to the contents being aspects of a single unified act of consciousness) and some attempts to model this relationship. We might call this the *relational model* of unified consciousness. It is a descendant of Kant's claim examined in Section 1 that unified consciousness requires conceptual interconnectedness in the objects of consciousness; as he put it,

all appearances stand in a thoroughgoing connection according to necessary laws, and hence stand in a *transcendental affinity* of which the empirical affinity is the mere consequence. (1781/1787: A113–114)

Kant's argument for this claim seems to have been that synthesis of represented objects to produce a single complex object is a necessary condition of consciousness of self as single common subject. Without represented objects being tied together in a single complex object, one might be aware of the subject of an individual representation but one could not be aware of the subject of one such representation as the subject of other such representations. Rather, I should have "as many-coloured and diverse a self as I have representations of which I am conscious ..". (B134)—as are in fact had by me, for I would not, of course, be aware that it was me.

One recent expression of the idea is Hurley's (1998) claim that conscious states must satisfy a normative requirement if unified consciousness is to result. Specifically, they must 'cohere semantically'. (It is not entirely clear that satisfying this normative requirement requires that the contents of consciousness be linked in the way that Kant urged.) Even more recently, Revonsuo (2003) has urged that phenomenal contents must be situated in the same 'phenomenal space' in order to be unified, adding, "I am inclined to treat phenomeno-spatiality as the basic unifying feature of human consciousness".

For theorists of this persuasion, these phenomenally evident spatial, causal, etc., relations among contents explain why my perceptual states typically present one coherent world in which, for instance, a wall in front of me and starting at one end of my visual field will continue across that field. Are such connections among the contents of an experience *necessary* for their being presented together in experience? Some recent theorists have argued that they are not (Bayne 2004; Brook 2005). One can have unified consciousness of a siren that that one is hearing, an average grade that one is calculating, and a fictitious landscape that one is visualizing. In what possible way could items as diverse as these have to be connected to one another? They are not even all in space or contiguous to one another and they are certainly not causally interconnected, yet I can experience all three in a single act of unified consciousness.

Doesn't there have to be at least logical coherence among the contents? As we just saw, Hurley (1998) makes this claim, as does Baars (1988). Hurley, for example, argues that we cannot believe mutually inconsistent things when we are conscious of both in a single unified experience. Could the disconnect among unified conscious states extend to them actually being inconsistent with one another? Contrary to Hurley and Baars, the evidence suggests that it could. Suppose that one sees a stick immersed in water as being bent but feels it to be straight or knows that this is an illusion. Here, one's conscious perception that it is bent conflicts with one's conscious belief that it is not bent, yet these states are unified in one consciousness (Bayne 2000). Tye (2003: 38) does not consider this illusion to be an example of incoherence. He holds that here touch corrects vision, making the stick appear to be straight, and so belief renders the appearance mere appearance. That claim is controversial. Bayne (2004: 227) discusses another example, inverting spectacles, more plausibly. These glasses render one's visual contents inconsistent with one's tactile contents, yet consciousness of the visual contents remains unified with consciousness of the tactile contents.

In fact, it would seem that there can be incompatibilities even within a perceptual modality. Thus, Tye (2003: 38–39) notes that there are pictures that depict impossible situations. He also discusses the waterfall effect, in which, after staring at a waterfall for some time, if one looks at the adjacent rock face, a portion of the rock surface will appear to be moving—and not moving (relative to the area around it; not everyone accepts that both elements are simultaneously present in the waterfall illusion; see Crane 1988). These examples suggest that we can have unified consciousness of pretty much any collection of items whatsoever, no matter how they are related to one another. Indeed, it is not easy to specify any relation among unified contents or acts of experiencing (beyond their being unified) that is required for them to be unified. If so, Hurley's (1998) suggestion that meeting a normative requirement is necessary for unified consciousness, specifically, a requirement that the experienced properties of things in unified consciousness cohere semantically, is in trouble.

7.4 The Co-Ownership Theory

Finally, there is a model that holds that unity of conscious states consists in their ownership by a single subject, Bayne's (2004) co-ownership. Is co-ownership meant to be necessary, or sufficient, or both? The idea that unified conscious experience must be had by a single subject could be trivially true, as it would be if the subject at a time is just defined as a set of unified contents. For the thesis to become interesting, advocates of it would have to offer a richer conception of the subject than that. On such a conception, the claim that experiences are had by the *same subject* would involve their attribution to the same extra-phenomenal substrate or bearer of experiences, one that can be individuated independently of what is to be found in experience, and thus independently of the notion of a unified field of conscious contents. Stated thus, the thesis would not be trivial and may well state a necessary condition of unified consciousness.

However, if co-ownership is necessary, is it also sufficient? It seems that is is possible for items that are *not* unified with one another to be simultaneously presented to one and the same subject. This seems to happen, for example, in split brain cases, or fictional variations thereof—e.g., Parfit's example of a single subject who is able simultaneously to try out two alternative approaches to solving a math problem (1984: 246–248). This state of affairs would seem to be a case of parallel but *nonunified* sets of conscious states had by the *same subject*, in some good sense of the term 'same subject'. The same would seem to hold of the contents of a subject who switches back and forth between lobes who lacked memory of earlier contents. If so, co-ownership would appear not be sufficient for unity. *A fortiori*, co-ownership would appear not to capture what is *distinctive* about unified consciousness. Put differently, if there is a requirement here of any kind, more than co-ownership seems to be needed. The subject must have a certain kind of relationship to the material. As Kant put it, the material must be something to the subject (A116)—and this requires a subject to whom things can be something. Mere ownership by itself would appear to fall short (Brook 1994: 135–9, discusses these issues in connection with Kant).

Thought insertion may pose another problem for the co-ownership thesis. In thought insertion, the alien states are unquestionably co-owned with the avowed ones but there seems to be less than full unity of consciousness.

In Section 5.2, we examined Kant's claim that instances of diachronic unified consciousness are able to extend beyond one person (by any criterion for being one person other than unified consciousness). If so, diachronic unity is not sufficient for singleness of person. On the standard account, brain bisection cases suggest roughly the reverse claim about synchronic unity; where there seem to be two instances of unity in one body, by many criteria there is just one person (remember, there is no question about singleness of person outside the laboratory). If so, singleness of person is not sufficient for synchronic unity.

8. Neural Architecture of Unified Consciousness

We will conclude this article with a brief look at some philosophical speculations about what the neural architecture of unified consciousness might or must be like. One of the hottest issues in current consciousness research is the issue of how brains achieve consciousness and what parts of the brain are most involved in doing do, what the 'neural correlates of consciousness' (NCC) are. Any real insights into the NCCs of consciousness in general are also likely to contain insights into the NCCs of unified consciousness. This literature is now so vast that it would take a whole additional article to discuss the topic. (Koch 2004 is an excellent review of the empirical neuroscience and Chalmers 2000 is the most extensive exploration of the conceptual issues to date.) Because of space limitations, here we will restrict ourselves to three of the most influential philosophical approaches to what the neural architecture of consciousness might be like, those of Paul and Patricia Churchland (see for example Paul Churchland 1995: 214), Daniel Dennett (1991), and Susan Hurley (1998).

The Churchlands' view flows from a radical picture of neural architecture in general. They urge that the architecture of the processes underlying cognition and consciousness consists not of transformations of symbolically encoded representations, as most philosophers have believed, but of something like vector transformations in phase spaces. Thus on their view, neural correlates of unified consciousness are nothing remotely symbol- or sentence-like.

Dennett articulates an even more radical view, on both unity and the architecture of it. For him, unified consciousness of 'self' is simply a short-lasting 'virtual captain' coming to be as a result of a small group of information-parcels gaining temporary dominance in a struggle with other such groups for control of such cognitive activities as self-monitoring and self-reporting. We take these transient phenomena to be more than they are because each of them is the 'me' of the moment and they are tied to earlier transient selves by the special form of autobiographical memory identified earlier. If the temporary coalition of conscious states that is winning at the moment is what I am, is the self, each temporal chunk of 'self' is likely to be found in different parts of the brain from other such chunks and there will be many NCCs of unified consciousness in many different places.

If Dennett is right, there would be reason for scepticism about what Hurley calls the *isomorphism hypothesis*. The isomorphism hypothesis is the idea that a given kind of change in consciousness will always reflect, even be the result of, a given kind of change in the brain. Hurley is sceptical about it, too. One way in which skepticism about this hypothesis arises in her work is via consideration of acallosals (people born without a corpus callosum). Even though the corpus callosum, when present, is the chief channel of communication between the hemispheres, acallosal people show all the behavioral signs of having fully unified consciousness. If so, it has to be achieved by mechanisms such as cuing activity that are utterly different from communication though a corpus callosum. And the same can be true the opposite way. Different changes in consciousness can go with the same changes to structure and function in the brain. And if both these claims are correct, then the neurological/behavioral basis of unified consciousness would be very different in different people. The isomorphism hypothesis would be false, attractive though it has been to many people.

Dennett's and the Churchlands' views fit naturally within a dynamic systems view of the neural implementation of cognition and consciousness, the view that unified consciousness is a result of certain self-organizing activities in the brain and interactions between brain and world. Dennett thinks that, given the nature of the brain, which is nothing more than neurons sending and receiving signals to and from other neurons, consciousness could not take any form other than something like a pandemonium of competing bits of content. The Churchlands don't agree with Dennett about this. They see consciousness as a state of the brain, the 'wetware', not a result of information processing, of 'software'. Both sides in this debate agree that it is unlikely that the processes that subserve unified consciousness are sentence-like or language-like.

9. Conclusions

A great deal of work has been done on the unity of consciousness in the past few decades. Our introduction to it has been grouped around the following themes:

- In some form, the unity of consciousness is a pervasive, cognitively important feature of our kind of mind.

- Even phenomenal unity of consciousness at a time comes in a number of forms and consciousness is also unified across time.
- The ways in which unified consciousness can break down raise interesting questions about the phenomenon and throw important light on its structure.
- The topic connects to a number of important issues concerning the relationship of consciousness to cognition, including whether unified consciousness across time plays a role in personal identity (the philosophers' concept of personal identity).
- All the leading theories of the unity of consciousness face problems.
- The state of theorizing on the topic suggests that there is still much room for further work.

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A Unified Theory of Consciousness Could Be on the Cusp

The world's top neuroscientists are assembling to crack the ultimate code of brain science.

- An EU team of neuroscientists asked their peers: "Can't we all just get along?"
- They analyzed how five major theories of consciousness overlap in both fundamentals and details.
- Ultimately, consciousness is not well understood at all—everyone could be right *and* wrong.

In newly published research, a full baseball team worth of neuroscientists from around Europe have combined their theories of the mechanics of **consciousness**. By breaking theories into pieces and comparing like with like, the scientists realized that certain kinds of experimentation can answer several questions at once across the different theories. Why reinvent the wheel, or better yet, reinvent the science grant-funded experiment? In the **journal *Neuron***, the group laid out their new, collaborative approach to brain science.

These researchers (hailing from universities in Netherlands, German, Italy, Estonia, and more) have come together from the Human Brain Project—a European Union-created committee of scientists from many disciplines who all collaborated towards the goal of accelerating research on the **human brain**. The project lasted from 2013 to 2023, so it's not surprising that two high-profile neuroscience papers have come from this larger group in the first half of 2024. The other is **a position paper** in the MIT journal *Imaging Neurosience* that was coauthored by dozens of scientists and supported by many more.

Even outsiders can see there are some workplace and industry politics rumbling below these two papers. Someone writing a **manifesto** or pushing a new model of collaboration is speaking against a status quo in some way. Indeed, while some areas of scientific research are more collaborative in a public way (like nuclear fusion research facilities around the world that trade top-tier scientists like ace pitchers), others (like many human sciences and national defense) become proprietary as companies, governments, and universities seek to patent their work.

"Historically, most researchers have emphasized the development and validation of their preferred theoretical framework in isolation," the researchers wrote. "[W]e show that many aspects of the various theories of consciousness do not necessarily contradict each other, as sometimes claimed; instead, **theories** often try to explain different aspects of consciousness and tend to converge on fundamental neuronal mechanisms and processes."

In other words, researchers are agreeing on many of their findings—at least, as far as physical observations inside the brain and its cells go. It's only in the subsequent steps, where **scientists** form theories to explain what they're seeing, that differences begin to seem insurmountable. To study this in more depth, this paper's authors chose five major working theories of consciousness. These cover three of the four suggested types of models **laid out by two influential neuroscientists**.

All five theories, according to the researchers, share two major underpinnings: recurrent processing and integration. There are also **nitty-gritty** qualities that subgroups share, like the main role of the brain's posterior cortex or the importance of localized feedback within the brain's microcircuitry. Overall, they say, there are some interesting convergences on each level of granularity. And that could be a key first step to building a unified theory of consciousness.

Perhaps more importantly, the researchers explained, the wide spread of theories "has even led to accusations of illegitimacy between competing theories"—something that could stop with more understanding. After all, there's still an enormous amount we don't know about consciousness or the physical **structures** of the brain.

At the end of the day (or century!), just one theory will prove to be entirely correct. When that happens, there will be a lot of excitement—and a lot of humble pie.

Is Consciousness the Unified Field ? A Field Theorist ' s Perspective

- Philosophy, Physics

Progress in theoretical physics during the past decade has led to a progressively more unified understanding of the laws of nature, culminating in the recent discovery of completely unified field theories. The parallel discovery of a unified field of consciousness raises fundamental questions concerning the relationship between the two. Following a general introduction to unified quantum field theories, we consider the proposal due to Maharishi Mahesh Yogi that the unified field of modern theoretical physics and the field of "pure consciousness" are identical. We show that the proposed identity between consciousness and the unified field is consistent with all known physical principles, but requires an expanded physical framework for the understanding of consciousness. Such a framework may indeed be required to account for experimentally observed field effects of consciousness and phenomenological aspects of higher states of consciousness.

Fourth major state of human consciousness

The **unified field of consciousness** is a **fourth major state of human consciousness**, distinct from waking, dreaming, and deep sleep[1]. It is considered the **most fundamental state of human awareness** and is sometimes referred to as "pure consciousness"[2].

A New Theory of Consciousness: The Mind Exists as a Field Connected to the Brain

Between quantum physics and neuroscience, a theory emerges of a mental field we each have, existing in another dimension and behaving in some ways like a black hole.

The relationship between the mind and the brain is a mystery that is central to how we understand our very existence as sentient beings. Some say the mind is strictly a function of the brain — consciousness is the product of firing neurons. But some strive to scientifically understand the existence of a mind independent of, or at least to some degree separate from, the brain.

The peer-reviewed scientific journal NeuroQuantology brings together neuroscience and quantum physics — an interface that some scientists have used to explore this fundamental relationship between mind and brain.

An article published in the September 2017 edition of NeuroQuantology reviews and expands upon the current theories of consciousness that arise from this meeting of neuroscience and quantum physics.

Dr. Dirk K.F. Meijer, a professor at the University of Groningen in the Netherlands, hypothesizes that consciousness resides in a field surrounding the brain. This field is in another dimension. It shares information with the brain through quantum entanglement, among other methods. And it has certain similarities with a black hole.

This field may be able to pick up information from the Earth's magnetic field, dark energy, and other sources. It then "transmits wave information into the brain tissue, that … is instrumental in high-speed conscious and subconscious information processing," Dirk wrote.

In other words, the "mind" is a field that exists around the brain; it picks up information from outside the brain and communicates it to the brain in an extremely fast process.

He described this field alternately as "a holographic structured field," a "receptive mental workspace," a "meta-cognitive domain," and the "global memory space of the individual."

> Extremely rapid functions of the brain suggest it processes information through a mechanism not yet revealed.

There's an unsolved mystery in neuroscience called the "binding problem." Different parts of the brain are responsible for different things: some parts work on processing color, some on processing sound, et cetera. But, it somehow all comes together as a unified perception, or consciousness.

Information comes together and interacts in the brain more quickly than can be explained by our current understanding of neural transmissions in the brain. It thus seems the mind is more than just neurons firing in the brain.

Neuroscientists are still searching for a mechanism for this "binding" of disparate parts of the brain's information processing. Meijer has turned to quantum entanglement and tunneling for part of the answer.

Quantum entanglement is a phenomenon in which particles appear to be connected over vast distances. When actions are performed on one of the particles, corresponding changes are observed on the others simultaneously.

Quantum tunneling is a phenomenon in which a particle tunnels through a barrier it shouldn't be able to according to classical physics.

These quantum phenomena allow for processes so rapid, they can't be explained with classical physics. So they may help explain ultra-fast subconscious mental processes.

Principles of quantum physics may explain how the mind processes information.

If the “mind” or mental field could interact with the brain this way, it could be a step toward explaining the rapidity of mental processes.

Meijer also uses the wave-particle nature of matter in quantum physics to explain the relationship between the mental field and the brain. Essentially this principle holds that electrons and photons exist in the form of waves, but can also behave like particles. In a manner of speaking, they are both waves and particles.

Similarly, Meijer said the mental field is both non-material and, at the same time, physically part of the brain: “The proposed mental workspace is regarded to be non-material, but in relation to the individual brain, entertains a non-dual wave/particle relation according to quantum physical principles: it is directly dependent on the brain physiology but not reducible to it."

The mind and the brain, according to Meijer, are connected. They are unified, yet separate. Such an apparent paradox is characteristic of quantum physics.

The mind may reside in another spatial dimension.

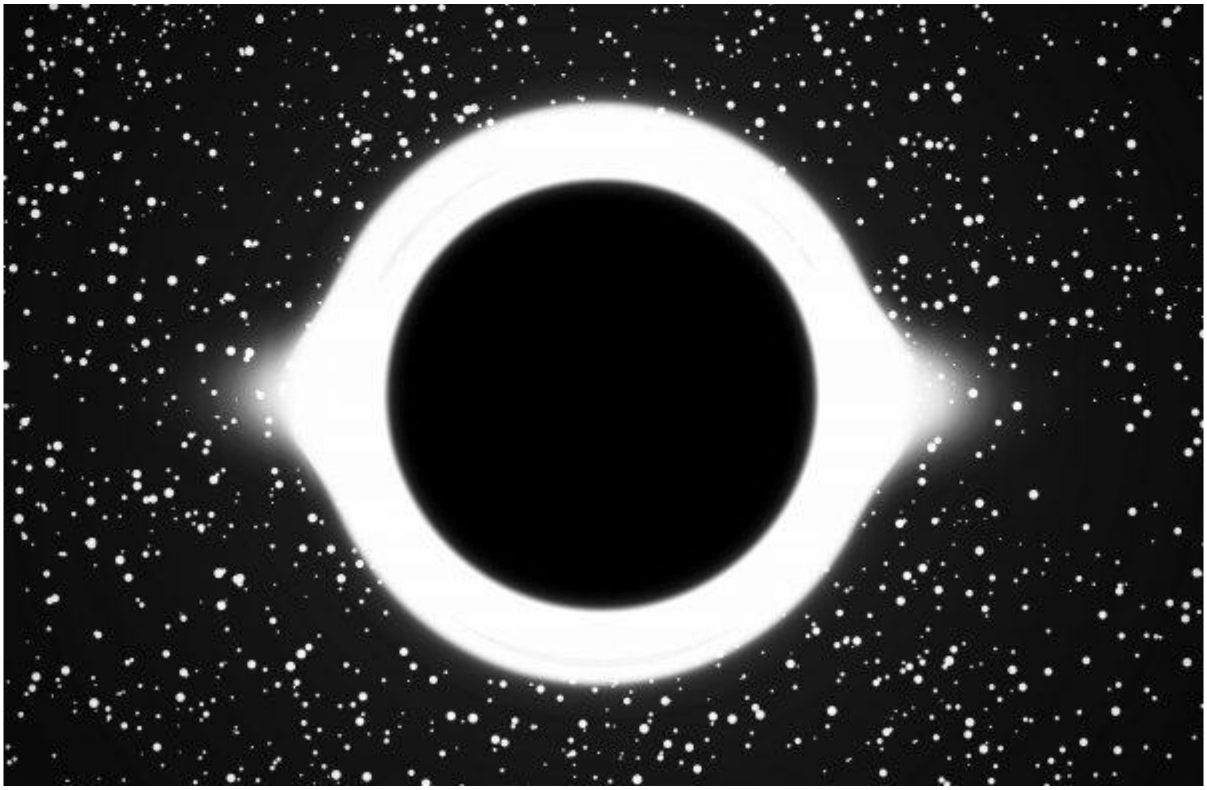
Meijer hypothesizes that the mental field is in another dimension: "That we cannot directly perceive this information aspect is traditionally ascribed to a hidden fourth spatial dimension … which cannot be observed in our 3-D world, but can be mathematically derived."

He clarified that this fourth spatial dimension is not time (time is commonly described as the "fourth dimension"). Rather, this is a concept of space-time that includes four spatial dimensions, plus time (a "4+1 space-time structure").

He cited studies that have suggested this concept of dimensions could reconcile the miss-matches between traditional physics and quantum physics that plague scientists today.

The mind would exist in the fourth spatial dimension.

The mind could be like a black hole.



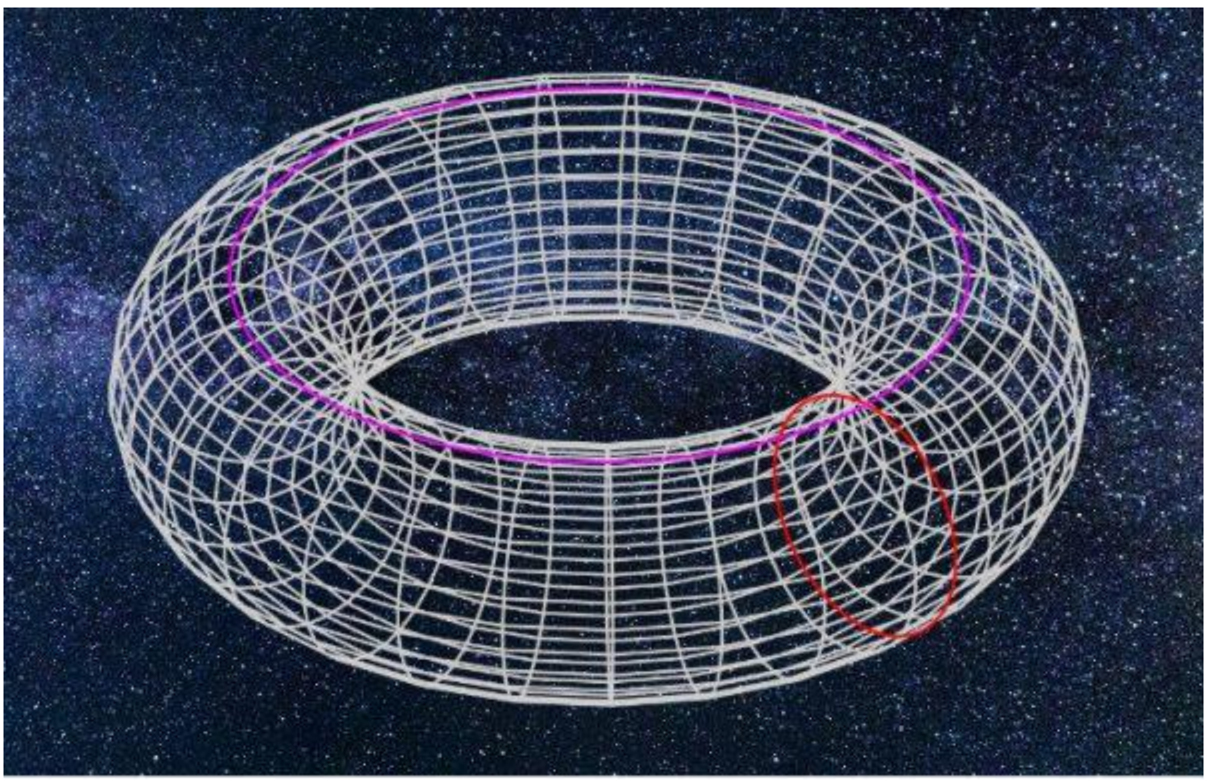
Meijer envisions a sort of screen or boundary between the outside world and the individual mental field. He likens this boundary to the event horizon of a black hole.

“It is assumed that information entering a black hole from the outside is not lost, but … rather is being projected on its outer screen, called the ‘event horizon,’” Meijer wrote.

“Consciousness is a boundary condition between a singularity (black hole) and space within the brain.” The event horizon separates “a mental model of reality for internal use in each individual” from all that exists outside of it. Yet it is connected to a “universal information matrix.”

Meijer described via email how this “dynamic holographic boundary” collects information from inside the brain as well as from the “information fields in which our brain is permanently embedded.” He said: “In this manner, it is implicitly connected to a universal information matrix.”

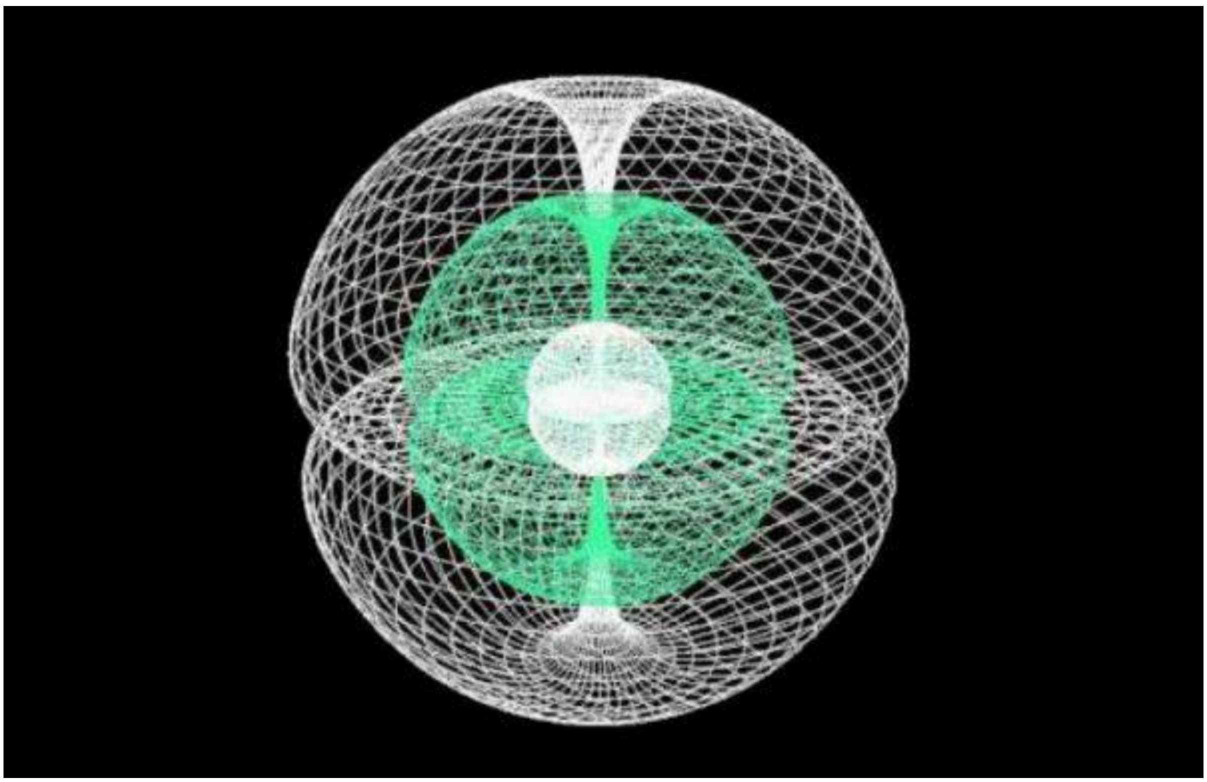
The structure of the hypothesized mental field could take the shape of a torus.



The geometrical shape known as a torus is well suited for the nature and functions Meijer attributes to the mental field.

A torus is described by the Merriam Webster dictionary as, “a doughnut-shaped surface generated by a circle rotated about an axis in its plane that does not intersect the circle.”

Meijer presented various reasons within physics theories for choosing this shape for his hypothesized mental field. One reason is related to a theory of how electrical activity in the brain oscillates.



The nested torus structure suggested by Dr. Dirk Meijer for the mental field connected to the brain. (Courtesy of Dr. Dirk Meijer)

These rhythms have been compared to microscopic features of the universe, such as those described by String Theory. Meijer described these as “multidimensional torus movements.”

The torus structure is found in physics from the micro-scale to the extreme macro-scale of black holes and the universe as a whole, Meijer explained. It could be instrumental in dynamically integrating information in the mind and brain.

Meijer discusses the broader implications for the philosophy of mind–matter relationships.

Meijer wrote: “Our paper, may directly contribute to an answer on the famous question of [cognitive scientists and philosopher David] Chalmers …: how can something immaterial like subjective experience and self-consciousness arise from a material brain?”

The ability of the mental field to pick up information from other fields, as conceived by Meijer, could also explain some anomalous phenomena, such as extrasensory perception, he noted.

In his view, “Consciousness can be regarded as the most basic building block of nature and consequently is present at all levels of the fabric of reality.”

Since quantum physics emerged, scientists have been exploring its ability to explain consciousness. Meijer’s work fits within that exploration.

Another theory called "orchestrated objective reduction," or "Orch-OR," was developed by physicist Sir Roger Penrose and anesthesiologist Dr. Stuart Hameroff. On his website, Hameroff describes the theory: "… it suggests consciousness arises from quantum vibrations in protein polymers called microtubules inside the brain's neurons."

Like Meijer, Penrose and Hameroff have said "there is a connection between the brain's biomolecular processes and the basic structure of the universe." They have also called for a major change in how scientists view consciousness.

Hameroff said in an interview with the blog Singularity: "Most scientists can't explain consciousness in the brain, so they can't say that consciousness out of the brain is impossible."

Update: Dr. Dirk Meijer has provided The Epoch Times with an update on his paper, clarifying that quantum tunneling and entanglement are not the most likely methods of information transfer between the mental field and the brain. These two phenomena have been shown to provide only a correlation between two particles, not necessarily information transfer (although that may prove to be the case with further research).

Rather, *quantum wave resonance* is a more likely mechanism of extremely rapid information processing in the brain. This means, instead of signals being sent between neurons in the brain, a wave pattern that encompasses all neurons, as well as the mental field, transmits the information instantaneously.

Picture a vibration wave going up and down in a consistent pattern and running all through your brain and even outside of it. That pattern communicates information that can be understood by vibratory receptors in your brain. All of this is happening in a dimension and at a microscopic level not directly perceptible through conventional scientific instrumentation at our disposal today, yet can be inferred through physical and mathematical modeling.

Theoretical Models of Consciousness: A Scoping Review

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Editor: Gerry Leisman

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Abstract

The amount of knowledge on human consciousness has created a multitude of viewpoints and it is difficult to compare and synthesize all the recent scientific perspectives. Indeed, there are many definitions of consciousness and multiple approaches to study the neural correlates of consciousness (NCC). Therefore, the main aim of this article is to collect data on the various theories of consciousness published between 2007–2017 and to synthesize them to provide a general overview of this topic. To describe each theory, we developed a thematic grid called the dimensional model, which qualitatively and quantitatively analyzes how each article, related to one specific theory, debates/analyzes a specific issue. Among the 1130 articles assessed, 85 full texts were included in the prefinal step. Finally, this scoping review analyzed 68 articles that described 29 theories of consciousness. We found heterogeneous perspectives in the theories analyzed. Those with the highest grade of variability are as follows: subjectivity, NCC, and the consciousness/cognitive function. Among sub-cortical structures, thalamus, basal ganglia, and the hippocampus were the most indicated, whereas the cingulate, prefrontal, and temporal areas were the most reported for cortical ones also including the thalamo-cortical system. Moreover, we found several definitions of consciousness and 21 new sub-classifications.

Keywords: consciousness, neural correlates, cognition, consciousness theory, consciousness definition, subjectivity

1. Introduction

The scientific literature debating themes on consciousness is huge. Contributing scientists come from different disciplines such as medicine, philosophy, physics, psychology, neurobiology, mathematics, and computer science. Authors from these disciplines have led to an increase in knowledge about consciousness, giving new and interesting inputs for neuroscience. However, all this information has created a multitude of viewpoints and it is difficult to compare (and synthesize) some of the various issues that have emerged in the last few decades. For example, one of the main problems related to consciousness is its definition. Indeed, as remarked by Sommerhoff [1], “A precise definition of the word [‘consciousness’], of course, can only be the endpoint of a theory of consciousness, just as the concepts of work and energy found a precise definition only as part of a theory of mechanics" [1]. Therefore, the probability of having different definitions of the same object correlates directly to the number of theories that try to explain the nature of consciousness itself. In this sense, the concept of 'consciousness' can be found in historical documents since ancient times, and it can be proven in various traditions and cultures with some perspectives that, although the expression language has become different, seem to be concepts that had evolved throughout history [2]. Fritjof Capra [3] describes how some eastern ancient concepts on a universal consciousness are consistent with modern physics, considering that some physics perspectives try to invalidate the concept of atomic particles as consisting of smaller independent building blocks made of different substances. Capra believes that one substance exists that comes from a 'cosmic consciousness' (this was the definition of consciousness used) out of which all matter is made of. This is a position commonly used also by those who argue that consciousness supervenes on the whole embodied animal in dynamic interaction with the environment [4]. Another example proposed in the last decade derived by some eastern reductionist perspective highlighted that consciousness could be defined as "the ability to maintain an alert state, attention, and awareness of self and environment" [5] or as the "the subjective character of our mental states" [6], according to the clinical and representational perspective used to describe it. This provides particular attention to the role of introspection and metarepresentation, two themes cited by Aristotle that contribute to current debates over the nature of consciousness [7].

Therefore, the analysis of the general framework and the perspectives proposed by each model of consciousness is important for improving the science of consciousness and, consequently, its definitions.

Another issue is represented by the definition of the neural correlates of consciousness (NCCs). If we consider consciousness as a human phenomenon deriving from matter, one of the main neurobiological questions is the definition of the minimum neuronal mechanisms jointly sufficient for any one specific conscious percept [8,9]. The definition of what we mean by consciousness and the brain neurons/areas/processes linked to the appearance of this phenomenon is a crucial issue for all theories of consciousness. The evolution of imaging and neurophysiological techniques, as well as the possibility to change brain activities online using tailored magnetic and electrical stimulations during tasks requiring wakefulness and awareness of external stimuli, has led to increases in the possibility of verifying/falsifying different hypotheses. Moreover, it has led to study the of consciousness modulation through the stimulation of different brain areas, overpassing the limits derived from the anatomo-clinical model based on the lesional approach. However, every theoretical approach has some assumptions according to which consciousness could be generated by a multitude of processes. This is grounded in the activity of a wide range of structures that vary from the single neuron to the whole brain. Consequently, the number of NCCs is presently very large.

There are other main issues debated in the scientific literature related to consciousness. The problem of how we can "quantify" the conscious level, for example, is one of the most important questions that many scientists are still studying. This question is crucial for clinicians during the clinical diagnosis of patients with disorders of consciousness after a severe brain injury (to assess the consciousness level beyond behavioral abilities of patients), as well as for computer science/artificial intelligence researchers involved in machine and computer development.

All the examples reported above makeup only a minimal part of the literature on consciousness, which has increased over the last few years. Therefore, the general aim of this article is to offer an exhaustive framework on the theoretical models of consciousness that currently exist, without committing to a specific perspective or viewpoint. To achieve this goal, the specific aims of this research are twofold: Firstly, we sought to systematically review the scientific literature on theoretical models of consciousness published from 2007 to 2017 in major scientific databases and, secondly, to describe each theory collected using a common thematic grid called the dimensional model (DM) in order to qualitatively and quantitatively analyze how each article, related to a specific theory, debates/analyzes specific issues.

2. Materials and Methods

We included all the published studies that analyzed theoretical aspects of consciousness.

2.1. Search Strategies and Information Sources

The authors performed a systematic search in the Medline (PubMed), Embase (EMBASE.com), Scopus, Web of Science (WoS), and PsycINFO databases. A tailored search strategy was developed for each database according to their thesaurus characteristics. The search method for the identification of studies is reported in Supplemental Materials (Table S1). Results obtained from each database were exported in a web-based bibliographic management software (RefWorks; https://www.refworks.com/it/, accessed on May–December 2017) and duplicate deletion was done by two independent raters, which were then matched. Moreover, all records were imported in a tailored Excel spreadsheet including title, abstract, and record information for each article.

2.2. General Selection Criteria

Studies were excluded if they met any of the following criteria: (1) studies published before 2007; (2) article type: book, generic, magazine article, or monograph; (3) studies not published in the English or Italian languages.

This review was performed following the preferred reporting items for systematic reviews and meta-analyses criteria [10].

2.3. Screening and Eligibility Criteria for Each Step

Search results were independently screened by different reviewers using a three-step procedure due to the high number of articles selected. Duplicate articles were removed before step 1.

2.3.1. Step 1: Abstract Selection

In the first step, one author (Rater #1) screened the articles by title, abstract, and keywords using the following assessment scale: 0 = the article does not debate consciousness itself (the term consciousness appears in the title or the abstract but with general meaning (e.g., people are conscious of their life, etc.); 1 = the rater doubts this article; 2 = the article debates some aspects related to consciousness. In total, 20% (4100 studies) of the total number of articles were selected with random data extraction (using SPSS software; SPSS Inc., Chicago, IL, USA) for an independent rating made by Rater #2. The agreement between the two raters (Cohen K analysis) was predetermined; it had to be over 0.90 to proceed with the second step of the screening process. If the agreement value was below 0.90, a third rater was involved in the screening of abstracts, and then a second analysis was performed. The third author (Rater #3), who had senior experience in systematic reviews and consciousness issues, checked the quality of data collection, helping to solve the discrepancy between the evaluations of the first- and second-rater.

2.3.2. Step 2: Full-Text Selection

In the second step, two raters (#2 and #3) analyzed all full-text articles extracted during step 1 to assess them for final eligibility. The assessment scale used in this step was as follows: 0 = the article does not report theoretical aspects related to consciousness; 1 = the rater doubts this article; 2 = the article discusses theoretical aspects related to consciousness. The term “theoretical aspects” was used in referring to papers that accomplished three things: (a) describe a theory of consciousness; (b) describe one dimension of the DM (see below for its description) concerning consciousness as a topic; (c) describe a specific issue concerning different models of consciousness. In the case of a disagreement between raters regarding a selected study, consensus was achieved by means of discussion involving Rater #4, who read the article/s and participated in the discussion.

2.3.3. Step 3: Data Extraction and Management

In the final step, full-text analysis of the selected records classified as “included” in the previous step was performed. Raters #2, #4, and #5 independently analyzed the selected articles. Each of them completed the DM (see below for the full description) and then summarized each theory of consciousness. Additional relevant papers were retrieved through a cross-reference check. The bibliography of each article was read to collect information on other studies not included in the final list.

2.4. Outcome Measures

Before beginning the review process, we developed a DM. The DM is a thematic grid used to quantify how each article, belonging to one specific theory, debates/analyzes specific issues. Dimensions are selected according to (i) important questions that emerged from previous consciousness studies [11,12,13,14,15] and (ii) questions on which authors wanted to point out.

2.5. Main Dimensions Analyzed

2.5.1. Neural Correlates of Consciousness (NCCs)

NCCs are defined as the minimum neuronal mechanisms jointly sufficient for any one specific conscious percept [8,9,16]. In each article, the rater analyzed how much NCC was debated (quantifying this dimension using the Likert scale described below). Further, the rater reported the DM in the main brain structures. Moreover, the raters indicated whether the NCCs were described at the neuronal or brain area levels and whether the NCCs were correlated to a process involving different neural circuits. In this review, we did not consider the distinction between content-related consciousness NCC (i.e., the local state) and awakening state NCC (i.e., the global state or the activity which determines a particular phenomenal distinction within an experience) as eligibility criteria. Rather, raters reported more specific information when a clear description was found in the analyzed articles.

2.5.2. Association between Consciousness and Other Cognitive Functions

In this dimension, raters were asked to analyze how much each article explained the relationships between consciousness and other cognitive functions such as attention, memory, mental imagery, and so on. In each study, raters were asked to analyze how much the theoretical process linked conscious information to cognitive functions (specifically about information processing). For instance, raters were required to analyze how stimuli conscious elaboration is related to memory or how consciousness generation mechanisms work in relation to attentional functions [17].

2.5.3. Translation from Theory to Clinical Practice

In this area, we spotlighted information useful for the clinical management of patients with neurological/psychiatric disorders related to consciousness manifestations. Raters evaluated if each article provided information about clinical implications for either the diagnosis or the treatments of patients (e.g., with disorders of consciousness or with loss of consciousness due to epilepsy, etc.). Moreover, raters evaluated if the article reported any implications that would determine some prognostic markers based on the theory described. Specifically, the translation from theoretical aspects to clinical practice was examined, looking for words such as “marker”, “recovery of consciousness”, “diagnosis”, “clinical impact”, and “clinical implications”, as is reported in the supplementary materials.

2.5.4. Quantitative Measures of Consciousness

Raters observed if an article reported information about the quantification of consciousness levels. We analyzed if instruments/tools to measure consciousness were described and if tailored algorithms were reported. Special attention was paid to the “index” definition directly related to the consciousness definition reported in the theory.

2.5.5. Consciousness, Sensory Processes, and the Autonomic Nervous System

This area was chosen to explore if the selected theories of consciousness debate on the relationships between peripheral information derived from the autonomic nervous system (ANS) (also including sensory processes) and consciousness. In detail, raters were asked to quantify how much the elaboration of information coming from ANS was described in each article and how this information was linked to a consciousness percept (e.g., pathways that provide visceral sensation to conscious perception).

2.5.6. Subjectivity

The final dimension analyzed by raters refers to how each article/theory of consciousness explains where subjectivity comes from and how it is related to conscious experience. A specific definition of subjectivity was not provided to raters to avoid the exclusion of new concepts and alternative viewpoints about subjectivity. In this sense, raters were instructed to search within for text-specific words such as “subjective experience”, “subjectivity”, “first-person experience”, and other terms linked to the discussion about how subjective experience could emerge from neural activity, and then to analyze how much this topic is analyzed in the text of each article.

2.6. Outcomes

2.6.1. Quantitative Outcomes

For each study collected, we analyzed the full text, giving a score on a Likert scale ranging from 0 to 5. The score for each dimension was assigned according to the following criteria:

0 = the issue was not debated in the article.

1 = the article gave minimal attention to the issue. The theme was cited in the text (introduction or discussion) as a marginal topic that used fewer words.

2 = the issue was not reported in the abstract. The theme was debated in the text using some sentences as collateral/secondary issues in refers to other main topics.

3 = the issue was not reported in the abstract but there was a short paragraph that discussed the issue reporting specific references.

4 = the issue was cited in the abstract. In specific sections of the paper (introduction, results, or discussion) there was at least a long paragraph on the issue reporting specific references.

5 = the issue was cited in the title and/or in the abstract and/or as a keyword. The issue was the main topic of the article, which was debated in different parts of the text.

2.6.2. Qualitative Outcomes

A series of information, although not evaluable in a quantitative way, was also collected from full texts.

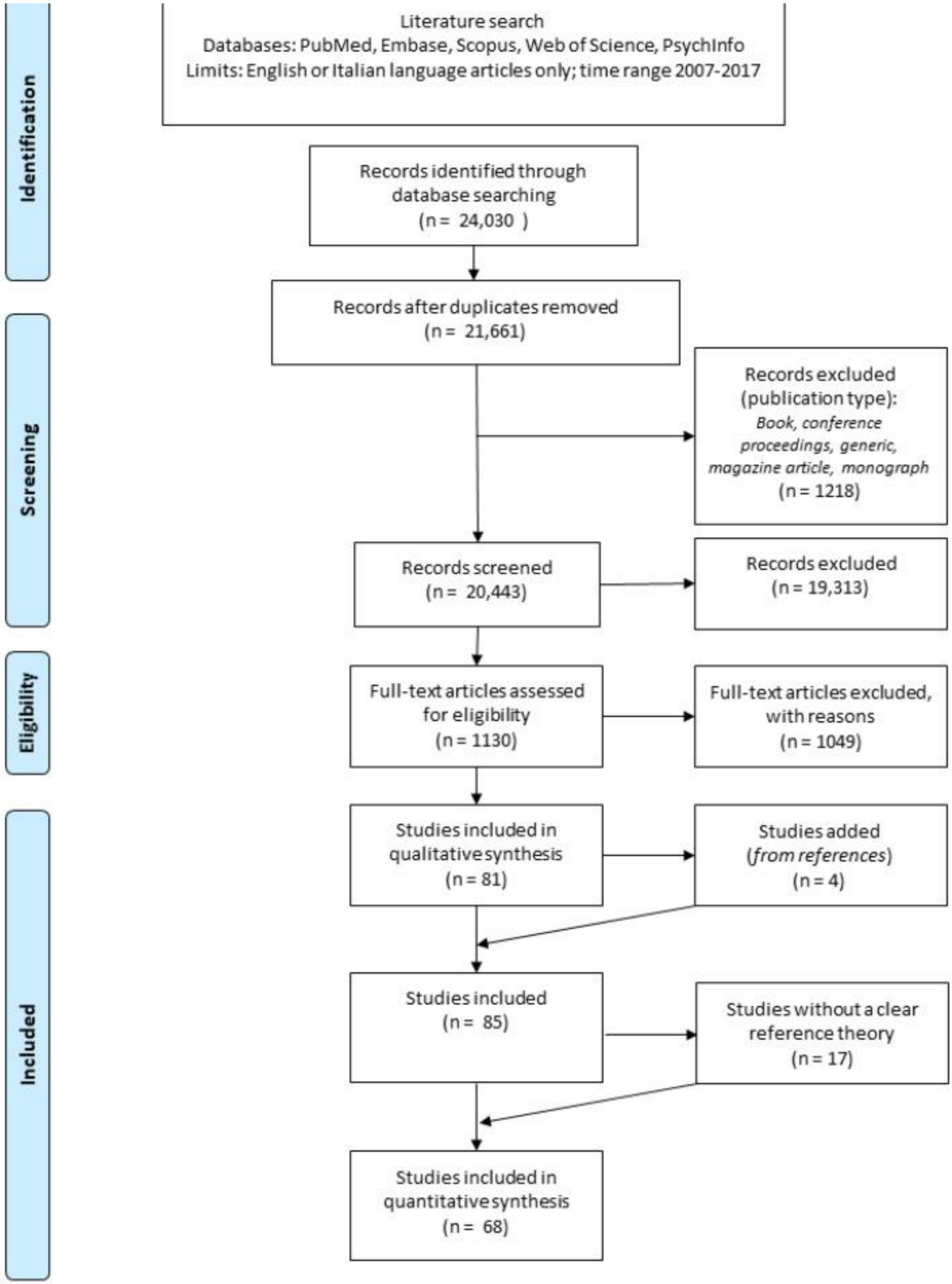
1. Main definitions of consciousness. Raters were asked to report if there was a main definition of consciousness (e.g., consciousness is/represents/serves/refers to/consists of/results in/defined as/has to do with) linked to the main theory described in the articles they read. The definition of consciousness expressed by other authors and only cited in the text was not reported unless strictly related to the theory presented in the article. Definitions of what is not consciousness were also included.
2. Definitions of consciousness' components/parts/sub-elements. Raters noted any definitions concerning parts and elements of consciousness and their definitions (if available).
   Related terms/features. Raters reported specific terms and/or features concerning the nature of consciousness as described by the single article/theory that is complementary to the main definition.

3. Results

3.1. Review Results

The search identified 21,661 records after duplicates deletion performed in the step. In total, 11130 full-text articles were analyzed in step 2. Further, 68 articles were analyzed using the DM (see Figure 1).

Figure 1.


Identification
Screening
Eligibility
Included
Literature search
Databases: PubMed, Embase, Scopus, Web of Science, PsychInfo
Limits: English or Italian language articles only; time range 2007-2017
Records identified through database searching (n = 24,030)
Records after duplicates removed (n = 21,661)
Records excluded (publication type): *Book, conference proceedings, generic, magazine article, monograph* (n = 1218)
Records screened (n = 20,443)
Records excluded (n = 19,313)
Full-text articles assessed for eligibility (n = 1130)
Full-text articles excluded, with reasons (n = 1049)
Studies included in qualitative synthesis (n = 81)
Studies added (*from references*) (n = 4)
Studies included (n = 85)
Studies without a clear reference theory (n = 17)
Studies included in quantitative synthesis (n = 68)

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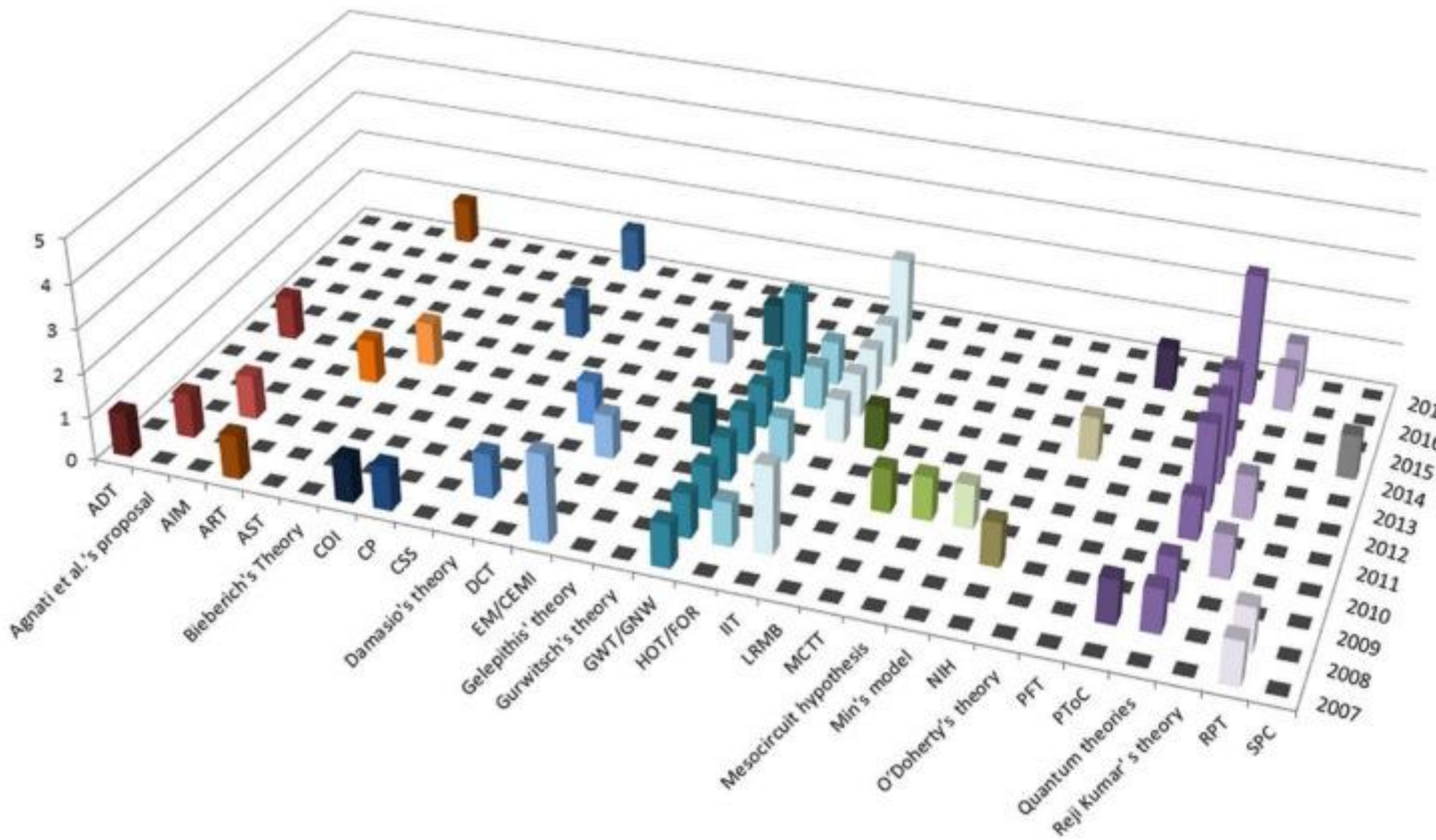
Prisma flow diagram.

The criteria used to exclude records before the final analysis consisted of using the term "consciousness" with a generic meaning (e.g., "conscious about their condition") or with a moral viewpoint (e.g., "conscious about the consequences of his actions").

During the analysis of the final 68 articles, we identified 29 different theories of consciousness (Figure 2). Each of them was synthetized following alphabetical order. Figure 2 graphically represents the number of record distribution over the years.

Figure 2.



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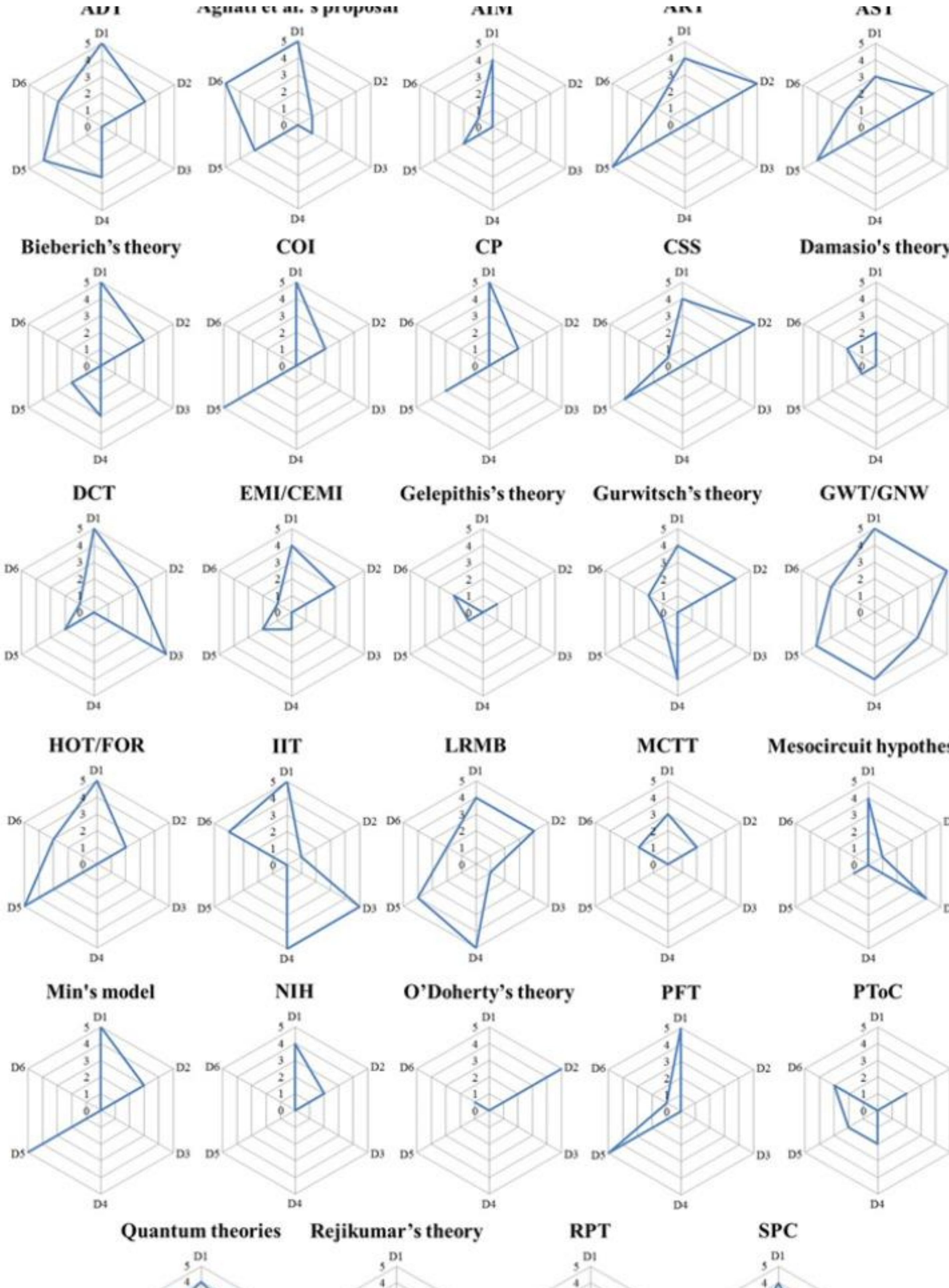
Graphic representation of the number of articles found for each theory in the period analyzed. ADT: apical dendrite theory; AIM: activation/information/mode-synthesis hypothesis; ART: adaptive resonance theory; AST: attention schema theory; COI: cross-order integration theory of consciousness; CP: centrencephalic proposal; CCS: consciousness state space model; DCT: dynamic core theory; EM/CEMI: electromagnetic field hypothesis/consciousness electromagnetic Information field theory; GWT: global workspace theory; GNW: global neural workspace; HOT/FOR: higher order theories of consciousness/first order representational theory; IIT: integrated information theory; LRMB: layered reference model of the brain; MCTT: memory consciousness and temporality theory; NIH: network inhibition hypothesis; PFT: passive frame theory; PToC: psychological theory of consciousness. Q theories—Orch OR: orchestrated objective reduction theory; single particle consciousness hypothesis; quantum no-go theorems; the three layer model; Koehler's mathematical approach; timeless and spaceless; the four-dimensional Einstein; RPT: radical plasticity thesis; SPC: semantic pointer competition theory of consciousness; Agnati et al.; Bieberich's; Damasio; Gelepithis's; Gurwitsch's; Min's; O'Doherty's; Rejikumar's. The Mesocircuit hypothesis is not abbreviated.

Figure 3 reports the maximum score obtained by the articles analyzed for each theory. In in dimension number 1 (NCC), the maximum score was observed in 11 theories; in D2 (Association between consciousness and other cognitive functions) in three theories; in D3 (translation from theory to clinical practice) in two theories; in D4 (quantitative measures of consciousness) in four theories; in D5 (consciousness, sensory processes, and the autonomic nervous system) in six theories; and in D6 (subjectivity) in two theories. Regarding the total number of dimensions debated by each theory, we found that the range was comprised of a minimum of two dimensions debated in the selected articles (NIH and O'Doherty's theory) to a maximum of all dimensions, as reported in Table S2. The theories with the highest number of analyzed articles were the group of the quantum theories of consciousness (*n* = 12), the IIT (*n* = 8), and the GWT/GNW (*n* = 9), whereas 18 theories were described by a single article.

Figure 3.


Bieberich's theory
COI
CP
CSS
Damasio's theory
DCT
EMI/CEMI
Gelepithis's theory
Gurwitsch's theory
GWT/GNW
HOT/FOR
IIT
LRMB
MCTT
Mesocircuit hypothes
Min's model
NIH
O'Doherty's theory
PFT
PToC
Quantum theories
Rejikumar's theory
RPT
SPC
D1
D2
D3
D4
D5
D6

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Graphic representation of the maximum scores obtained in the six dimensions analyzed by each theory. The figures depicted the scores achieved by each theory (displayed in alphabetical order) in each dimension of the dimensional model. We considered the maximum score for each theory among the articles belonging to it. The y-axis represents the scores ranging from 0 to 5. **D1** refers to the neural correlates of consciousness dimension. **D2** refers to the association between consciousness and other cognitive functions dimension. **D3** refers to translation from theory to clinical practice dimension. **D4** refers to the quantitative measures of consciousness dimension. **D5** refers to consciousness, sensory processes, and the autonomic nervous system dimension. **D6** refers to the subjectivity dimension.

For each analyzed article, we reported the definition of consciousness (Table 1). Regarding the various definitions found, we decided to report the exact sentences found in each article to avoid misinterpretation. Frequencies of the main terms used in the main definitions of consciousness by each theory were also reported in Table 2.

Table 1.

Consciousness definitions found in the collected articles.

Theory	Authors (year)	Main Definition	Other Terms/Subcategorization Related to Consciousness (Definitions Reported If Available)
ADT	LaBerge and Kasevich (2007) [18]	Consciousness is an activity that is extended in time and typically continues from the time we awake to the time we fall asleep.	- Background consciousness: some processes in the brain create "cognitive event that may be called 'having an impression' of something". - Elevated consciousness for selected aspects of background consciousness is assumed to arise when sustained activity of a primary sensory area is sent to higher sensory areas, and where a selected part of the sensory scene is amplified by attentional activity controlled from the frontal lobes. - Foreground consciousness: the elevated attentional activity of a part of the sensory scene in higher sensory areas. - Content of consciousness: the simultaneous impressions from both foreground and background consciousness together;
	Cook (2008) [19]	nf	

Theory	Authors (year)	Main Definition	Other Terms/Subcategorization Related to Consciousness (Definitions Reported If Available)
Agnati et al.'s proposal	Agnati et al. (2012) [20]	Consciousness may be thought as the global result of integrative processes taking place at different levels of miniaturization in plastic mosaics	
AIM	Hobson (2009) [21]	Waking consciousness can be defined as the awareness of the external world, our bodies, and ourselves (including the awareness of our awareness) that humans experience when awake.	- Primary consciousness can be defined as simple awareness that includes perception and emotion. - Secondary consciousness depends on language and includes such features as self-reflective awareness, abstract thinking, volition, and metacognition.
ART	Grossberg (2007) [22]	nf	
	Grossberg (2017) [23]	Consciousness is not just a whir of information-processing.	- Core consciousness (see Damasio's theory)
AST	Graziano and Kastner (2011) [24]	Consciousness is not an emergent property or a metaphysical emanation but is itself information computed by an expert system. […] Consciousness=awareness (i.e., a perceptual model of attention).	
Bieberich's theory	Bieberich (2012) [25]	Consciousness determines what is perceived as reality.	
COI	Kriegel (2007) [26]	When a subject has a higher-order representation that is unified with the first-order representation it represents, their representational unity constitutes a conscious state. Consciousness determines what is perceived as reality.	
CP	Merker (2007) [27]	Consciousness may be regarded most simply as the "medium" of all possible experience. Consciousness as the state or condition presupposed by any experience whatsoever.	- Reflective consciousness: is one of many contents of consciousness available to creatures with sophisticated cognitive capacities; it is "a luxury of consciousness on the part of certain big brained species, and not its defining property"; self-consciousness, unselfconsciously.

Theory	Authors (year)	Main Definition	Other Terms/Subcategorization Related to Consciousness (Definitions Reported If Available)
CSS	Berkovich-Ohana et al. (2014) [28]	Consciousness is an experienced property of mental states and processes, which is lost during a dreamless deep sleep, deep anesthesia, or coma	- Minimal self (MS): a self that is short of temporal extension and endowed with a sense of agency, ownership, and non-conceptual first-person content. - Narrative self (NS): it involves personal identity and continuity across time, as well as conceptual thought. - Core consciousness (CC): it supports the MS; its scope is in the here and now. - Extended consciousness (EC): it supports the NS and involves memory of past, imagination of future, and verbal thought. It deals with holding in mind, overtime, a multiplicity of neural patterns that describe the autobiographical self.
	Berkovich-Ohana et al. (2017) [29]	nf	
Damasio's theory	Bosse et al. (2008) [30]	Proto-self: The proto-self is a coherent collection of neural patterns which map, moment by moment, the state of the physical structure of the organism in its many dimensions. Core consciousness (or feeling a feeling) is what emerges when the organism detects that its representation of its own body state (the proto-self) has been changed by the occurrence of the stimulus. Thus, it becomes (consciously) aware of the feeling, i.e., extended consciousness;	
DCT	Ward (2011) [31]	Phenomenal consciousness is generated by synchronized neural activity in the dendritic trees of dorsal thalamic neurons: a thalamic dynamic core.	Meta-consciousness and Self-consciousness are viewed as contents of consciousness that are built from recursive application of primary consciousness to conscious contents.
EMI/CEMI	McFadden (2007) [32]	Consciousness is that component of the brain's electromagnetic information field that is downloaded to motor neurons and	

Theory	Authors (year)	Main Definition	Other Terms/Subcategorization Related to Consciousness (Definitions Reported If Available)
		is thereby capable of communicating its state to the outside world. Consciousness is what electromagnetic field information feels like from the inside.	
	Pockett (2007) [33]	nf	
	Lewis and MacGregor (2010) [34]	Consciousness itself is a dispositional form of energy that may relate to physical forms of energy as the phase state of a gas relates in a material way to its liquid phase.	
Gelepithis' theory	Gelepithis (2014) [35]	nf	
Gurwitsch's theory	Yoshimi (2011) [36]	nf	
	Yoshimi and Vinson (2015) [37]	Consciousness is the totality of co-present data […] Any field of consciousness can be parsed into these three co-present domains of data: theme, thematic field, and margin.	Marginal consciousness: unattended data not relevant to the theme. Theme: data at the focus of attention organized according to Gestalt law. Thematic field: unattended data relevant to the theme.
GWT/GNW	Baars and Franklin (2007) [38]	Consciousness serves as a lookout function to spot potential dangers or opportunities so that there is a particularly close relationship between conscious content and significant sensory input.	
	Prakash et al. (2008) [39]	nf	
	Baars and Franklin (2009) [40]	nf	
	Raffone and Pantani (2010) [41]	nf	Phenomenal consciousness consists in phenomenally conscious states that are not cognitively accessible.

Theory	Authors (year)	Main Definition	Other Terms/Subcategorization Related to Consciousness (Definitions Reported If Available)
			Access consciousness represents a content information which is 'broadcast' in the GW.
	Dehaene and Changeux (2011) [42]	The availability of information is what we subjectively experience in a conscious state. "Conscious" is an ambiguous word. In its intransitive use (e.g., "the patient was still conscious") it refers to the state of consciousness, also called wakefulness or vigilance, which is thought to vary continuously from coma and slow-wave sleep to full vigilance. In its transitive use (e.g., "I was not conscious of the red light"), it refers to conscious access to and/or conscious processing of a specific piece of information.	
	Sergent and Naccache (2012) [43]	It is possible to use subjective reports to probe the content of consciousness and therefore define any representation which is not reported by the subject as non-conscious, even when questioned about it, the existence of which can be demonstrated through behavioral and/or functional brain-imaging measures.	Phenomenal consciousness is a much larger domain of conscious contents than the one accessible through reports perceptual consciousness; micro-consciousness
	Baars et al. (2013) [44]	Conscious experiences reflect a flexible "binding and broadcasting" function in the brain, which mobilize a large, distributed collection of specialized cortical networks and processes that are not conscious by themselves.	Sensory consciousness; perceptual consciousness.
	Dehaene et al. (2014) [45]	Conscious access is the process by which a piece of information becomes conscious content. Conscious processing refers to the various operations that can be applied to a conscious content (as when multiplying two numbers mentally). Conscious report is the process by which a conscious content can be described verbally or by various	Self-consciousness is a particular instance of conscious accessibility where the conscious 'spotlight' is oriented toward internal states […] The state of consciousness, associated with fluctuations in wakefulness or vigilance, refers to the brain's very ability to entertain stream of conscious contents.

Theory	Authors (year)	Main Definition	Other Terms/Subcategorization Related to Consciousness (Definitions Reported If Available)
		gestures. Such reportability remains the main criterion for whether a piece of information is or is not conscious, i.e., I can report something if and only if I am aware of it.	
	Bartolomei et al. (2014) [46]	The global availability of information through the workspace is what we subjectively experience as a conscious state.	
HOT	Lau (2007) [47]	Perceptual consciousness depends on the representation of the probability distributions that describe the behavior of the internal signal.	
	Lau and Rosenthal (2011) [48]	Consciousness consists in perceptual processes that occur with subjective experience, of which we are aware and about which we can report under normal circumstances. This contrasts with perceptual processes that occur without subjectivity, of which we are unaware and about which we cannot report. The term 'conscious awareness' can also apply to thoughts and volitional states of which one is subjectively aware	
	Friesen (2014) [49]	nf	
	Mehta and Mashour (2013) [50]	Consciousness is the story that our perceptual system tells us about the world. Any conscious state is a representation of what it is like to be in a conscious state, which is wholly determined by the content of that representation.	General consciousness: it pertains the levels of consciousness; - Specific consciousness pertains the content of consciousness
IIT	Balduzzi and Tononi (2008) [51]	Consciousness has to do with a system's capacity to generate integrated information. This suggestion stems from considering two basic properties of consciousness: (i) each conscious experience generates a large amount of	

Theory	Authors (year)	Main Definition	Other Terms/Subcategorization Related to Consciousness (Definitions Reported If Available)
		information by ruling out alternative experiences; (ii) the information is integrated, meaning it cannot be decomposed into independent parts.	
	Tononi (2008) [52]	Consciousness is integrated information and its quality is given by the informational relationships generated by a complex of elements.	The quantity of consciousness generated by a complex of elements is determined by the amount of integrated information it generates above and beyond its parts. The quality of consciousness is determined by the set of all the informational relationships its mechanisms generate.
	Tononi (2012) [53]	Consciousness is what vanishes every night when we fall into dreamless sleep and reappears when we wake up or when we dream. Consciousness is synonymous with experience.	
	Casali et al. (2013) [54]	Conscious experience is both differentiated (i.e., it has many specific features that distinguish it from a large repertoire of other experiences) and integrated (i.e., it cannot be divided into discrete, independent components).	
	Oizumi et al. (2014) [55]	An experience (i.e., consciousness) is thus an intrinsic property of a complex of elements in a state: how they constrain—in a compositional manner—its space of possibilities, in the past, and in the future.	
	Tononi and Koch (2015) [15]	Consciousness is a fundamental property possessed by physical systems having specific causal properties. Consciousness is a fundamental, observer-independent property that can be accounted for by the intrinsic cause–effect power of certain mechanisms in a state—how they give form to the space	

Theory	Authors (year)	Main Definition	Other Terms/Subcategorization Related to Consciousness (Definitions Reported If Available)
		of possibilities in their past and their future. Consciousness is a fundamental property of certain physical systems, one that requires having real cause–effect power, specifically the power of shaping the space of possible past and future states in a way that is maximally irreducible intrinsically.	
	Tononi et al. (2016) [56]	Consciousness is subjective experience.	The quality or content of consciousness is identical to the form of the conceptual structure specified by the PSC. The quantity or level of consciousness corresponds to its irreducibility (integrated information Φ).
	Tsuchiya et al. (2016) [57]	Consciousness usually refers to either level or contents of consciousness.	The level of consciousness ranges from very high in the aroused awake state to low as in coma, vegetative states, deep dreamless sleep, and deep general anesthesia. At a given level of consciousness, every experiential moment contains various contents of consciousness. The contents of consciousness are synonymous with the other concepts such as qualia (its singular is a quale) or phenomenal consciousness.
LRMB	Wang (2012) [58]	Consciousness is a collective mental state of self-awareness that represents the bodily and mental status and their relations to the external environment, which is inductively generated or synthesized from the levels of metabolic homeostasis, unconsciousness, subconsciousness, and consciousness from the bottom-up. Consciousness is the basic characteristic of life and the mind, which is the state of being awareness of oneself, of perception to both internal and external	- Subconsciousness

Theory	Authors (year)	Main Definition	Other Terms/Subcategorization Related to Consciousness (Definitions Reported If Available)
		worlds, and of responsive to one's surroundings. Consciousness is a collective state at the perception layer of the 7-layer LRMB model, such as the sensation, action, memory, perception, metacognition, inference, and cognitive layers from the bottom-up. Consciousness is the sense of self and sign of life in natural intelligence. Consciousness is a collective and general state of advanced living organisms encompassing all cognitive attributes, which is generated based on the physiological structures, memory, and the brain's power for acquiring and manipulating sensory and mental information.	
MCTT	Dalla Barba and Boissè (2010) [59]	Consciousness is not a generic and a specific dimension that then becomes the consciousness of its object. It is immediately conscious of something. We would also add that consciousness is always consciousness of something in a certain way. This means that consciousness takes a certain point of view of its object and of the same object consciousness can take various points of view.	Knowing consciousness (KC) describes what is usually referred to as semantic memory. KC is temporal since it is a synthesis of what I have been. At the same time, KC is also atemporal in the sense that the time of which it is made is unrecognizable. Temporal consciousness is an organized, original, and irreducible form of consciousness for addressing the world. Unlike KC, TC transcends the mere presence of the object to set it in time.
Mesocircuit Hypothesis	Schiff (2010) [60]	Consciousness is the combination of different components: arousal, which relates to behavioral and physiological observations and establishes a threshold level that allows other aspects of higher consciousness to occur; awareness and motivation, which presupposes the will to interact with the environment and therefore can be intense as a "tension towards something".	

Theory	Authors (year)	Main Definition	Other Terms/Subcategorization Related to Consciousness (Definitions Reported If Available)
Min's Model	Min (2010) [61]	Consciousness is a mental state embodied through TRN-modulated synchronization of thalamocortical networks. Consciousness consists of each mental unit, which is an individual thalamocortical looping mechanism, no matter what cognitive stages it involves. Consciousness is referred to as thalamocortical response modes controlled by the TRN and is embodied in the form of dynamically synchronized thalamocortical networks ready for upcoming attentional processes	Awareness: conscious perception of an attended mental representation by strengthening relevant neural networks through thalamocortical reiterating.
NIH	Yu and Blumenfeld (2009) [5]	Consciousness is the ability to maintain an alert state, attention, and awareness of self and environment	
O'Doherty's theory	O'Doherty (2013) [62]	Consciousness represents the storage of past events for use in future situations and it is altered by external experience of the organism. Consciousness results from the gradual evolutionary development of the human information processing function. Consciousness is a phenomenon resulting from interactions between organisms rather than being located within an organism. Consciousness may consist of higher level of signal detection that has evolved through categorization and storage of past events.	
PFT	Morsella et al. (2015) [63]	Consciousness is a phenomenon associated with perceptual-like processing and interfacing with the somatic nervous system.	
PToC	Shannon (2008) [64]	Consciousness is the subjective experience and there are three types of consciousness: the sensed being, mental awareness, and meta-mentation.	Sensed being or sentience concerns the primitive and elementary aspect of consciousness that distinguishes the living from inanimate organisms. It has

Theory	Authors (year)	Main Definition	Other Terms/Subcategorization Related to Consciousness (Definitions Reported If Available)
			no specific context or structure; it is pervasive, and it is present during all our life. Mental awareness, typical of higher-order mammals, relates subjective experience that is distinct and differentiated, and the contents and forms of those experiences, such as mental images, ideations, flows of consciousness, and internal verbal monologues. Meta-mentation is the mind's ability to take its own productions as object for further reflection. This type of ability has different manifestation like meta-observation, reflection, monitoring, and control.
Quantum theories	Klemm and Klink (2008) [65]	Consciousness is the capacity of a system to opt among presented alternatives.	Unreflected consciousness refers to conscious acts and meanings in their immediate experiential and direct givenness.
	Das (2009) [66]	Consciousness is a property of the Nambu-Goldtone bosons created by Yukawa coupling between the Namubu-Goldstone boson scalar field and the electron Dirac field.	
	Di Biase (2009) [67]	Consciousness is non-local information with a status equal to matter and energy.	
	Koehler (2011) [68]	nf	
	Argonov (2012) [69]	Consciousness in the phenomenal sense is a synonym of "subjective reality", i.e., perception, volition, mental images, and emotions	
	Georgiev (2013) [6]	Consciousness is a collective term that refers to the subjective character of our mental states, and of our ability to experience or to feel. A conscious state is a state of experience.	

Theory	Authors (year)	Main Definition	Other Terms/Subcategorization Related to Consciousness (Definitions Reported If Available)
	Li (2013) [70]	nf	
	Hameroff and Penrose (2014) [71]	Consciousness consists of a sequence of discrete events, each being a moment of 'objective reduction' (OR) of a quantum state (according to the DP scheme), where it is taken that these quantum states exist as parts of quantum computations carried on primarily in neuronal microtubules. Such OR events would have to be 'orchestrated' in an appropriate way (Orch OR), for genuine consciousness to arise.	
	Hoffman and Prakash (2014) [72]	A conscious agents as a six tubules C = ((X,X), (G,G), P,D, A,N)), where: (X, X) and (G, G) are measurable spaces; P: W × X⟶[0, 1], D: X × G⟶[0, 1], A: G ×W⟶[0, 1] are mathematical formalism of Markoviank kernels, where N is an integer.	
	Kak et al. (2016) [73]	States of consciousness are mediated by languages and metalanguages with varying capacity or ability to recruit memories.	
	Sieb (2016) [74]	Conscious experience is defined as the direct observation of conscious events. A conscious event [...] is the fundamental entity of conscious experience (observed physical reality) represented by three coordinates of space and one coordinate of time in the space–time continuum: conscious event that consist of a set of qualia; conscious experience that is intimately tied to perception; postulated for conscious experience; conscious experience that is essentially an orientation in space and time.	

Theory	Authors (year)	Main Definition	Other Terms/Subcategorization Related to Consciousness (Definitions Reported If Available)
	Brabant (2016) [75]	nf	
Reji Kumar's theory	Reji Kumar (2010) [76]	Human consciousness is built with models and these models are involved in the development of consciousness at a very basic level. As such, consciousness is subject to all advantages and limitations of models. Consciousness is the result of all information processing activities that occur in the mind.	
	Ahmad and Khan (2012) [77]	Consciousness is the core component of the mind. Consciousness can be defined as the spirit of consciousness and the transitivity of an information system. Transitivity can be defined as a certain correspondence between the system of information and outside matters. Consciousness is the final output of all information processing activities that occur in the mind.	
	Reji Kumar (2016) [78]	Consciousness is the result of all processes that occur in the brain.	
	Reji Kumar (2016) [79]	Consciousness is the totality of all effects of the functions of the brain and the supporting nervous system that produces the feeling of the objective world and the subjective mind or self	
RPT	Cleeremans et al. (2007) [80]	Consciousness is the brain's theory about itself, gained through experience interacting with the world, and, crucially, with itself […] Conscious experience occurs if and only if an information processing system has learned about its own representations of the world […] Experience is, almost by definition ("what it feels like"), something that takes place not in any physical entity but rather only in special	

Theory	Authors (year)	Main Definition	Other Terms/Subcategorization Related to Consciousness (Definitions Reported If Available)
		physical entities, namely cognitive agents.	
	Cleeremans (2008) [81]	nf	
SPC	Thagard and Stewart (2014) [82]	Consciousness is a neural process resulting from three mechanisms: representation by firing patterns in neural populations, binding of representations into more complex representations called semantic pointers, and competition among semantic pointers to capture the most important aspects of an organism's current state.	

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Note. The table enlists the qualitative data retrieved from each article included in the review grouped by theory (first column). The main definitions of consciousness are quoted from the original articles (please see Table S3 for other definitions of consciousness and related terms). nf = not found in the article analyses.

Table 2.

Number of citations. The table shows how many times (second column) a specific term (first column) was used when referring to consciousness by theories (third column).

Terms	N. of Citations	Theory
Activity	4	ADT, DCT
Awareness	13	AIM, AST, HOT, LMRB, Mesocircuit Hypothesis, NIH, PToC
Brain	6	EMI/CEMI, GWT/GNW, LRMB, Reji Kumar's theory, RPT
Cognitive	4	LRMB, Min's Model, RPT
Collective	6	LRMB, Quantum theories
Component	4	EMI/CEMI, IIT, Mesocircuit Hypothesis, Reji Kumar's theory
Content	7	GWT/GNW, HOT, IIT
Events	7	O'Doherty's theory, Quantum theories
Experience	26	AIM, CP, CSS, GWT/GNW, HOT, IIT, O'Doherty's theory, PToC, Quantum theories, RPT
External	4	AIM, LRMB, O'Doherty's theory

Terms	N. of Citations	Theory
Feeling	7	Damasio's theory, Reji Kumar's theory
Field	6	EMI/CEMI, Gurwitsch's theory, Quantum theories
Form	4	EMI/CEMI, IIT, Min's Model
Function	5	GWT/GNW, O'Doherty's theory, Reji Kumar's theory
Information	20	ART, AST, EMI/CEMI, GWT/GNW, IIT, LRMB, O'Doherty's theory, Reji Kumar's theory, RPT
Integrated	5	IIT
Level	6	Agnati et al.'s proposal, IIT, LRMB, Mesocircuit Hypothesis, O'Doherty's theory, Reji Kumar's theory
Mental	10	CSS, GWT/GNW, LRMB, Min's Model, Quantum theories
Mind	5	LRMB, Reji Kumar's theory
Neural	4	Damasio's theory, DCT, SPC,
Object	5	MCTT, Quantum theories, Reji Kumar's theory
Organism	7	Damasio's theory, LRMB, O'Doherty's theory, SPC
Past	5	IIT, O'Doherty's theory
Perception	5	LRMB, Quantum theories
Perceptual	5	AST, GWT/GNW, HOT, PFT
Physical	7	AST, Damasio's theory, EMI/CEMI, IIT, Quantum theories, RPT
Possible	5	CP, GWT/GNW, IIT
Power	4	IIT, LRMB
Processes	17	Agnati et al.'s proposal, CSS, GWT/GNW, HOT, Min's Model, Reji Kumar' theory
Property	9	AST, CSS, IIT, Quantum theories
Reality	4	Bieberich's theory, COI, Quantum theories
Representation	12	COI, Damasio's theory, GWT/GNW, HOT, RPT, SPC
Something	5	GWT/GNW, MCTT, Mesocircuit Hypothesis, RPT
Space	6	IIT, Quantum theories
State	28	CP, Damasio's theory, EMI/CEMI, GWT/GNW, HOT, LRMB, Min's Model Quantum theories
Subjective	14	GWT/GNW, HOT, IIT, PToC, Quantum theories, Reji Kumar's theory

Terms	N. of Citations	Theory
System	11	AST, HOT, IIT, PFT, PToC, Reji Kumar's theory, RPT,
Thalamocortical	4	Min's Model
World	7	AIM, EMI/CEMI, HOT, LRMB, Reji Kumar's theory, RPT

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Moreover, other terms related to definitions or sub-categorizations of consciousness were also reported in Table 1. Considering only adjectives/nouns reported before the word consciousness, we found 21 different terms related to consciousness or consciousness sub-categorization (in alphabetical order): access consciousness; background consciousness; core consciousness; elevated consciousness; extended consciousness; foreground consciousness; general consciousness; knowing consciousness; marginal consciousness; meta-consciousness; micro-consciousness; perceptual consciousness; phenomenal consciousness; primary consciousness; reflective consciousness; secondary consciousness; self-consciousness; specific consciousness; subconsciousness; temporal consciousness; and unreflected consciousness.

Table 3 shows the main NCC reported in the various theories. The most cited neural structures were related to sub-cortical structures, although several theories reported cortical structures as well, defining in detail NCCs that could refer to cortico-thalamic systems.

Table 3.

Main neural correlates of consciousness reported in the various theories. In the second column, the percentage of theories referring to a specific neural structure is reported. The third column contains the name of theories that were reported for each neural structure. The fourth column indicates the percentage of theories that refer to either micro-, subcortical-, cortical-structures, or entire systems as neural correlates of consciousness.

Brain Structures	Theories Percentage Single Structure	Theories	Theories Percentage
	Micro-structures		
Single Neuron	3.44%	Agnati's theory	24%
Pyramidal neurons	6.89%	ADT, Bieberich's Theory	
GABAergic inhibitory neurons	3.44%	Min's model	
Periaqueductal gray neurons	3.44%	CP	

Brain Structures	Theories Percentage Single Structure	Theories	Theories Percentage
Astroglial-pyramidal cells	3.44%	CEMI	
Glia cells	3.44%	Agnati's theory	
Dendritic cells	10.34%	ADT, Bieberich's Theory, Quantum Theories	
Neural Microtubules	3.44%	Quantum Theories	
Ionic channels	10.34%	Agnati's theory, Bieberich's Theory, Quantum Theories	
Cortical minicolumns	3.44%	ADT	
Cortical single structures			
Prefrontal cortex (PFC)	24.13%	Agnati's theory, CP, GWT, HOT, Min's model, Quantum Theories, RPT	48%
Orbitofrontal areas	3.44%	ART	
Dorsolateral prefrontal cortex (dlPFC)	6.89%	COI, CSS	
Medial pre-frontal cortex (mPFC)	10.34%	AST, COI, CSS	
Cingulate cortex	13.79%	CSS, Damasio's theory, GWT, NIH	
Anterior cingulate cortex	13.79%	Agnati's theory, COI, CSS, GWT	
Experidorsal anterior cingulate cortex (dACC)	3.44%	CSS	
Medial cingulate gyrus	3.44%	CP	
Posterior cingulate cortex (PCC)	3.44%	CSS	
Precuneus	6.89%	CSS, NIH	
Medial frontal cortex	3.44%	NIH	
Supplementary motor area (SMA)	3.44%	CSS	
Premotor cortex	6.89%	CSS, GWT	
Parietal cortex	10.34%	CSS, GWT	
Superior parietal lobule	3.44%	CSS	
Inferior parietal lobule	3.44%	CSS	

Brain Structures	Theories Percentage Single Structure	Theories	Theories Percentage
Posterior parietal cortex (PPC)	10.34%	CP, HOT, quantum theories	
Temporoparietal junction	6.89%	AST, CSS	
Temporal lobe	17.24%	ART, AST, CSS, GWT, MCTT	
Occipital cortex	3.44%	GWT	
Subcortical single structures			
Basal ganglia	10.34%	ART, CP, quantum theories	52%
Nucleus accumbens	3.44%	Agnati's theory	
Claustrum	3.44%	Agnati's theory	
Insula	6.89%	Agnati's theory, CSS	
Amygdala	3.44%	ART	
Hippocampus	17.24%	ART, CSS, GWT, quantum theories, RPT	
Cerebellum	10.34%	GWT, LRMB, Reji Kumar's theory	
Thalamus	24.13%	Agnati's theory, CP, Damasio's theory, DCT, GWT, HOT, LRMB	
Anterior Pretectal nucleus	3.44%	DCT	
Medial thalamus nuclei	3.44%	NIH	
Thalamic reticular nucleus	6.89%	DCT, Min's model	
Pulvinar	3.44%	DCT	
Hypothalamus	6.89%	ART, CP	
Midbrain	3.44%	CP	
Superior colliculus	6.89%	CP, Damasio's theory	
Ventral tegmental area	3.44%	Agnati's theory	
Brain stem	3.44%	NIH	
Raphe nuclei	3.44%	Agnati's theory	
Brain systems/regions			
Cortico-thalamic system	17.24%	ART, AIM, IIT, Mesocircuit hypothesis, quantum Theories	28%
Fronto-parietal areas	6.89%	CSS, GWT	

Brain Structures	Theories Percentage Single Structure	Theories	Theories Percentage
Sensory cortical areas	3.44%	GWT	
Perceptual regions	3.44%	PFT	
Limbic system	3.44%	AIM	
Striate regions	3.44%	GWT	

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3.2. Analytical Description of Each Theory

In the next sections, we report a brief description of each theory analyzed (in alphabetical order).

3.2.1. The Apical Dendrite Theory (ADT)

The apical dendrite theory (ADT) of consciousness, proposed by LaBerge and Kasevich [18], focuses on input-processing, which seeks to understand how consciousness is generated by neurons and how information processing sustains itself over a prolonged time period without apparent outputs.

The theory affirmed that the pyramidal neurons within the thalamus-cortical circuit are important anatomical structures for consciousness due to their long apical dendrite, which produce a special kind of electrical activity.

Authors focused on structures called “minicolumns”, which are mini structures composed of major pyramidal neurons, stellate neurons, inhibitory neurons, and axons. The minicolumn is regarded as the functional unit of the cortex [83], based on the observation that neurons in each minicolumn share many receptive field properties. This theory analyzed two main circuits of the minicolumn: the shell and axis circuit.

The first one is a one-directional input–output circuit that connects one minicolumn with another, and the processing component consists of connections between layer 2 and 3 of neurons within the minicolumn, creating a sort of “horizontal” circuit. The axis circuit, instead, is considered as an “input-stayput” circuit due to its apparent role as a holder of neural activity over time. It constitutes the “vertical” circuit of the layer 5 cortical minicolumn, which extended to the thalamus in a reciprocally connected manner in a looping way.

The theory assumed that sustained activity in a primary sensory area provides the ongoing activities for a background consciousness. Elevated consciousness for selected aspects of background consciousness is assumed to arise when sustained activity of a primary sensory area is sent to higher sensory areas, where a selected part of the sensory scene is amplified by attentional activity controlled by the frontal lobes.

Within this attentional selection process, the control for the selective amplification/suppression activity is hypothesized to be provided by frontal cortex axions, which connect with the thalamic nuclei that serve those microcolumns. On the other side, the thalamic nuclei receive both this frontal information and data from primary sensory microcolumns, which remain relatively constant.

The shell circuits in early sensory areas that receive V1 inputs identify object appearances and locations. Later, sensory areas process these identifications into categories. In the frontal areas, categories are organized into propositions that may be based mainly on activity in the shell circuitry, which is spread across many minicolumns. On the other side, the global axis pathway begins with the initial cortical registration of the sensory inputs in the primary sensory minicolumns, and it extends into the frontal cortex (where presumably special supporting functions are performed and act as holding circuits that sustain activity for extended periods of time). When the intensity of the apical dendrite component of the thalamus-cortical holding circuit is sufficiently high, it produces the cognitive event, which may be labeled as "having an impression" of something. Two kinds of pathways are shown to sustain this activity: global ascending pathways that connect posterior cortical columns with anterior cortical columns and the global descending pathways that connect anterior cortical columns with posterior cortical columns.

Finally, the authors analyzed the properties of the electromagnetic activity of the apical dendrite to determine what properties of conscious impressions they may support. Interestingly, they affirmed that clusters of neighbor apical dendrites developed electric field energy in their core structures from the combined electric field components parallel to the dendritic axes. The development of magnetic field energy between parallel electric field dipoles is much less significant compared to electric field energy coupling between pairs of parallel apical dendrites with internal collinear dipoles moving at the conduction velocity. According to the present theory, the electromagnetic field intensity would underlie our immediate impressions of consciousness.

3.2.2. Agnati et al.'s Proposal

Agnati et al. defined consciousness "as the global result of integrative processes taking place at different levels of miniaturization in plastic mosaics" [20].

The authors mainly referred to Cook and Sevush's idea of a single-neuron theory of consciousness [19,84]. Accordingly, the synaptic connections within a network could represent the substrate of cognition, whilst the ion-flows during the action potential could represent the substrate of sentience. The authors claimed that both cognition and sensitivity could be present in the glial cells (other than neurons), which could represent in this way a prerequisite for consciousness and subjectivity. Furthermore, it is postulated the existence of the so-called functional modules representing microcircuits of neurons and astrocytes, which are well-organized in specific patterns to carry out a specific process. The functional modules do not have anatomical boundaries as they are determined by a functional structure. Furthermore, the functional modules are characterized by both vertical and horizontal organizations. The vertical organization includes 3 well-segregated levels, namely the molecular, local circuit, and cell network. Each level is then characterized by a horizontal organization; thus, the molecular level includes transmitters and receptors. The local circuit includes aggregates of synapses working as a unit. The cell network is composed of neurons and glia cells representing a network. A set of different functional modules could correspond to diverse sensory information that needs to be gathered in a high order fashion to give rise to conscious processes. The functional modules perform the first-level integrative functions that transform sensation into perception. The sensory information deriving from the outside world is spread to the cortex by the thalamus, which receives and redirects both sensory (from the outside world to the cortex) and cortical (from the cortex to other structures/nuclei) afferences. The resting-state network (encompassing medial prefrontal, parietal, and cingulate cortices) activity has been considered by the authors as a background condition to bind different information together. However, what is the phenomenon that is directly responsible for such a bind is still under debate. The authors considered the synchronization of the neural activity (detected through the gamma range recording) as a possible explanation [20]. A similar hypothesis was advanced by Cook who affirmed that the contents of both cognition and subjective feeling were grounded in temporal synchronization of synaptic activity and firing of action potentials, respectively [19].

As for the anatomical structures involved in the emergence of consciousness, the authors focused on the key role of the thalamus in receiving and redirecting both sensory and cortical input [20]. Furthermore, they considered the role of the brainstem system as necessary for the emergence of consciousness. The locus coeruleus has a role in the arousal maintenance, the raphe nuclei (by means of its projections) has a role in slow-wave sleep maintenance, and the ventral tegmental area is crucial because of its projections to the limbic and prefrontal cortex (two areas implicated in reward, attention, working memory, and emotions). Lastly, the claustrum is considered as a region of integration between perceptual, sensory, and motor information. Its role is similar to the thalamus, the main different being the integration mechanisms. The thalamus is assumed not to directly integrate the activity of all of its nuclei.

3.2.3. REM Sleep–Dream Protoconsciousness Hypothesis (AIM)

Hobson [21] took into account the definition of primary and secondary consciousness, as postulated by Edelman [85], along with rapid eye movement (REM) sleep and dream models, to hypothesize the existence of waking consciousness, defined as “the awareness of the external world, our bodies and ourselves (including the awareness of our awareness) that humans experience when awake” [21].

He analyzed the difference between the awake experience and the sleep experience in relation to Edelman's definitions [86] before considering the evolutionary and developmental aspects of REM sleep.

Waking consciousness is richer than dream consciousness, especially considering the measurable evaluation between task and brain activity, or between background and foreground processing. This contrasts with dream consciousness, which appears richer than waking consciousness in creating a scenario with different mental images. For the author, dreaming abounds in features of primary consciousness, especially perceptions and emotions, which are produced by the brain without external stimulation, whereas waking is fulfilled by secondary consciousness.

The hypothesis gives particular attention to the cortical-thalamic and limbic systems, which are active in waking and REM sleep for conscious experience. Moreover, this hypothesis considers dream consciousness and REM to start at the age of 5 years or as late as 8 years (there is an open debate on this point). This is when brain development has advanced sufficiently so that the narrative organization of subjective experience becomes possible. Considering that REM sleep appears before dreaming, the authors suggested that REM is one of the first signals that indicates that the brain is preparing itself for gradual development of integrative work among different functions, one of which is consciousness. The activation of the forebrain in the absence of external input during sleep could be important for the provision of an automatic, built-in, self-organized process that offers a spontaneous solution to the so-called binding problem, as demonstrated by the fact that REM sleep enhances sensorimotor integration.

The theory considered three factors that may be computerized: activation (A) (large parts of the brain are not only a collection of passive reflexive circuits but they also possess the means of regulating their own activation); input–output gating (I) and input–output gate control (factor I), which is mediated by a brainstem [87] that guarantees the coordination of factors A and I; modulation (M) (all modulatory brain cell populations in the brainstem during the move of being awake to nREM sleep to REM sleep, the so-called REM-off cells (which are active during waking and inactive during REM sleep [88], and REM-on cells (which are active during REM sleep and inactive during waking)). Joining the AIM model (which proposes that the wake–nREM–REM sleep cycle is the result of interactions between aminergic REM-off cells and cholinergic REM-on cells) to this 'activation synthesis' hypothesis of dreaming [89] (which posits that brain activation during REM sleep results in the synthesis of dream mentation), the authors affirmed that waking consciousness, with its impressive secondary features, might be present only in humans, who have the highly evolved and extensive cortical structures necessary to mediate the abstract aspects of conscious awareness.

3.2.4. Adaptive Resonance Theory (ART)

Grossberg [23] aimed to develop a theory of consciousness that is able to answer to the so-called "hard problem" of consciousness. The authors stated that "consciousness is not just a whir of information-processing" [23], which purports to the already existing adaptive resonance theory (ART), where resonance consists of dynamical states represented by the amplification of neuronal firing and interactions between top-down and bottom-up processes [23]. This resonance is adaptive since it can trigger learning and memory traces. ART's assumption is that "adaptive resonance refers to the fast learning that resonant states can drive" [22]. Resonant states bind together to build coherent world representations (i.e., learned bottom-up categories are bound with learned top-down expectations). The bottom-up categories and top-down expectations are bound only if there is a match between them. The matching between bottom-up external input and the top-down expectation results in resonant states. In this framework, all conscious states are resonant states, but the reverse is not true. The authors stated that the rules of ART align with several sensory and cognitive processes, as attested to by different evidence.

A key process for producing conscious states is represented by attention. The authors enlisted three different types of attention in the framework of the spatial cognition: (i) boundary attention (throughout propagation, the spatial attention selects a certain object for inspection); (ii) surface attention (acting in a scene with eye movements that allow the learning of view-invariant categories); (iii) prototype attention (the kind of attention produced via the ART model, which enhances critical features of certain bottom-up patterns). The latter kind of attention represents the attentional process involved in the ART mode of functioning.

Furthermore, the authors introduced the concept of the stability–plasticity dilemma to explain the way by which the brain can quickly learn new information without falling into catastrophic forgetting. This principle, in the author's view, should be at the base of the way the brain unifies different sources of information into a coherent conscious experience. In order to explain the mechanism at the base of the stability–plasticity dilemma, the authors firstly considered the human beings as both intentional (meaning that the individuals learn expectations and make predictions about what is going to happen in the real world) and attentional (meaning that processing resources are focused on a restricted pool of information each time). If one has some expectations (i.e., searching for an object of a specific color among objects of different colors), then the attentional mechanism leads to the matching process between the bottom-up pattern and the expectations, amplifying the activation of the pattern resulting in a resonant state. In such a framework, only resonant states lead to rapid new learning. Hence, only experiences that attracted our attention and which have been learned can be considered conscious experiences.

As for the neural underpinnings of the learning process, a pivotal role is played by the thalamo-cortical circuit. Indeed, the first-order thalamic nuclei relay the sensory information towards cortical areas whilst the second-order thalamic nuclei receive inputs from low-order cortical areas. The learning of neural representations should correspond to the match between the first- and the second-order thalamic nuclei.

The authors explained the mechanisms underlying the ART model by using the visual system as an example. In this framework, the concept of attentional matching was introduced, meaning that matching between bottom-up and top-down processes were responsible for learning mechanisms. Specifically, whenever an individual receives an input, this can lead to the activation of target cells (bottom-up mechanism), while, at the same time, top-down mechanisms activate the on-center cells (inhibiting the off-surround of the same cells) and the attentional focus arises from the eventual match between top-down and bottom-up mechanisms. The attentional matching is characterized by a reinforcement mechanism as the attentional focus boosts the bottom-up process, which, in turn, emphasizes the top-down process. Thus, the learning process occurs only if there is a good match between bottom-up and top-down processes. Conversely, when something new has to be learned, it is necessary to activate the orienting system. This situation happens with unfamiliar events that are related to a mismatch between bottom-up and top-down mechanisms. This “mismatched” situation elicits a memory search mechanism. Whilst the prefrontal cortex is supposed to be related to attentional matching, the hippocampus seems to be related to mismatch processing. Furthermore, evidence supports an association between attentional matching and faster gamma oscillations, while mismatch processing appears to be associated with slower beta oscillations.

Furthermore, the authors also considered the role of emotions because they are different from visual and auditory inputs since they are internally generated. However, even in this case, a cognitive-emotional resonance process has been hypothesized by using feedback interactions between invariant objects categories, value categories (representations), homeostatic representations, and object-value categories that receive object and value category inputs.

3.2.5. Attention Schema Theory (AST)/Graziano’s Theory

The present hypothesis suggested that awareness is a perceptual reconstruction of the attentional state. The fundamental position of Graziano and Kastner [24] was that consciousness is not an emergent property but is itself information computed by an expert system.

According to previous results [90,91], the authors affirmed that “the machinery that computes information about other people’s awareness is the same machinery that computes information about our own awareness” [24]. In other words, when a subject constructs a perceptual model of someone else’s attention (e.g., “person A is aware of X”), he/she also computes secondary information such as “I am aware of X”. In this sense, social perception is the mechanism through which stimulus representation surpasses neural competition derived from other representations.

For this theory, awareness is a form of meta-social intelligence reconstructing someone else's thoughts, beliefs, or emotions, which also determines the state of someone else's attention. Consequently, when social perception is applied to oneself, it provides not only a description of one's own inner thoughts and feelings but also "a description of one's awareness of items in the outside environment" [24].

To support their hypothesis, the authors cited results from studies on neglect and out of body experience, discussing the role of the superior temporal sulcus, temporal-parietal junction, medial prefrontal cortex, and the frontal-parietal circuits as key areas for social perception. In relation to this point, the authors discussed interesting predictions derived from their theory. For instance, they hypothesized the existence of different kinds of neglect associated with two neural networks—one for controlling attention (neglect caused by damage to parietal-frontal attentional mechanisms) and the other for perceptual attention (caused by the temporo-parietal junction and superior temporal sulcus impairment).

3.2.6. Bieberich's Theory

In the model proposed by Bieberich [25], "consciousness determines what is perceived as reality" [25]. It is composed by sentyons that belong to the physical world.

In the authors' view, the binding mechanism is at the base of the perception of reality, i.e., there are stimuli (visual, auditory etc.) within the space (i.e., environment) that are consciously perceived in an internal space (i.e., endospace); in doing so, the system needs to bind together different information deriving from the space to consciously experience the endospace. This binding mechanism should be operated at the single neuron level. However, according to the authors' view, in the neural space there would only be a summation process without any integration mechanism leading to conscious perception.

The dendritic trees are sites where the input signal starts and are summed with other signals: The sum of different signals, when surpassing the threshold level, provokes the firing of a client neuron. The latter sends the signal to other neurons in the network, and, in turn, it receives recurrent signals from the network's neurons, thus creating a so-called "psychic loop". Furthermore, the dendritic trees in a neuron receive the synaptic activity of different frequencies. Since the signal flowing inside the dendritic trees is slower than the signals' propagation within the network, the signal looping times of a closed and distant network would be the same; this leads to an inverse connectivity due to the reverse relationship between the signal delay times within the dendritic tree and the recurrent signal delay times of the psychic loop. Thus, in the recurrent network with inverse connectivity, the farther the signal travels outside of the client neuron, the shorter it travels inside the neuron when the signal returns. This recurrent network is supposed to have a fractal architecture. The idea at the base is that the maps of a single part (e.g., dendritic tree inside the client neuron) are similar to the whole map (e.g., the neural network). To switch from the whole map to part of the map, a downscaling mechanism should be applied. Both mapping in a fractal way and downscaling are mathematically defined by the author who attempts to explain how these principles could describe how the entire brain functions. By assuming a refractal structure and by applying a downscale computation, it would be possible to describe both macro- and the micro-neural structures. These mechanisms define the recurrent fractal networks intended to underlie the emergence of consciousness as defined by the author.

Within this view, consciousness (derived from the activity of the recurrent fractal networks) resides at a single neuron level. However, because the networks connected between them are structurally fractal, consciousness is also diffused, as hypothesized by the global workspace theory [92].

In discussing the brain areas associated with consciousness, the authors suggested that the olfactory system were the more likely candidate to be the site of consciousness due to neuron features. It could at least represent a system with the minimum requirement for consciousness. Another site linked to consciousness is represented by both the hippocampus and the emotional centers of the brain (such as the amygdala). At a molecular level, calcium has been identified as responsible for the emergence of consciousness. Furthermore, by applying the downscaling, the fractal structure is supposed to present at the molecular level (at the level of ions channels and calcium).

3.2.7. The Cross-Order Integration (COI) Theory

The COI theory provides a hypothesis for the NCC, focusing on the following question: "Why would this particular neural feature, rather than another, correlate with consciousness?" [26].

One of the COI assumptions is that psychological events and states are representations in the brain, some of which can be conscious whilst others can remain non-conscious. Yet we can envisage both a conscious and non-conscious representation of the same stimulus.

Considering Rosenthal [93,94], Kriegel affirmed that "although representing something is not the mark of conscious states, it may well be that being represented is. This family of views is motivated by the basic idea that conscious states are states we are aware of" [26].

According to COI theory, conscious states arise from the integration, or unification (two representations become a single representation), of what is initially separate: (i) a first-order representation of an external stimulus and (ii) a higher-order representation of that first-order representation. Thus, when an individual has a higher-order representation that is unified with the first-order representation it represents, the conscious state consists of this representational unity. In this sense, the COI is different from the high order theories because high order representation is external to the conscious state, i.e., it is unconscious and does not take part in the subject's overall phenomenology.

Therefore, to generate a testable hypothesis about the NCC using the COI theory, the authors identified three levels: (i) a floor-level representation that determines the specific contents of consciousness (e.g., visual and auditory inputs) once consciousness is present, rather than ensuring the presence of consciousness in the first place; (ii) a higher-order representation of that floor-level representation; and (iii) the functional integration of these two representations. There is a neural triad of correlates that need to be pinned down before we can specify the neural correlate of a given conscious state.

According to COI, the second and third elements of the triad—the functional integration with the higher-order representation—constitutes the correlate of consciousness and not the content of consciousness.

The second element requires the ability to direct the cognitive system onto itself (involving prefrontal cortex), which is associated with executive and other forms of cognition functions (e.g., state-metacognition) [26]. Finally, the theory describes the third element as "the process of unifying disparate bits of information into a single representation in a functionally significant way, that is, in such a way that the functional role of the single representation is in some sense more than the sum of the functional roles of the different bits of information making it up" [26].

The COI affirmed that there are seven possible hypotheses about the neural correlates of higher-order representations. Three hypotheses suggest a single neuroanatomical site (the anterior cingulate cortex (ACC), the dorsolateral prefrontal cortex (dlPFC), the medial prefrontal cortex (mPFC)), whereas three other hypotheses suggest two neuroanatomical sites (ACC and dlPFC; ACC and mPFC; and dlPFC and mPFC. Lastly, one hypothesis suggests three sites (ACC, dlPFC, and mPFC).

As for the NCC associated with the third element (integration), the authors cited some studies regarding patients who exhibit "misbinding" or "illusory conjunctions" [95] due to different activities not coordinated by specific brain areas. Specifically, the authors considered the results deriving from research on the visual system to hypothesize that the synchronized activities in the visual and prefrontal cortices would be responsible for a fusion of the visual world- and self-awareness. Consequently, these areas can be considered neural correlates of visual consciousness.

3.2.8. The Centrencephalic Proposal (CP)

The so-called centrencephalic proposal, developed and revisited by Merker [27], is grounded in Penfield and Jasper's assumption of a "highest integrative function which, while anatomically subcortical, is functionally supra-cortical" [27,96]. These authors claim that the brainstem structure plays a pivotal role in determining a certain level of consciousness. Indeed, lesions at the brainstem level can impair normal cortical functionality. Specifically, the main subcortical structures, which are part of this "brainstem system", are the ventral tegmental area, substantia nigra, colliculus, thalamus, raphe nucleus, and pontine reticular formation. According to Merker's view, consciousness can be defined as "the medium of any and all possible experience" [27] and, similarly to Penfield and Jasper's assumption [96], it is determined by sub-cortical activity that influences the cortical one. Within this framework, Merker's theory postulated the existence of the so-called "triangle selection", which encompassed the (i) target selection, (ii) action selection, and (iii) motivational ranking. Each component is stand-alone as they can be defined in their own way; however, they are interrelated as the action selection could depend on the target, and the motivational ranking could influence both the target and the action selection. The authors claimed that to interact with the environment and to take any kind of decision, this interaction must occur in real-time and, usually, it happens in the form of simulation. Using Merker's words, "The way this simulation is structured constitutes a conscious mode of function" [27]. Furthermore, when anyone is conscious, the above-mentioned interaction happens in an ego-centric frame of reference (where the contents of sensory consciousness are disclosed), which could be biased by the motivation. The neural structures involved in such interaction are represented by a system ranging from the colliculus to the periaqueductal gray. The colliculus, however, is considered the key structure in the present theory due to its bidirectional connections with the cortex and its laminar structure, which is strongly related to a multisensory topography. This multisensory layered structure (due to the afferences coming from different cortical areas) leads to a sort of multisensory integration mechanism. Furthermore, when the neural information crosses the collicular threshold, the cortical activity enters the mesodiencephalon, which is considered the first step for a process to be conscious.

3.2.9. The Consciousness State Space Model (CSS)

CSS represents a three-dimensional neurophenomenological model composed of three dimensions: time, awareness, and emotion.

According to the CSS, consciousness is fragmented into two different but interrelated categories [28,29]. The first is core consciousness (CC), which is related to the here and now. For instance, this category supports a sense of agency, ownership, and first-person content (by using the authors' words, "it encompasses the minimal self") [28]. The second category is represented by extended consciousness (EC), which is related to both episodic and prospective memory, as well as to verbal thoughts ("it encompasses the narrative self") [28]. These two categories are organized in an embedded way as the CC represents a 'low-order' category being strongly related to the body-sense, whilst the EC is far away from the body and is related to higher-order cognitive processes. Furthermore, each category is organized along a continuum of three dimensions. Specifically, the time dimension (strongly supported by the mnemonic functions) ranges from past to future (i.e., retrospective and prospective memory-related; EC) passing through the here and now (i.e., working memory-related; CC). Similarly, the awareness dimension extended from an absence of the awareness to a full-awareness state (included in the EC category), passing through a sensory and subliminal bodily awareness (included in the CC category). Moreover, the awareness dimension appears to be related to attentional processes that determine the degree of awareness itself. Finally, the emotional dimension is subdivided into two sub-components, namely the valence component (through which a positive or negative value is ascribed to a specific event; EC) and the arousal component (which represents the bodily and visceral activations in relation to a specific event; CC).

As for the neural underpinning of CSS, the authors attributed the activity of those regions belonging to the default mode network to the EC, whilst the activity of regions implicated in multisensory integration processes would be at the base of the CC. This implies a widespread set of regions underlying the CSS, which encompass both cortical and subcortical areas. Since CC and EC are assumed to be interrelated, the responsible network of such interaction could be represented by the frontoparietal network, which encompass both the executive control network (i.e., dorsal attention network) and the salience network.

3.2.10. Damasio's Theory

The aim of the study by Bosse et al. [30] was to test a simulation model related to Damasio's theory of consciousness [97].

The authors considered three components as conceptualized by Damasio: (i) emotion as a neural representation (deriving from neural activation after a certain change in the environment); (ii) feeling as body change perception (the emotion causes body changes that represent observable emotional states); and (iii) core consciousness (or feeling a feeling) as the detection of the body change after a stimulus has occurred.

To create a simulation model of Damasio's theory, the authors referred to the temporal trace language (TTL; [98]), which allows computing a change of the state if given temporal parameters. For instance, the change of state A into B is computed by considering the duration of state A, the delay from state A to state B, and the duration of state B.

By using this model, an emotion is the result of external stimulation (e.g., auditory), which is detected and induces an internal representation (which is supposed to be multidimensional). This, in turn, prepares the body to act (each representational dimension corresponds to a component of body preparation to action).

The feeling is related to two different dynamics in the model: the “body loop” and the “as if body loop”. The first represents real change in the body and the second represents a cognitive change related to the body instead of a real change in the body.

The core consciousness (i.e., feeling a feeling) occurs when changes caused by the external event/stimulus are detected and attributed to a specific event/stimulus. In this context, the temporal specification plays a pivotal role (see the TTL principles as specified before). Moreover, the authors stated that a false core consciousness could occur when, for instance, two events occur even if only one of these is detected. The body change may occur due to the event not being detected; however, the subject, in this case, would erroneously associate the occurred body change with the only detected event.

For neural correlate concerns, the authors referred to Damasio’s theory, which considers the pivotal role of the cingulate gyrus, thalamus, and superior colliculus [97].

In this framework, subjectivity is outlined as a possible explanation for different feelings related to the same event/stimulus in different individuals.

3.2.11. The Thalamic Dynamic Core Theory (DCT)

In 2011, Ward proposed the thalamic DCT, which is grounded in similar mechanisms explained by other authors. Further, it consists of the synchronous firing of large cortical neuronal population [86,99]. However, different from previous theories, the authors affirmed that neither a specific cerebral structure nor a single specific kind of neural activity is necessary nor sufficient for explaining conscious states [31]. In other words, the theory assumes the existence of consciousness thanks to a distributed neural activity with a central role of the synchronized neural activity in cortico-thalamic circuits. The central role of the thalamus is supported by evidence on both patients with disorders of consciousness and from the functional data during the REM and NREM sleep patterns in healthy subjects. A novelty in this theory is represented by the distinction of two different neuronal populations within the thalamus, although this was already postulated by Jones [100]. Specifically, the “core neurons” are typical of sensory and motor thalamic nuclei and represent relay stations for sensory and motor pathways, whilst “matrix neurons” are typical of non-sensory thalamic nuclei and project mainly to frontal areas bound by the activity of the thalamus and cortex. Furthermore, the authors distinguished the burst mode of functioning as a promotion of sleep, and the tonic mode of functioning as a promotion of wakeful consciousness. In the latter condition, there is both thalamo-cortical and cortico-cortical synchronization, which are promote matrix neurons and are mediated by the thalamo reticular nucleus and brainstem. Within this framework, the cortex represents the site where computation takes place, thus creating the contents of consciousness. The thalamus integrates information derived from the cortical computation.

3.2.12. The Electromagnetic Field Theories

The electromagnetic field theories consider neurons densely packed in the brain, with about 104 neurons/mm^2. The basic idea of this group of theories is that when any neuron receives a signal from upstream neurons, synaptic transmitters stimulate ion pumps that cause the membrane to become negatively polarized. This massive membrane depolarization generates an electromagnetic field perturbation that influences the probability of firing of adjacent neurons, so the electromagnetic fields of adjacent neurons are not discrete but form a complex overlapping field composed of the superposition of the fields of millions of neurons [101].

The key feature of this superposition field is its ability to integrate vast quantities of information into a single physical system. Therefore, it can account for the binding of information for consciousness.

The consciousness electromagnetic information field theory (CEMI). CEMI [32]) is one of the theories that studied the above-mentioned process. Specifically, it affirmed that an electromagnetic field generated by brain activity inevitably influences the membrane's dynamics and the action of ion pumps, thus creating a self-referred "feedback loop" that can represent the physical substrate of consciousness.

The authors suggested that, normally, this superposition field is not influenced by the external electromagnetic field at all, because the high conductivity of the cerebral fluid creates an effective 'faraday cage' that insulates the brain from most natural exogenous electric fields.

In contrast to other viewpoints, the CEMI's proposal is that consciousness corresponds to the component of the brain's electromagnetic field that impacts motor activity in the widest sense [101]. As McFadden wrote: "Digital information within neurons is pooled and integrated to form an electromagnetic information field. Consciousness is the component of the brain's electromagnetic information field that is downloaded to motor neurons and is thereby capable of communicating its state to the outside world" [32]. This process can unify information and account for the unity of consciousness because a field is a continuum of information within space and time dimensions.

The authors criticized the need to use quantum mechanics to explain consciousness because the brain is not an optimal place for quantum coherence, considering the infinite number of information that should be stored in a qubit (unit of quantum information). In this sense, he suggested that our brain may be capable of implementing quantum algorithms to perform quantum computing without the need for physically unrealistic quantum states in the brain [102]. The CEMI accounts for all essential features of consciousness rather than for direct consciousness generation.

The electromagnetic field hypothesis (EM). The hypothesis of the electromagnetic field theory of consciousness by Susan Pockett [33] postulated that conscious experience is identical with certain spatiotemporal patterns in the electromagnetic field.

The theory was based on the idea that consciousness is a local, brain-generated, configuration of patterns, and the hypothesis was also confirmed by the evidence that localized electromagnetic fields are known to be capable of causing neurons to fire, which in principle offer a mechanism by which consciousness can cause a "behavior". Consequently, for this theory, what is important is not individual neurons but the spatiotemporal pattern of neural firing over large groups of neurons, which generates a conscious field-configuration in some circumstances but not in others (explanation of why some processes could be unconscious).

The explanation offered by the present theory is that only some configurations of the electromagnetic field have the property of consciousness, although the definitions of these characteristics have not yet been investigated. The implications of the EM theory should be analyzed considering different perspectives. Specifically, the EM supports the existence of different types of consciousness: the human consciousness probably differs from the consciousness of bats [103] because the spatiotemporal electromagnetic field-configurations generated by a bat's brains differs from those generated by a human brain. Furthermore, it would be theoretically possible to generate specific electromagnetic fields in the total absence of neurons that could be an experimental test of the theory.

The resonator. Lewis and MacGregor [34] proposed a model of consciousness based on the exchange of energy between the mental and the physical realms. Considering the limitation of natural science, they worked on nine hypotheses, two of which are particularly important [34]. The two most important hypotheses are:

- (i)

  Hypothesis 7. The neural foundations and the nature, actions, and properties of consciousness are all describable in terms of a system of resonator elements by which consciousness participates in energy exchanges with the brain, which mediate both the generation of conscious awareness and the active modulation of volitional processes in the brain. All resonator elements produce P → M transformation and engage in collective partially-free M–M selections, but some (perceptual) may produce lesser or no M → P transformation";

- (ii)

  Hypothesis 8. (a) The capacity for consciousness is undergirded by the physical matter of resonator elements, which are target structures of a consciousness gene. (b) Consciousness itself is a dispositional form of energy (DE) that may relate to physical forms of energy, similar to how the phase state of a gas relates in a material way to its liquid phase. Conscious awareness and its selective release are parts of DE and under the partially-free regulation of home resonator DE advised by collective systemic DE. (c) The functional identity of conscious perceptions and feelings is intrinsically determined by the anatomical locations of neurons which either house resonators or are connected directly to non-neural cells which house resonators (the labeled line hypothesis).

Following these hypotheses, the authors introduced the concept of an energy-based resonator, intended as a brain element, that “may receive and project metabolic, traditional neural, and perhaps electromagnetic energy with traditional neural and brain elements”. The consequence of the introduction of the resonator is that the receiving and projecting connections of resonators with neural structures allows for the generation of a composite conscious–subconscious cooperative action [34].

The neural candidates for energy transformation have different locations according to resonator elements, and the theory presumes a special role for the astroglial systems and their modulators of metabolite transmission (e.g., glutamate receptors) to pyramidal cells as the conscious modulators of attention, which is in line with hypothesis number 9 (i.e., consciousness consists of dispositional energy generated by metabolic biomolecules in resonator regions of astrocytes, which undergird attention in the human brain). By merging the electromagnetic models with an astroglial effector, the total resonator’s influence on pyramidal neurons and their apical dendrites can be coupled with modulation of traditional metabolic and neural actions, as well as possible EM effects. This is the core of the theory that also offers an upgrading of consciousness levels citing the Damasio’s model [104].

3.2.13. Gelepithis’s Theory

The theory described by Gelepithis analyzes different approaches of consciousness study, highlighting the problems related to all of them [105], especially for the definition of consciousness derived by these theories. Then, Gelepithis formulated a theory based on seven definitions that compose a definitional system [35]:

Definition 1.

For a human, H, I call neural formation, N, a structure of interacting sub-cellular components across nerve cells able to influence the survival or reproduction of H.

Definition 2.

For a human, H, a neural formation is meaningful (symbol Nm), if and only if it is an N that influences the attention of that H.

Definition 3.

The meaning of a novel Sc (i.e., stimulus within its context), for the human H at time t, is whatever Nm is created by the interaction of Sc and H at time t.

Definition 4.

The meaning of a previously encountered Sc, for the human H, at time t is the prevailed Np of Ɲ.

Definition 5.

A human, H, is conscious of an external Sc, at time t, if and only if, there are Ɲm structures that correspond to Sc and these structures are activated by H's attention at that time.

Definition 6.

A human, H, is conscious of an internal Sc, at time t, if and only if, the Ɲm structures identified with the internal Sc are activated by H's attention at that time.

Definition 7.

A human, H, is reflectively conscious of an internal Sc, at time t, if and only if, the Ɲ structures identified with the internal Sc are activated by H's attention at that time and they have already been modified by H's thinking processes activated by primary consciousness at least once.

3.2.14. The Global Workspace Theory

The Global Workspace Theory (GWT). The core idea grounding the GWT is the presence of an interaction between bottom-up and top-down attentional modulation mechanisms which, throughout a broadcasting process, allows for a specific percept/event to became conscious [106]. This idea has been developed by several authors with slight differences. Baars et al. [38,40,44] stated that several inputs enter the so-called workspace and only the more salient ones are selected and broadcasted, thus becoming conscious. Since the selection of the more salient inputs can affect the already stored internal and external representations, this process has been considered particularly important for the interaction with the environment, thus influencing selection [40,44]. Similarly, Prakash et al. [39] affirmed that some information reaches a sort of buffer and, by means of the top-down attentional amplification, they became conscious. Successively, Raffone and Pantani [41] supported the existence of two different forms of top-down attentional modulation hypothesized in the GWT, namely attention for perception and attention for access. The first is supposed to affect both the phenomenal consciousness (i.e., related to the sensory information; phenomenally conscious states that are not cognitively accessible; [107]) and the access consciousness (i.e., content information broadcasted in the global workspace). Conversely, the attention for access is supposed to only affect access consciousness. Despite the segmentation of the top-down attentional modulation for access perception and attention, the layered model hypothesized by the authors is similar to models postulated in the above-mentioned works [38,39,40]. The authors claimed that the sensory maps generate sensory representations that pass through intermediate levels (i.e., the phenomenal registry and global workspace gate) before reaching the workspace where, thanks to the so-called consumer system, broadcasting process takes place, thus enabling a conscious experience.

As for the neural correlates of consciousness, it has been hypothesized that the key role of an extended cortico-thalamic system is the responsibility of different sensory areas [108] to bind and integrate sensory information. The prefrontal cortex has a pivotal role in the broadcast process and for access to consciousness [41]. Within this system, the thalamus has a key role in redirecting both sensory and cortical input [20]. Furthermore, the mediotemporal lobe plays a crucial role in organizing the subjective experience and episodic memory, following the theory presented by Baars et al. [44].

Besides the anatomical description of the neural correlates of consciousness, some authors supported the pivotal role of the neural firing patterns at the base of consciousness within the GWT. Specifically, Prakash et al. [39] suggested that the spatiotemporal patterns of the electromagnetic fields generated by neuronal firing can be indicative of the emergence of consciousness. Experimental evidence attested to more complex neural electromagnetic dynamics in conscious states/events compared to unconscious state/events. Similarly, Bartolomei et al. [46] considered the neural network synchronization as a key feature at the base of consciousness. It is determined by slow oscillations (theta, alpha, and beta bands) in a long-ray, as well as by fast gamma-band activity at the local level and supported by clinical evidence derived from epileptic patients with alterations of consciousness. Indeed, in this population, alterations of consciousness seem to be mainly caused by slow electrical activity in the associative cortices, which appear deactivated along with a subcortical activity during epileptic discharges. From this evidence, it is hypothesized that hyper synchronization (impairing both local and distant networks) underlies an alteration of consciousness. The neural structures mainly implicated in such hyper synchronization are represented by the corticothalamic system with cortical areas mainly involving the prefrontal and the parietal cortices [46].

Finally, among the retrieved works on the GWT, Sergent and Naccache [43] were the only ones to explicitly reference subjectivity. For the authors, this had great importance in determining what is consciously perceived. Indeed, the authors stated that if someone was conscious of something, he/she must be able to report (either verbally or not) the content of their consciousness. However, subjectivity has not been integrated within the GWT into the author’s article.

The Global Neuronal Workspace hypothesis (GNW). The GNW hypothesis [45] was born from Baars idea of a model where current conscious content is represented within a distinct mental space called a global workspace, which is a structure shared and updated by many specialized modules [45]. The GNW hypothesis proposes associative perceptual, motor, attention, and memory areas interconnect to create a unified space where information is shared in a global blackboard and is sent back to lower-level processors [42]. Dehaene and Changeaux proposed, in their simulations, that this neuronal workspace is anatomically formed by cortical pyramidal cells in layers II/III with long-range excitatory axons, particularly dense in prefrontal, cingulate, and parietal regions, together with relevant thalamocortical circuits [109].

For GNW, what we subjectively experience as consciousness is the selection, amplification, and global broadcasting of a single piece of information selected for its salience or relevance to current goals, while the rest of the neurons composing the GNW are inhibited. In other words, the hypothesis postulated that the availability of information is what we subjectively experience as a conscious state [110].

This global availability of information, which is the main core of conscious access, was hypothesized through two mechanisms. The first is the feed-forward propagation of information, during which input progresses through high-order areas in a feed-forward manner involving all probabilistic representations of the stimuli. All signals converge in high-order areas and then return to lower sensory representations that favor an increase in the power of representations compatible with current goals. The second mechanism postulates that the NMDA-mediated feedback connections (composed of GABAergic inhibitory interneurons) inhibit other neurons from amplifying the input that cross the threshold for the “ignition” and cause a self-amplification of the global state of the selected representation. According to Dehaene and Changeaux [109], “In GNW simulations, ignition manifests itself, at the cortical level, as a depolarization of layer II/III apical dendrites of pyramidal dendrites in a subset of activated GNW neurons defining the conscious contents, the rest being inhibited”. This is in order to prevent multiple ignitions.

The ignition mechanism has an important role in GNW. Some simulations demonstrated that it could fail to be triggered for very brief or low amplitude stimuli because it is not able to achieve sufficient reverberant activation during the feedforward process [111]. Moreover, several experiments with visual stimuli seem to provide robust results about the role of ignition. Indeed, some evidence seems to support that the early stages of non-conscious processing show a linear variation in activation, whereas conscious access is often characterized by a late non-linear amplification of activation through the cortex areas reported above [112,113,114]. The sharing of information creates a global workspace formed by high-level interconnected areas that work differently with respect to non-conscious stimuli, which are processed in parallel by specialized cortical processors. The global workspace allows for the explanation of when a novel operation is required, especially when a behavioral decision requires a subsequential serial strategy [115,116].

In conclusion, the GNW focuses on the well-delimited issue of how an external or internal piece of information goes beyond nonconscious processing and gains access to conscious processing, a transition characterized by the existence of a reportable subjective experience.

3.2.15. Gurwitsch's Theory

Gurwitsch accounted for the totality of conscious experience, delineating its structure and dynamics by using the phenomenological method. Using his words, Gurwitsch proposed a theory of the "articulation of the total field of consciousness and the patterns and forms in which co-present data are organized with respect to each other" [117]. According to the theory, any field of consciousness is organized according to the following three domains: theme, thematic field, and marginal consciousness.

Gurwitsch defined the theme as "that which engrosses the mind of the experiencing subject, or as it is often expressed, which stands in the 'focus of his attention" [117]. The thematic field has been defined as a domain of relevance. It comprises all data co-present with the theme and experienced as materially belonging and related to the theme. Finally, for the marginal consciousness, Gurwitsch claims that data in the margin are irrelevant to the theme. The only relation between marginal data and the theme is simultaneous occurrence. These are "data which, though co-present with, have no relevancy to, the theme" [117]. The author elaborated upon three distinct categories in marginal consciousness: (1) Self-awareness, which consists of awareness of one's own inner thoughts, a stream of ideas, concepts, and inner speech running through the mind. Gurwitsch states that "self-awareness permanently and necessarily pervades all of our conscious life" [118]. The author referred to the self we are aware of in the sense of our "psychic self". In addition to the sense of our psychic selves, we also have an ongoing sense of our bodies, corresponding to what Gurwitsch calls the corporeal or "somatic" self: "There is no moment in conscious life when we are completely unaware of our bodily posture, of the fact that we are walking, standing, sitting, lying down, etc." [118]. Finally, insofar as we are aware of our body, we are aware of it as positioned at some location in the physical world, according to Gurwitsch: "Our body appears in experience under the perspective of the perceptual world and derives its positional index... from this horizon" [118]. Thus, we always have at least some marginal consciousness of where we are in the perceptual world: "The perceptual world has...the privilege of omnipresence" [118]. According to Gurwitsch, we pass from the theme to an item in the thematic field along a "line of relevancy". Regarding relevance, the author wrote: "Two co-present items in the field of consciousness are relevant if they are felt to be 'intrinsically related' due to their 'material contents' transition". In contradistinction to marginal data, items belonging to the thematic field not only present themselves along with the theme but are also experienced as intrinsically related to the theme due to the material content involved.

Yoshimi and Vinson, in 2015, proposed an extension of this theory, focusing on three points [37]:

1. Considering some results about inattentional blindness and changes in blindness, subjects sometimes fail to report seeing anything, so they hypothesized that there also exists a peripheral experience.
2. They distinguished several types of relevance, showing how one of these concepts (i.e., “causal relevance”) can be empirically tested. They introduced a new type of relevance called “predictive relevance”.
3. They developed the idea that the theme has a “variable size”, expanding and contracting, and sometimes disappearing.

Furthermore, Yoshimi [36] showed phenomenological and connectionism approaches as having the same mathematical solution for some problems, e.g., giving an interpretation of the space of possible brain state and the relationship with a possible conscious state using connectionist dynamical system approach. He described some axioms in his approach, such as the idea that the base state of a system at a time is sufficient for determining the main state of that system at that time.

3.2.16. The Representational Theories: High-Order (HOT) and First-Order (FOR) Models

The representational theories affirmed that consciousness is directly linked to “mental representations” rather than to a physical state. The main technical question related to this group of theories could be expressed as followed: What makes a mental state a conscious mental state?

The representational theories were mainly divided into two groups: FOR and HOR representationalism.

There are several varieties of HOR yet they all share common neural correlates at the level of the prefrontal (PFC) and parietal cortex, which assumed a crucial role for the creation of high representation that link different information. Conversely, the FOR performs a distinction between post-sensory structures that correspond to the same neural correlates of consciousness in the HOR, which determine the so-called “general consciousness”. Further, sensory structures correspond to specific neural sensory areas and sensory thalamic nuclei, deputing to the so-called “specific consciousness”, which corresponds to the contents of consciousness [50]. HORs, based on the thinking of Locke and Kant [119,120], contrast with FOR, which affirmed that perceptual representations formed in the sensory regions and are able to determine a conscious mental state, as reported by Dretske [121] and Michael Tye [122,123]. In other words, the HORs affirmed that consciousness depends on the supra-mental representation, while the FOR argued that the supra-mental representation must be determined by a specific content so that the sensory structures have a pivotal role in determining specific consciousness [50].

The high-order thoughts (HOT) theory, one of the most cited HOR theories, posits that consciousness awareness depends mainly on mental representation in the terms of mental states that represent oneself as being in a representational character of a first-order representation [48]. In other words, as Rosenthal wrote, “What makes a mental state M conscious is that it is the object of some kind of higher-order mental state directed at M” [124]. To empirically sustain this position, Lau and Rosenthal [48] considered the results from different studies, showing how transcranial magnetic stimulation (TMS) applied to PFC can affect the awareness in healthy subjects without impairing their task performance [125].

At the moment, the debate about HOR and FOR is sizable, although it is important to observe the critical consequence derived from HOR, including the fact that “if PFC activity is necessary for all conscious experience, and if there is little or no PFC activity in infants and most animals, then either infants and most animals do not have conscious experience”, as was noted by Gennaro [126].

3.2.17. The Integrated Information Theory (IIT)

The IIT tries to explain the enigmas of conscious experience. Within this framework, Tononi [52] offered a mathematical definition to measure whether a system is conscious, to what degree it is conscious, and to explain consciousness itself. The IIT claims that consciousness is determined by its causal properties and it is, therefore, an intrinsic, fundamental property of any physical system. Consciousness is linked to integrated information (identified by the symbol φ), which represents the information generated by a system that goes beyond what can be explained by its parts working independently [51]. The IIT identified the main properties of consciousness, namely information and integration. Information is defined as the reduction of uncertainty; indeed, it is the ability to discriminate among many alternatives. Thus, the more numerous alternatives to be excluded, the greater the reduction of uncertainty, and thus the greater the information [52]. Integration allows the unity of experience, which is due to causal interaction between the elements of a system. Thus, if they are disconnected, their performance breaks down [52].

More precisely, Tononi explains both the quantity and the quality of consciousness. The first corresponds to the amount of integrated information generated by a system and it corresponds to its irreducibility, φmax (i.e., the highest value of φ). The second is identified by the set of informational relationships generated within that complex system [52,54]. The quality of consciousness could be geometrically represented within a space, called qualia space, in which it is possible to see the complexity of informational relationship that determines it [52]. Citing Tononi: “Qualia space (Q) is a space where each axis represents a possible state of the complex, each point is a probability distribution of its states, and arrows between points represent the informational relationships among its elements generated by causal mechanisms (connections)” [52].

The cortico-thalamic system is one of the most important NCCs for IIT since cortical damage leads to the permanent loss of consciousness. On the contrary, the cerebellum removal, even if it is full of neurons, does not considerably hurt consciousness [52]. The IIT addresses the hard problem of consciousness by proposing a set of phenomenological axioms, ontological postulates, and identities. The axioms are as follows [15,55]:

- Existence: Consciousness exists—it is an undeniable aspect of reality. Paraphrasing Descartes: "I think, therefore, I am".
- Composition: Consciousness is compositional (structured)—each experience consists of multiple aspects in various combinations. Within the same experience, one can see, for example, left and right, red and blue, a triangle and a square, a red triangle on the left, a blue square on the right, and so on.
- Information: consciousness is informative—each experience differs from other possible experiences. Thus, an experience of pure darkness is what it is by particularly differing from an immense number of other possible experiences. A small subset of these possible experiences includes, for example, all the frames of all possible movies.
- Integration: consciousness is integrated—each experience is (strongly) irreducible to non-interdependent components. Thus, experiencing the Italian word "SONO" (i.e., I am) written in the middle of a blank page is irreducible to an experience of the Italian word "SO" (i.e., I know) at the right border of a half-page, plus an experience of the Italian word "NO" (i.e., no) on the left border of another half page—the experience is whole. Similarly, seeing a red triangle is irreducible to seeing a triangle but no red color, plus a red patch but no triangle.
- Exclusion: consciousness is exclusive—each experience excludes all others. At any given time there is only one experience having its full content, rather than a superposition of multiple partial experiences; each experience has definite borders—certain things can be experienced while others cannot; each experience has a particular spatial and temporal grain—it flows at a particular speed and has a certain resolution such that some distinctions are possible, whereas finer or coarser distinctions are not.

The postulates are sufficient conditions concerning the requirement that each system has to satisfy to account for experience (reported from [55]):

- Existence: mechanisms in a state exist. A system is a set of mechanisms.
- Composition: elementary mechanisms can be combined into higher-order ones.
- Information: a mechanism can contribute to consciousness only if it specifies "differences that make a difference" within a system. That is, a mechanism in a state generates information only if it constrains the states of a system that can be its possible cause and effect repertoire. The more selective the possible causes and effects, the higher the cause–effect information specified by the mechanism.
- Integration: a mechanism can contribute to consciousness only if it specifies a cause–effect repertoire (information) that is irreducible to independent components. Integration/irreducibility φ is assessed by partitioning the mechanism and measuring what difference this makes to its cause–effect repertoire.

- Exclusion: a mechanism can contribute to consciousness at most one cause–effect repertoire, the one having the maximum value of integration/irreducibility φMax. This is its maximally irreducible cause–effect repertoire (MICE, or quale sensu stricto (in the narrow sense of the word)). If MICE exist, the mechanism constitutes a concept.

Finally, identities are posited between phenomenological properties and informational/causal aspects of systems. IIT identifies the central identity as follows: "An experience is a maximally integrated conceptual information structure" [53].

The maximally irreducible conceptual structure (MICS) generated by a complex of elements is identical to its experience. The constellation of concepts of the MICS specifies the quality of the experience (its quale "sensu lato"; i.e., in the broad sense of the term). Its irreducibility ΦMax specifies its quantity. The maximally irreducible cause–effect repertoire (MICE) of each concept within a MICS specifies what the concept is about (how it contributes to the quality of the experience, i.e., its quale sensu stricto, in the narrow sense of the term), while its value of irreducibility (φMax) specifies how much the concept is present in the experience. The experience is thus an intrinsic property of a complex of mechanisms in a state. In other words, the maximally irreducible conceptual structure specified by a complex exists intrinsically (from its own intrinsic perspective), without the need for an external observer.

3.2.18. Layered Reference Model of the Brain (LRMB)

Wang et al. developed the LRMB theory [127], which affirms the hierarchical life functions of the brain as being divided into two categories. The first one is the subconscious life functions encompassing the layers of sensation, action, memory, and perception. These functions are provided by layers 1 to 4, which are inherited, fixed, and relatively matured when a person is born. The conscious functions include the layers of metacognition, inference, and cognitive functions sustained by layer 5–7. These functions are acquired, highly plastic, and intentionally controlled based on willingness, goals, and motivations [58]. In the model, the thalamus and cerebellum are considered key structures for consciousness. The role of the cerebellum in the cognitive and logical approach to consciousness was analyzed by the author who declared that it has a functional role of conscious status memory (CSM), which is a "new type of memory identified in the brain, it is supplementary to other types of memories such as the short-term, long-term, sensory buffer, and action-buffer memory" [127,128,129,130]. The thalamus, instead, was considered as a processor, empathizing its role of switching center through the number of connections to almost all parts of the brain such as the cerebral cortex, eyes, and visual cortex [131,132,133,134].

Analyzing the mathematical, cognitive, behavioral, computational, and structural models of consciousness, Wang et al. described the cognitive process of consciousness using denotational mathematics. They affirmed that a conscious state is a function (fc) that maps a Cartesian product of entire events (E) and the current status of conscious status memory (CSM) into an updated state of the memory in CSM. Entire events in an individual’s brain can be classified as external stimuli (S) and⁄or internal motivations (M), E =S u M. Thus, external and internal sub-functions of consciousness (fc-e and fc-i) can be expressed using individual or combinatorial expressions.

3.2.19. The Memory Consciousness and Temporality Theory (MCTT)

Dalla Barba and Boissè [59] redefined the concept of consciousness in the framework of the MCTT. Specifically, they claimed that consciousness is always related to a certain object. In other words, when someone is conscious, he/she is always conscious of something. Furthermore, they distinguished between temporal and the knowing consciousness. The latter refers to specific features of an object; consequently, there are many knowing consciousnesses that refer to the same object. Temporal consciousness, instead, encompasses three other different sub-categories of consciousness. The first one is represented by past consciousness, which corresponds to the remembering of something. This is strictly related to the self; it is not a piece of generic semantic information related to the past. The second category is represented by present consciousness, which is different from other constructs, such as the “objective present” and the “psychological present”, as postulated by William James. Present consciousness encompasses all the present events, perceptions, and sensations related to the self. The third component is represented by future consciousness, which encompasses the future possibility of being (taking into consideration the past and the present). The three components altogether (i.e., the temporal consciousness) make it possible for the temporal existence for the subject. Furthermore, the temporal consciousness allows one to perceive the uniqueness of an object against its multiplicity, which is, in contrast, related to knowing consciousness (e.g., I perceive one specific pen as mine rather than a generic object belonging to the category “pen”). For what concerns the neural correlates of consciousness, the authors claimed a key role of the mediotemporal lobe and its related structures in determining the temporal consciousness. However, their hypothesis was developed to better frame the confabulatory behavior of patients suffering from brain damages.

3.2.20. The Mesocircuit Hypothesis

In 2010, Schiff formally described the so-called “mesocircuit hypothesis”, which considers the thalamus (and globus pallidus) as the key structure for conscious states due to its widespread direct and indirect connections with both brainstem and frontal areas [60]. The author notes that in normal conditions medium spiny neurons (MSN) in the striatum inhibit the globus pallidus interna, thus allowing the thalamus to communicate with the frontal brain areas, which, in turn, project to the striatum. If the inhibitory mechanism of the striatum ceased, the globus pallidus interna inhibit the thalamus, thus shutting down the necessary connections and activity needed to sustain a conscious state. Consequently, the entire network would appear dysregulated, and, without thalamic input, the frontal areas would not be able to communicate and regulate the striatum activity anymore. This theory accounted for both evidence from patients with disorders of consciousness following thalamic damages (see for example [135]), from neuromodulation studies [136,137,138] and the mechanisms underlying the paradoxical effect of the Zolpidem in restoring the level of consciousness, thanks to its inhibitory action on the globus pallidus interna.

3.2.21. The Min's Model

In 2010, Min defined consciousness as "a mental state embodied through thalamic reticular nucleus (TRN)-modulated synchronization of thalamocortical networks" [61]. More specifically, it "consists of each mental unit, which is an individual thalamocortical looping mechanism, no matter what cognitive stages it involves" [61]. According to the present theory, the TRN could act as a mediator for the signals derived from the other thalamic nuclei to the cortex and vice versa, exercising in this way a sort of "control" over the thalamic activity in a feed-forward fashion. Specifically, the neural synchronization is considered as a prerequisite to neural signal association, and it seems to be at the base of conscious events. In physiological terms, the synchronization takes place thanks to the inhibitory GABAergic neurons, which allow for the detection of classic gamma range signal (>30 Hz) (in general, the gamma range signal indicates the presence of information processing within a network). Because the TRN is equipped with GABAergic neurons, it is plausible that it is responsible for the synchronization of the cortical and thalamic neural activities given the rise of information processing and, hence, consciousness. In other words, the author's hypothesis considered that the emergence of consciousness due to the thalamocortical activation above a specific threshold level could determine the synchronization of neural activity. Thus, it is predicted that when the system does not reach the threshold level of activation, the sensory stimuli simply pass through the thalamus without becoming conscious. Furthermore, the contents of consciousness are supposed to be determined by the degree and the distribution of the cortical activity. Indeed, given the connections between the TRN and the cortex, the presence of an attentional top-down modulation operated by the prefrontal cortex can be postulated. Specifically, the attention could act as a signal amplifier whilst it eliminates unnecessary information. At the same time, the working memory retains the elements which are processed during the so-called "attended conscious awareness" [61]. Even if the attentional process is strictly linked to the prefrontal cortex' activity, this theory assumes the pivotal role of TRN in triggering prefrontal cortex activity. However, the attentional process is considered optional to the so-called "conscious awareness" and insufficient for the emergence of consciousness. The theory takes into account a background condition to be conscious, which is represented by arousal. Arousal is indeed considered a necessary condition for consciousness and, even in this case, it is assumed that it serves pivotal role for TRN due to its connections with the brainstem [61]. Finally, given the TRN' modular structure (i.e., different sensory-modality maps exist within the TRN), the emergence of a unitary consciousness awareness is explained via a characterization of shagginess across the boundaries of the receptive fields of the TRN neurons [61].

3.2.22. The Network Inhibition Hypothesis (NIH)

The NIH aims to explain consciousness from the evidence reported in epilepsy studies [5]. The idea is that the so-called "conscious system" is analogous to other systems (e.g., motor, limbic, etc.) by involving different cortical and sub-cortical structures and that consciousness system must include neural areas that govern functions such as attention (i.e., a prerequisite for consciousness), awareness, and an alert state. In this sense, the medial thalamus, upper brain stem, hypothalamus, interhemispheric regions (including medial frontal cortex, cingulate cortex, and precuneus), lateral frontal, and temporal-parietal associative cortices seem to be important structures involved in the loss of consciousness due to the absence of seizure. Therefore, they could have a role in the appearance of consciousness [5]. The authors observed that the high-frequency neural activities in the temporal lobe during seizures reach the midline sub-cortical neurons and are correlated to an inhibition of frontal and parietal activities with a decrease in cerebral blood flow (CBF), as shown by studies that used single photon emission computed tomography (SPECT; [139,140]). The NIH hypothesized that loss of consciousness is a secondary effect due to the dysregulation of the networks described above and that focal limbic seizures propagate subcortical structures involved in the arousal systems. This could be correlated due to decreased activity in the fronto-parietal association cortices [141] caused by an increase in effective inhibition, or a decrease in effective excitation, within these networks [141].

The NIH affirmed that the upper brainstem interacts with the cerebral cortex to maintain wakefulness. However, during seizures, if they remain confined in the mesial temporal lobe, then a simple-partial seizure occurs without impairment of consciousness. In the case of seizure activity from the temporal lobe to midline subcortical structures, the propagation of the contralateral temporal lobe is possible. Finally, the NIH hypothesized that temporal lobe seizures inhibit the subcortical arousal systems leading to activity decrement in the bilateral fronto-parietal associative cortex, causing a deep sleep-like activity that is followed by the loss of consciousness.

3.2.23. O'Doherty's Theory

In O'Doherty's view, "Consciousness represents the storage of past events for use in future situations and it is altered by external experience of the organism", resulting "from the gradual evolutionary development of the human information processing function" [62].

The framework adopted by the author encompasses evolution, learning, and behavioral theories. Hence, consciousness can be conceptualized as the product of an interaction between an individual and the environment, rather than something located inside the individual himself/herself. The author's attempt is to overtake both dualistic and monistic notions of consciousness. Furthermore, language is considered a precursor of consciousness in an evolutionary fashion.

In other words, consciousness could be the result of an evolutionary process involving both learning mechanisms and information processing, which must be conscious (different learning and information processing exist that take place without awareness). Furthermore, the language is supposed to be involved in coherently connecting the experiences with their outcomes, so that language allows the categorization of past events and the access to them. Within this view, memory is considered a prerequisite for language development, as it allows for information storage. Finally, qualia are considered as a key feature of consciousness since an individual cannot be conscious in the absence of an experience/stimulation and its storage. Furthermore, the experience of qualia can be modified through language (which builds links between different stored information) and the interaction of an individual with other individuals and the environment (as it happens, for instance, in sensory illusions).

3.2.24. Passive-Frame Theory (PFT)

The PFT, proposed in 2015 by Morsella et al., represents a framework within which consciousness can be viewed as a phenomenon strictly related to voluntary actions. Indeed, the authors defined consciousness as “a phenomenon associated with perceptual-like processing and interfacing with the somatic nervous system” [63]. In other words, consciousness determines the skeletal muscle outputs to produce adaptive behavior when different motor plans are available and in conflict with each other. This conflict arises due to the awareness of different contents (i.e., what is experienced in a given moment), which requires specific actions to reach the goal. The sum of the conscious contents represents the conscious field, which is continuously updated (through the frame-check process) to select the most adaptive skeletomotor plan in that moment.

As for the neural correlates of consciousness, the authors considered different evidence, concluding that both the sensorium hypothesis [142,143] supporting the pivotal role of perceptual regions of the brain along with subcortical structures, and the hypothesis supporting the pivotal role of cortical circuits, are valid. To disentangle the role of cortical regions and perceptual regions, they suggest future research study simple neural systems such as the olfactory one.

The theory did not analyze the subjectivity dimension which corresponds to the first-person perspective in the authors’ view.

3.2.25. A Psychological Theory of Consciousness (PToC)

Shannon proposed a theory from a psychological and phenomenological point of view [64]. He defines consciousness as a multifaceted phenomenon that includes different forms that be sorted into clusters. Originally, Shannon identified three types of consciousness (identifying consciousness as the region of the internal subjective experience), hierarchically ordered and interdependent among them. They form a well-integrated system, which is defined as a “tripartite system” [64].

The first type of consciousness is the Cons1, the “sensed being or sentience”. It concerns the primitive and elementary aspect of consciousness that distinguishes living from non-living organisms. It has no specific context or structure, it is pervasive, and it is present all our life [144,145]. The Cons2, called “mental awareness”, is typical of higher-order mammals and is related to subjective experience, as well as to the contents and forms of those experiences, such as mental images, ideations, flows of consciousness, and internal verbal monologues. The Cons3, called “meta-mentation”, is the mental ability to take its own productions as object for further reflection. This type of ability has different manifestation, such as meta-observation, reflection, monitoring, and control. The Cons2 and Cons3 are interrelated and someone can go up a level (from 1 to 2) without stepping down onto level 3 [64].

The system of consciousness encloses different regions and each one presents different levels: There is the self (self 1, 2, 3) concerning personal identity, the world (world 1, 2, 3), which is inherent in the relationship between knowledge and world and, finally, the temporality (temp 1, 2, 3) that concerns the temporal part of the experience.

Shannon [64] has identified other non-ordinary levels of consciousness, which are considered “mystical experiences”, namely Cons 4 and 5. Cons 4 involves internal subjective experiences that the person does not feel like the product of his/her own mind (i.e., hallucinations); Cons 5 is considered by Shannon as “the highest state of mind”, according to which the inner subjective experience leads the subject to experience things as coming from something supreme. It is a phenomenon very similar to nirvana and to the bliss that implicates the transcendence of the self and thus becomes ineffable [64].

This theory also provides a structural analysis of consciousness, through the identification of a series of parameters. The first parameter concerns the sense of perception, as well as sensory information recording and perception and how they are considered pertinent to reality; the parameter of the sense of meaningfulness concerns the meaning attributed to the perceptual experience, while the aesthetic sense parameter allows giving organization and composition to experienced things.

Moreover, Shannon [64] described five main features of consciousness: the quality of sentience; having experiences; making experiences the object of reflections and mentations; orientation and disposition towards others; the eventual capacity for transcendence.

The author specified that consciousness is a dynamic system subjected to different operations. The first processes are differentiation and crystallization (from which the different levels of consciousness specified above arise). The process of distancing allows separation from the sentient being between one’s inner world and the surrounding environment and, therefore, permits a distinction between subject and object. This process is more evident towards the highest level of consciousness, even if it tends to decrease in Cons 4 and 5.

For what concerns the internalization, Shannon [64] stated that consciousness creates a mental domain in which the cognizer may operate even when actual action in the real world is not feasible. Moreover, Shannon described the reflexivization as a dynamic mental operation through which the products of mentation, in turn, generate other mentations; externalization, instead, concerns the ability of the mind to create objects that are not part of reality, even if they are experienced as real, e.g., hallucinations. Finally, PToC reported the semantic operations, which are defined as "semantic composition or narrativization, the poesis, metaphoricity, and enhanced creativity encountered in the psychedelic state, the interplay between losing oneself and concentrated control achieved in masterly skilled performance, role playing, and the adoption of modified identity as in the metamorphoses" [64].

3.2.26. Q-Theories

In this section, we summarize the different theories based on hypotheses that implied quantum mechanisms to explain the appearance of consciousness.

The four-dimensional Einstein. Sieb [74] affirmed that conscious experience oriented in space and time is fundamental for a coherent conscious experience. Considering that there are three dimensions of space (length, width, height; when one person analyzes the experience of a room where one is reading this paper, there are many events like light, walls, windows, etc. separated in time) and one dimension of time (e.g., moving the mouse of a PC we observe a series of events separated in time and having cause–effect and past–future relationships), conscious experience can be said to have four dimensions.

Taking into account that space–time is any mathematical model that combines space and time into a single continuum [146], the author considered the notion of space cells [147,148] and time cells of the hippocampus, following the MacDonald idea according to where place cells and time cells reflect fundamental mechanisms by which hippocampal neural networks parse any spatiotemporal context into quantal units of where and when important events occur, thereby organizing elements in a conceptual manner [149].

The authors suggested that the posterior parietal cortex (PPC) and prefrontal cortex (PFC) may extract space-time interval inequality information from the hippocampus in a process of relational integration [74,150]. The authors considered that the sensory neurons involved in this representation of the information, whenever present in the environment, are the same that maintain the information in working memory. In this case, the role of PFC not only contributes to working memory but, instead, manages attentional focus to select information and allows for the executive functioning to control cognitive processes.

In this macro system, quantum mechanical description is close to the classical description, and the authors suggested that conscious experience is when quantum systems and classical systems agree. In other words, when we represent a quantum system in conscious experience, we represent the system as a large (macroscopic) system wherein it is possible to use classical physics to describe it [74]. For example, the authors reported that our visual system transforms a quantum mechanical feature into the classical physics of conscious experience, so that wave-particle duality is reduced to classical physics in conscious experience.

Koehler's mathematical approach. Koehler's work was devoted to analyzing the possibility of checking experimentally regarding whether the perceptual process can lead to the collapse of the wave function. The author demonstrated that it is possible to describe the quantum collapse using a new Clifford algebra, obtained by the assignment of a numerical value in A(Si) by our cognition, which determines new commutation rules [68].

The idea is that a mathematical proof of the collapse of the wave function could be given every time we observed a direct cognitive attribution of a numerical value to the basic element of the A(Si). In other words, the author affirmed that the quantum collapse is a transition from a superimposed linear dynamic to a new dynamic in which a semantic act (the direct involvement of information, relating mental entities whose consciousness is the basics representative) is involved. For example, the act of seeing starts when the image is formed on the retina, an image which is not considered as a simple photodetector but, according to this new approach, as part of the brain that allows the perceptual and cognitive processes to be directly involved in the analysis of information following the role of quantum mechanics [68].

A Holoinformational Model of Consciousness. Di Biase [151] proposed a quantum-informational holographic model of brain–consciousness–universe interactions based on the holonomic neural networks of Karl Pribram [152] (found in the holographic quantum theory developed by David Bohm [153]). Pribram developed a neural wave equation, demonstrating that the cerebral cortex is the site of a holographic information process called a multiplex neural hologram, which is dependent on local circuits of neurons without long fibers that do not transmit ordinary nervous impulses. “These neurons function in the undulatory mode and are above all responsible by the horizontal layer connections of the neural tissue where holographic interference patterns can be built” [154]. Therefore, the author's model affirmed that the “quantum holographic brain dynamic patterns are conceived as an active part of the universal quantum-holographic informational field, and capable of generating an informational field interconnection that is simultaneously nonlocal (quantum-holistic) and local (Newtonian-mechanistic), i.e., holoinformational”. In this conception is the holoinformational non-local flux that permits the interaction of holonomic informational quantum brain dynamics—this theory considers the viewpoint of Eccles [155] extended dendrons with the quantum-holographic nature of the universe.

The orchestrated objective reduction (Orch OR) theory. The Orch OR theory [71] is grounded on quantum physics. Penrose noted that one of the fundamental questions in the study of consciousness is “how it is that any physical structure whatsoever can give rise to the puzzling phenomenon of awareness?” [156]. The theory, in contrast to strong artificial intelligence positions, which argue that all mental processes can be reduced to computational models, affirmed that consciousness depends on processes of the general nature of quantum computations that occur in the brain.

Using the argument of Gödel’s theorem [157], Penrose supports the view that consciousness is not a feature of computational activity, thus taking into consideration the mathematical possibility that non-computational activity could be the base for the appearance of consciousness [158].

Consequently, Stuart Hameroff and Sir Roger Penrose developed a new theory called “orchestrated objective reduction” (‘Orch OR’), in which the main actors are (i) the “objective reduction” (OR) and (ii) the brain microtubules as anatomical structures in which the quantum computation occurred.

The idea starts from the measurement problem derived from the two fundamental procedures in quantum physics. The first concerns the deterministic evolution of a quantum state linked to the Schrödinger equation [159] whilst the second is related to the collapse of the wave function, where probabilistic rules seem to be involved when a measure of a quantum state in a system is needed (measurement problem). Penrose supposed that an objective form of quantum state reduction (OR) could be a solution of this problem, hypothesizing that consciousness could be dependent by quantum computation present in the brain that terminated OR in some form.

As reported by the author, the “orchestrated objective reduction is a theory which proposes that consciousness consists of a sequence of discrete events, each being a moment of ‘objective reduction’ of a quantum state” (according to the Diósi–Penrose objective reduction scheme, where it is taken that these quantum states exist as parts of a quantum computations) [160]. This is primarily carried out on in neuronal structures. In Orch OR, consciousness is a collapsed, self-organized process on the edge between quantum and classical realms as reported by the authors [71].

The authors sought out structures in the brain that support such putative non-computational actions at the borderline between quantum and classical physics, which could plausibly have important influence on brain activity. In this sense, Hameroff suggested the role of microtubules (i.e., polymers with cylindrical forms of around 25 nanometers of diameters, a length of a few hundred nanometers, probably up to meters in long nerve axons) as one of the major components of the structural skeleton prevalent in neurons.

The theory affirmed that for OR to be operative in the brain, a super position of sufficient amounts of material accounting for gravitational self-energy is needed, undisturbed by environmental entanglement, where this reduction occurs following the above OR scheme in a specific time scale in line with conscious experience. Pragmatically, authors affirmed that a coherent quantum super position/computation evolves during the integration phases in integrate-and-fire brain neurons (the most logical place is supposed to be the post-synaptic dendrites and somata). This causes an increase in quantum super position until the threshold is met at time $\tau \approx \bar{h}/EG$ (where τ is the time until OR occurs and $\bar{h}$ is the reduced Planck constant), when a conscious moment occurs. Each OR selects microtubules' output states that govern axonal firings and regulate synapses. Synaptic inputs 'orchestrate' these quantum computations, from which they derived the name "orchestrated objective reduction" (Orch OR), a process that, in a progressive large scale, could be the base for consciousness.

The Quantum no go theorems and consciousness. Georgiev's viewpoint is related to two problems intrinsically linked to theories of consciousness [6]. The first consists of the fact that the material world in classical deterministic physical theories is causally closed [161]. In other words, if brain states produce conscious experiences, then these experiences cannot possibly have an effect upon brain dynamics, which is already fully determined by the fundamental physical quantities of the brain such as mass, charge, length, and time.

The second problem is represented by the illusion that consciousness is able to make a choice between alternatives as a "free" system, since the deterministic frameworks make it an illusion produced by our subjective brain [162].

The author considered that consciousness should work in a real short time window, and that decoherence time for quantum states within cytosketal proteins was estimated to be around 0.1 picosecond [163]. This could be coherent with consciousness process, considering that minds operate on a millisecond timescale and that a theory of consciousness consider this issue.

Moreover, the author provided mathematical proofs on the first two no-go theorems [164,165], positing that they invalidate Frankfurt's celebrated argument on the principle of alternate possibilities [166,167]. Georgiev's main idea is related to the fact that "because there is no measurement of q-bit A that would allow one to distinguish unequivocally between any pair of non-orthogonal states, it follows that unambiguous determination of an individual quantum state jWAi of a q-bit A is impossible by only measuring the q-bit A" and subsequently that "an unknown quantum state jWAi of a q-bit A cannot be cloned to another q-bit B". This implies that quantum theories of mind are the best candidates to explain consciousness, rather than the classical determinist theories of mind, as they avoid some paradoxes, such as the possibility to create perfect copies of one's mind (and brain), the non-existence of self-identity, and Frankfurt's thesis stating that free will exists in cases where the subject could not have done otherwise, guaranteeing the privacy of the mental state and our free will in relation to the presence of multiple choices [6].

The single particle consciousness hypothesis. Argonov [69] studied the unity of consciousness as one of the most important problems when approaching a consciousness theory. How spatiality and time unities to form stream of consciousness is a main topic. The author does not support the idea of macroscopic coherency as a collective quantum phenomenon working like a single super-particle [158], as well as the idea that microscopic intracellular collective quantum effects are more realistic than the macroscopic ones. Specifically, the author suggested that each electron has its consciousness, following the idea of Bohm and Hiley who said that “in some sense a rudimentary mind-like quality is present even at the level of particle physics. As we go to subtler levels this mind-like quality becomes stronger and more developed” [153].

The fundamental issues of this hypothesis are as follows: “Each electron (or fermions) is the subjective ‘observer’ of its quantum dynamics (energy, momentum, ‘shape’ of wave function). Each electron ‘feels’ its quantum dynamics as ‘own’ subjective sensations and volition” [69]. Most of the electrons (or fermions) in the universe have a primitive consciousness. However, some particles in biological cells (especially in the brain) have complex consciousness due to complex dynamics in complex organic environment. Animals are hierarchical structures of particles. Some chemically active electrons in animal brains are “on the top” of the hierarchy. Their dynamics are directly influenced by sensory data and have a direct influence over animal behavior. The author called them “pontifical particles (PPs)”.

These electrons work following synchronized dynamics in one brain and they “feel” the same performance and volitional act. The human brain might have many observers that share a similar “human” mind.

Argonov supposed that PPs or pontifical syncytium (i.e., networks of neuron connected, with common cytoplasm and many nuclei) [168] may be placed in voltage-gated ion channels (chemically active electrons in carboxyl groups of amino-acid molecules), which play a functional role in axonal signal transmission involved in different activities, such as thinking.

The three-layer model. The idea of this model is that there are different kinds of consciousness sustained by different neural correlates [73]. The proposed model considers communication among preconscious states, from maps to a single consciousness [169], postulating independent and distributed neural structures at three hierarchical levels: “The lowest Level 1, which may include subliminal and preconscious nodes. The nodes in the next higher Levels, 2 and 3, do not possess specific neuronal correlates and there is aggregation of several of the lowest consciousness and the unitary consciousness is defined at the highest Level 3.” Authors suggested that the “nature of the conscious experience would depend on what other nodes are accessible to the node at Level 3” [170]. The mind selects memories that emerge from any conscious state and are based on the stream of previous conscious information. Thus, states of consciousness depend on the degree to which preconscious and memory states are accessible to awareness [73]. The mediated variable of this hierarchical model are languages and metalanguages that work at Levels 1 and 2, whereas the highest node is not located in a physical space, but still allows for the unity of consciousness. Nonlocality, entanglement, and coherent behavior are required to model memories as quantum objects [171], which is an explanation for long range correlations inside the brain and in behavior. It has been proposed that the cognitive system, through its evolution, veils the nonlocal processes of the quantum interactions amongst consciousness states by creating classical narrative for them, suggesting that the entropy associated with the consciousness states is a projection of three-dimensional reality.

Timeless and spaceless. Li’s theory [70] focuses on a pre-space/time dimension starting from 4 principles. (1) “The quantum superposition principle is assumed to be universally correct; (2) any physical property, that is accessible by physical means, is extrinsic, and it is nothing more and nothing less than the relations of the entity to the rest of the world; (3) consciousness can feel or memorize the past largely determined the configuration of the emergent time; (4) equivalent principle is applicable to consciousness”.

The author introduced a super quantum state called Dao, which “contains everything but tells nothing” (similar to other theories of Bohm [172], Mensky [173] and Wheller-Dewitt [174]) but in which time and space are absent. Moreover, if the Dao is a composite number, then it is decomposed as an entangled state of a composite system, generating a smaller quantum state. When Dao is separated into two subsystems (consciousness and universe), time emerged, whereas space is defined in the further creation of subsystems from universe.

The four principles guided the mathematical demonstration of the theory, suggesting that the universe is completely determined and that the relative distance and mass (a negative mass for consciousness was hypothesized) could be defined by the entanglement entropies among physical entities separated from a pure quantum state.

The Conscious Agent Thesis. Hoffman and Prakash [72] focused their attention on the relationship between perception and reality, citing the interface theory of perception [175]. They presented several premises to introduce their model. The authors stated that (i) in evolutionary biology and psychological perspectives, the natural selection has shaped our perception to be an accurate depiction of reality especially of those aspects useful for our survival; (ii) veridical perceptions strategies tuned to the true structure of the world are routinely dominated by non-veridical strategies tuned to fitness. Therefore, strategy favored by selection is best thought as a windows interface of a PC instead of as a window on truth. Consequently, the color and shape of an icon for a text file do not entail that the text file itself has a color or shape, so our perceptions of space–time and objects do not entail that objective reality has the structure of space–time and objects [176,177,178]. Considering these perspectives, authors proposed a rigorous formalism called a conscious agent thesis.

According to the authors' perspective, consciousness involves three processes: perception, decision, and action. As for perception, "A conscious agent interacts with the world (W) and, in consequence, has conscious experiences. In the process of decision, a conscious agent chooses what actions to take based on the conscious experiences it has. In the process of action, the conscious agent interacts with the world in light of the decision it has taken and affects the state of the world".

They claim that every property of consciousness can be represented by some property of a conscious agent or system of interacting conscious agents. Then, the authors defined a conscious agent as a six tuble C = ((X,X), (G,G), P,D, A,N)), where: (X, X) and (G, G) are measurable spaces; P: W × X→[0, 1], D: X × G→[0, 1], A: G ×W→[0, 1] are mathematical formalism of Markoviank kernels, and N is an integer.

Regarding the explanation of the generation of a macro-subject in terms of assembling micro-subjects [179], i.e., combination problems, the theory of the conscious agent affirmed that it is necessary to discuss conditional probability of having a specific conscious experience, considering that most of our mental processes are unconscious processes [180]. Then, the theory of the conscious agent provides two ways to combine conscious agents, i.e., undirected combinations and directed combinations, giving a formal solution for the combination problem of conscious experiences explained through theorems. Finally, regarding the theorization of the object (the previous parts were described as a theory of the subject), the authors described the idea that "space–time and objects are among the symbols that conscious agents employ to represent the properties and interactions of conscious agents" [181]. Specifically, they observed that "the harmonic functions of the space–time chain that is associated with the dynamics of a system of conscious agents are identical to the wave function of a free particle", identifying a formal system and how it works. This part characterizes the conscious agent thesis. The authors affirmed that "one particular object, the quantum free particle, has a wave function that is identical in form to the harmonic functions that characterize the asymptotic dynamics of conscious agents; particles are vibrations not of strings but of interacting conscious agents". Consequently, this allows one to reinterpret physical properties such as position, momentum, and energy as properties of interacting conscious agents, rather than as pre-existing physical truths.

3.2.27. Reji Kumar's Theory

Reji Kumar suggested a model where consciousness is the result of the information processing taking place in the mind which, in turn, consists of information accepting, processing, and generating [76]. The information process was assumed to be similar among individuals (even if some variations can exist in internal processing); however, what subjectively changes is the information accepted. Furthermore, the author assumes that if the information's entry into the mind is blocked, consciousness does not exist [76].

The present theory is grounded on four different axioms: (i) A model represents a piece of information; (ii) the mind compares and classifies different models; (iii) new models can be created starting from the existing models; (iv) the mind attributes a value/preference to each model.

The above-mentioned models consist of three different parameters. The α-models concern the sensory information deriving from the outside world and processed by the mind (e.g., an object in the external environment). They consist in pieces of sensory information that can be processed even without consciousness, and they are also called "pre-linguistic models" [76]. The β-models allow one to express one's own experience of the external world (e.g., the name of the object in the external environment) and they consist of a one-to-one correspondence [76]. The γ-models are more complex and are useful to explain the experience of mind (e.g., a story or a poem; [76]). In other words, the α-models are supposed to contain raw data, whilst the β- and γ-models are deputed to raw data processing [78]. Furthermore, the models are characterized by a time component that is apparent in models happening in different instances (this means that simultaneous models have the same time component), and a space component which concerns difference in corresponding models [79].

In 2016, the author enlarged his theory by distinguishing the information from the knowledge. Whilst the information corresponds to data deriving from the outside world, the knowledge consists of forms that such information assumes [78]. Furthermore, the author attributed a pivotal role to memory by assuming the existence of temporary memory, which receives information from both the outside world and an individual's inside world, as well as a permanent memory where information is stored after their processing and integration according to the α-, β-, and γ- models [78].

Moreover, in the first conceptualization of this theory, the author outlined subjectivity as a core component of consciousness [76]. The concept has been further developed by the author. The model could be associated with different realities, thus producing ambiguity and confusion [79]. In these cases, it is necessary to perform a choice by selecting some items among many others in an arbitrary way. This idea has been mathematically developed by the author as follows [79]. Given the individual's models of consciousness ($M \in CX$), the subjectivity is a function ($f: CX \rightarrow [-1, 1]$) according to which the individual can like ($f(M) > 0$) or dislike a model ($f(M) < 0$). If the function value is equal to 0, the model must be considered objective. Furthermore, subjectivity changes over time and can be computed in different ways by considering the minimum/maximum of the values of the subjectivity of component models ($f_{min}(M) = \min_i (f(M_i))$), and by averaging the subjectivity of all component models ($f_{ave}(M) = \sum_i M_i/N$, where N represents the number of sub-models of M). Similarly, the stability of subjectivity over time can be computed via the following formula ($S = (x + b) - (x - b)$), which can range from 0 (maximum stability) to 1 (maximum instability).

The central role of subjectivity in this theory has been supported by other authors who stated that subjectivity arises when preferences are associated with a specific model [77]; in other words, subjectivity acts when individuals choose among models. The authors assumed that, within the α-models, there is no subjectivity, as these models represent an information registry where stimuli processing is unconscious. When information is associated with an entity within β- models, the perception is subjective and therefore conscious. Similarly, in the γ-models, additional subjective attention is required to perform information-entity association. This is different than the β- models, which allow the association of single information with multiple entities [77].

3.2.28. The Radical Plasticity Thesis (RPT)

In 2007, Cleeremans defined consciousness as “the brain’s theory about itself, gained through experience interacting with the world, and, crucially, with itself” [81].

The author proposed the radical plasticity thesis of consciousness by considering subjective experience as a core component. Experience is defined by the author as “something that takes place not in any physical entity but rather only in special physical entities, namely cognitive agents” [81]. Indeed, the author stated that whenever experience is experienced, something happens in the organism (such as experiencing emotions, retrieving memories, learning something new, and so on) and the organism itself registers its state. Metarepresentations play a pivotal role in this. The individual creates some representations based on the external input, and the metarepresentations inform the individual of his internal status by considering the previously created representations. Subjective experience occurs only if a certain system (i.e., individual) learns its representations. Consequently, consciousness is the awareness of both external and internal status.

Representations are always associated with the activation of neural networks, which can vary across different dimensions, such as the stability of time (i.e., how long a representation can be maintained active; prefrontal cortex involvement), strength (i.e., how many units are involved in a certain representation and how strong is their activation), and distinctiveness (i.e., how different a certain representation is from others; it is a measure inversely related to the degree of overlap among representations, and it characterizes the hippocampal representations compared to the cortical ones). Moreover, the representations can be different considering the extent to which they can influence behavior, the availability to control, and the availability to subjective experience. As such, three different forms of representation are described. The implicit representation is characterized by weakness so that they are out of the individual awareness and, as a consequence, out of control. However, this kind of representation can influence behavior. The second kind of representation is the explicit one characterized by enough strength to be available to individual awareness and thus to the control. They can influence behavior as long as the individual is involved in controlling them. The subjective experience is typical of this kind of representation. The third kind of representation is the automatic one characterized by high strength, which impedes these representations to be controlled. However, differently from the implicit representations, the individual is fully aware of this kind of representation. Within this framework, the availability of the representations to consciousness strongly depends on the representations' quality; furthermore, the learning process can produce higher quality representations in time (this mechanism is at the base of the development of adaptive behavior). In keeping with this, the role of consciousness is to control those representations strongly enough to affect the behavior but not strongly enough to be considered automatic adaptive representations. From here it derives that (i) consciousness involves the subjective experience along with the control dimension; (ii) the availability to consciousness correlates with the quality of representations; (iii) the development of high-quality representations takes time; and (iv) consciousness allows flexible and adaptive control over behavior.

The metarepresentations have the same features as the representations (strength, stability, and distinctiveness). Furthermore, they have specific functions, allowing for individuals to communicate their status and to make predictions. Cleeremans et al. provided empirical evidence by means of simulation experiments attesting how a higher-order network can be trained to observe the internal states of another network and use this information to perform tasks required to know the internal structure of such internal states [80]. In this way, the core idea of the radical plasticity thesis is that "the brain continuously and unconsciously learns not only about the external world, but about its own representations of it. The result of this unconscious learning is conscious experience, in virtue of the fact that each representational state is now accompanied by (unconscious learned) metarepresentations that convey the mental attitude with which these first-order representations are held" [81].

3.2.29. The Semantic Pointer Competition Theory of Consciousness (SPC)

The phenomenon of consciousness has been studied by the SPC through three different hypotheses. The first one supposes that consciousness is the result of a process within the brain that springs from neural mechanisms [82]. Thus, this hypothesis starts from the assumption that all conscious organisms possess a brain, and therefore complexes of neural processes represent a basic condition for consciousness to arise. Accordingly, consciousness is present in all entities capable of introspection, self-evaluation, and implementing behaviors that are indicative of consciousness itself.

The second hypothesis identifies representation by patterns of firing in neural populations, binding of these representations into semantic pointers, and competition among semantic pointers" [82]. The representations are created thanks to neuronal patterns of activation following the interaction within the environment. Consequently, representations of different natures (e.g., perceptive, motor, verbal) can be created. These kinds of representations are called "semantic pointers" [182,183,184], which, after a binding mechanism, can be combined into a single semantic indicator with symbolic function [185]. As for the neural correlates of consciousness, the present theory does not refer to specific brain areas, but rather considers the pivotal role of cellular systems activation in consciousness.

The third hypothesis assumes that consciousness derives from an interactive competition between semantic pointers after which the winning indicator determines the qualitative aspects of experience (i.e., qualia). The SPC addresses the subjectivity by assuming the existence of different qualitative experiences due to the linkage between different neural representations and semantic indicators. According to the authors, "Semantic pointers bind together neural representations of a situation, physiological changes, and cognitive appraisals to produce a combined representation" [82].

In addition to this qualitative experience, the SPC specifically addresses other issues concerning the main aspects of consciousness, namely onset and cessation, shifts in experience, different kinds of consciousness, unity and disunity of consciousness, and, finally, storage and retrieval. All these aspects are mathematically explained through computer simulations. Starting from the first aspect (i.e., the cessation of consciousness, such as in the case of sleep, anesthesia, stroke, etc.), it is linked to three mechanisms, which depend on the balance between neural excitation and inhibition. Neural inhibition involves a decrease in the number of semantic pointers. Conversely, in the case of epilepsy and convulsions in which neural hyperactivity occurs, the interruption of consciousness is due to the saturation of the semantic pointers network, which interferes with the mechanism of competition that no single semantic pointer can overcome, especially considering the threshold necessary to generate consciousness [82].

Regarding these kinds of consciousness, we must distinguish between a minimal form of consciousness linked to the "here and now" and a form of consciousness characterized by greater complexity that allows for self-representation [186]. The different kinds of consciousness depend on differences in complexity and the extent of the three mechanisms that generate experiences.

The unity of consciousness concerns the reasons why we experience in an integrated way experience and is made possible by the combination of the different mental representations and, therefore, by the association of the semantic pointers. On the contrary, this disunity occurs during the mechanism of competition, where there is no semantic pointer that prevails over the others other than different “winning” semantic pointers [82].

The SPC emphasizes the interactions between consciousness and memory since, during an experience of an event, similar experiences are recalled. This is determined by the storage and retrieval capacity of each semantic pointer [82].

4. Discussion

From the 68 analyzed articles, the present systematic scoping review found 29 theories of consciousness that show heterogeneous perspectives. The theories with the highest number of articles focused on them were quantum theories of consciousness (which represent a category including theories that refer to a quantum mechanism to explain consciousness), the IIT, and the GWT. The articles describing these theories were found in almost all of the considered years. This result was predictable considering the number of focus reviews published in the last five years on these theories (Hinterberger, 2015; Owen, 2019; Zhao et al., 2019). However, the total number of articles found is not directly correlated to the level of analysis of each theory on the themes we focused on. Indeed, different theories obtained the maximum scores in at least one dimension analyzed (in alphabetical order: ADT, Agnati et al.’s theory, ART, Bieberich’s theory, COI, CP, CSS, DCT, GWT, HOT/FOR, IIT, LRMB, Min’s model, Rejikumar’s theory, RPT) independently from the number of articles found (among the above-mentioned theories, ADT, Bieberich’s theory, COI, CP, DCT, LRMB, and Min’s model were represented by a single article).

4.1. Descriptive Analysis of the Results for Each Dimension

Subjectivity, NCC, and consciousness and cognitive functions were the most debated in the articles we found (i.e., dimensions with the lowest number of 0 scores during the assessment), showing the highest grade of variability.

The NCC dimension was the most studied among the others (the highest number of articles (n = 30; see supplementary materials for details) obtained a score of 4 or 5 in the NCC dimension during the assessment). Among the neural correlates of consciousness reported in Table 3, the thalamus, basal ganglia, and the hippocampus were the most reported sub-cortical structures, whereas the cingulate, prefrontal, and temporal areas were the most reported cortical ones. In general, the thalamo-cortical system was the macro system most described in the literature as the system able to sustain consciousness (intended as the neuronal mechanisms jointly sufficient for conscious percept), especially when consciousness is related to representation. However, our results highlighted the widest range of proposals. Consciousness was associated with different structures from a single electron to different brain areas. This is an important point that should be analyzed in the future, especially when studying the relationship between NCC and the “type” of consciousness they refer to. As recently pointed out by other authors [187], there could be a potential convergence among theories on the neural structures involved in the mechanisms that can explain consciousness and its alterations. Therefore, macro-perspectives are needed in the next future.

The dimensions called “consciousness and translation into clinical practice” and “subjectivity” were the two dimensions that obtained the lowest number of 4 and 5 scores during the assessment (3 and 6 articles respectively); in other words, they represent the dimensions with the fewest number of articles focused on them. In the first dimension, we analyzed the translation of theoretical models into procedures able to help patients with disorders of consciousness. The lack of findings in this dimension is likely due to the difficulty in translating the hypothesis made by the authors into clinical practice (i.e., definition of prognostic or diagnostic markers, ad hoc treatments, etc.). An example of these difficulties is represented by the challenges in developing technical systems able to help researchers in testing their hypothesis. Indeed, considering the hypothesis made by authors of the quantum theories of consciousness, it sounds difficult to test how a quantistic phenomenon can be observed/reproduced in a “wet” material such as the brain, or how we can experimentally modify the activity of specific cell populations (e.g., the glia), or to analyze the effect of vibrations present in some neural microstructures on human consciousness. However, this does not imply that this perspective should not be studied by a new generation of researchers able to match neurological and quantistic viewpoints. This reflects a real challenge for researchers and clinicians. Future research programs should be developed to foster new approaches that can help patients with disorders of consciousness through new therapeutic tools (e.g., neural stimulation programs) in parallel to new measures of consciousness (13 articles obtained a score of 4 or 5 in the Quantitative measures of consciousness dimension). This would allow for quantitative and qualitative evaluations of the outcomes.

Finally, we found 11 articles that obtained a score of 4 or 5 for the association between consciousness and other cognitive functions. As in the NCC dimension, we found interesting perspectives that ranged from the complete overlap of consciousness with other functions (e.g., memory and attention in the learning process) [22,23] to the definition of consciousness as a sort of metacognition in layered models (see [58]), which is debated in some articles that considered metacognition equivalent to consciousness (published after the time range of this review) [188,189].

4.2. A Definition of Consciousness: Problems and Perspectives

The number of articles that propose a definition of consciousness was quite high and almost all theories reported a main definition, offering several arguments and interpretation of the results that should be analyzed in the future. Indeed, the sentences analyzed, such as “consciousness is […]”, were supported by many interpretations—i.e., defining consciousness as “being aware of” something or as the “subject experience”. We also found definitions of “awareness” and “experience”, and, of course, some clear statements on what “awareness” and “experience” is not. However, we found that four terms— “(subjective) experience”, “information”, “processes”, and “(mental) state”—were used in most of the analyzed articles (Table 2) to define consciousness. These terms imply several reasons regarding their nature/structure and the ontology behind them. For example, “information” is a term that has been debated in the scientific literature over the last few decades [190,191]. New researchers can find many references sustaining a specific ontology linked to this term [192]. Although everyone can affirm to have an idea of what “experience” is, it is difficult to find a clear definition of what it is not. What experience is it? What is the structure of an experience? Is consciousness synonymous with experience or do we have to think about a tailored association between the structure of experience and the structure of consciousness? Some theories attempted to answer these questions, but the debate is still open and thus these questions still represent issues for the science of consciousness that researchers will face in the future.

We also found many new definitions and new subcategorizations of consciousness, such as “knowing consciousness” [59], “unreflected consciousness” [65], or “meta-mentation” [64], as reported in Table 1. These definitions constitute a new way to develop ad hoc perspectives and measurable concepts. Our impression is that authors are developing new models in which consciousness is not a monolithic meaning and can be sub-divided into different components (working hierarchically or in parallel), offering a test in experimental settings whenever possible.

4.3. Limitations

This scoping review does have limitations. Firstly, during the full-text analysis, we opted for a very strict selection of the articles to be included. Consequently, one of the articles’ criteria for selection was consciousness as the main object of an article. This rigid criterion implied that raters excluded records on topics related to other arguments such as body-representation, bodily-self, etc., or describing the elaboration of conscious vs. unconscious stimuli using fMRI or EEG paradigms (e.g., the existence of unconscious working memory, memory processes linked to subliminal stimuli only, etc.). Moreover, we excluded general theories that identified basic rules for life generation that explain consciousness indirectly, as well as papers that did not report clearly the original underlying theory.

We acknowledge that all of these arguments are linked to consciousness models and that our article selection process could have excluded works that contributed to the study of consciousness but, considering the difficulty of analyzing each collected model, we decided to limit our work to articles completely related to a consciousness model itself as the main topic, analyzing papers on these arguments only if they were linked specifically to a general theory of consciousness. The choice to include articles using strict inclusion criteria could have caused a loss of information, but we preferred to make this choice in order to offer a well-structured overview of the topic without diverging from the main aim of this scoping review. Another limitation was that we analyzed only the text of the articles included in the review found in the databases reported in the methodological section. As a matter of fact, details on some theories could be described in other papers published before the years considered in the present work or published in other online databases. Consequently, some missing information about either each dimension or definitions of consciousness may be due to the adopted methodology rather than to a real lack of information (this is the main reason why we inserted the Table 1 note “nf” (i.e., not found)). Moreover, the choice to search articles in “medical” literature databases could have caused the loss of important works marked by the conceptual (philosophical) perspectives on consciousness simply because they are not contained in those repositories. For this reason, we avoided distinguishing articles included as “conceptual” or “empirical” because many works contained both parts, as shown by the dimensional model analysis. Therefore, the limitation on the medical dataset and time range deployed in the search strategy determined that several articles that we knew to be important for a debate on consciousness models were not included in our analysis. There is an increasing amount of literature in computer science on the relationships between intelligence and consciousness (e.g., Drigas et al. presented a new layered model of consciousness that combines the dominant theories of intelligence adapted to recognized models of telecommunications and computer science [188,189]), affirming that cognitive processes contribute to the representation of knowledge. Some important metacognitive components are transformed into superior levels of consciousness (see [193]). Another example is provided by other studies that sought to define a precise formal definition of a conscious Turing machine, also called a conscious AI, [194,195]. We recognize that the analysis of a limited set of databases represents a limitation but we hope that this paper can be a useful tool for researchers to increase the debate on the frameworks underlying the various theories of consciousness, as noted by other authors (e.g., [187]). It could also be considered as a general framework from which the readers can start to analyze some arguments that are only cited in this review.

Finally, considering the different areas of study of the authors who wrote the analyzed articles, as well as the difficulty derived from the use of different technical languages, the probability that there are some theoretical aspects insufficiently treated in the summaries is high. To comply with the formatting guidelines, we had to limit the amount of information in the description of each theory, and this may have resulted in the above-mentioned limitations. Moreover, the Likert score attributed to each article in relation to the evaluation on how each dimension was debated in the text should not be intended as a qualitative score of the theories. For example, an article can debate many dimensions, such as the neural correlates that offer less “clear” messages on the structures involved in consciousness rather than an article that explicitly debated this point. The aim of this review was not to compare the different theories found or to discuss them in a critical manner (debating for one hypothesis or another one) but to synthesize them to provide a general overview on models that explain one of the most difficult topics known to humanity. Considering the limits of our work, this overview, overall, can be useful for readers and future researchers both to reflect on the variabilities that exist on the various topics related to consciousness in the scientific literature and to develop new ideas and collaborative research groups starting from the theories presented.

5. Conclusions

In conclusion, we found 29 theoretical models that described different perspectives on consciousness. Among the dimensions analyzed, the NCC was the most reported in the full-text collected and we found a very heterogeneous set of neural correlates of consciousness, ranging from the single electron to the whole brain. Moreover, we found fewer articles that focused on the development or implementation of new tools/strategy/markers for clinical practice in settings where consciousness levels were altered. Regarding the definition of consciousness, the review highlighted that the words “information”, “experience”, and “state” were often reported within definitions, and that several new terms/labels related to sub-categorization of consciousness (more than twenty terms) were also proposed. The results of this scoping review allows us to present the state-of-the-art research on consciousness studies and can offer a global vision on this issue for researchers all over the world. Because consciousness is one of the most ancient questions considered by human beings, this accomplishment is no small feat.

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Supplementary Materials

The following are available online at https://www.mdpi.com/article/10.3390/brainsci11050535/s1. Table S1: Search strategy; Table S2: Maximum score obtained in each dimension by the theories analyzed; Table S3: Secondary definitions and definitions of related terms and features of consciousness. Table S4: Abstracts of each theory analyzed.
Click here for additional data file. (401KB, zip)

Author Contributions

Conceptualization: D.S., M.P., and M.L.; methodology: D.S. and A.V.F.; formal analyses: F.G.M., M.C. (Milena Caputo), and L.B.; writing—original draft preparation: D.S. and F.G.M.; writing—review and editing: M.P., M.L., A.V.F., M.C. (Milena Caputo), L.B., and M.C. (Martina Cacciatore); supervision: D.S., M.L., and M.P. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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Associated Data

This section collects any data citations, data availability statements, or supplementary materials included in this article.

Supplementary Materials

Click here for additional data file. (401KB, zip)

Data Availability Statement

This is a review article. Data available at https://doi.org/10.5281/zenodo.4671955.

Scientist says human consciousness comes from another dimension

A baffling new theory to explain human consciousness has suggested it comes from hidden dimensions and is not just brain activity.

A physicist claimed that we plug in to these invisible planes of the universe when making art, practicing science, pondering philosophy or dreaming, and this could explain the phenomenon that has evaded scientific understanding for centuries.

Michael Pravica, a professor of physics at the University of Nevada, Las Vegas, has based the wild idea on hyperdimensionality, the idea that the universe is made up of more dimensions than just the four we perceive: height, length width and time.

But his theory is highly controversial, with one scientist saying that the cornerstone of Pravica's theory 'borders on science fiction.'

Physicist Michael Pravica believes that human consciousness transcend the physical world and move between hidden dimensions

'The sheer fact that we can conceive of higher dimensions than four within our mind, within our mathematics, is a gift... it's something that transcends biology,' Pravica told Popular Mechanics.

Scientists have been attempting to explain human consciousness and its origins for hundreds of years - and the theories run the gamut.

One leading theory suggests that consciousness is related to how much information is integrated between the different parts of the brain. The more information is connected and integrated, the more conscious a being is thought to be.

Another posits that conscious mental states are driven by top-down signaling in the brain. Top-down signaling refers to the process by which higher-level brain regions send information, expectations or context to lower-level brain regions.

But Pravica's theory ventures outside the realm of neuroscience and into theoretical physics.

He suggested that in moments of heightened awareness, like when we enter a dream state or use our brains for deeply creative or intellectual tasks, our consciousness could transcend our physical dimension and enter a higher plane.

In these moments, our consciousness syncs with hidden dimensions and receives a flood of inspiration, Pravica said.

To better understand the controversial theory, consider the following scenario.

Imagine you're a two-dimensional being living in a two-dimensional world, like a character in a comic book. Now, imagine that a sphere passes through your plane of view.

The sphere would look like a dot that grows into a larger and larger circle as it comes closer, then gradually shrinks until it's out of view. You would have no way of knowing that it's actually a three-dimensional shape.

Pravica sees us as a version of these 2D characters. Although we exist in a four-dimensional world, we can only perceive matter and energy that is of those four dimensions, just like how beings in a 2D world cannot perceive a 3D object.

Thus, the limitations of our world prevent us from detecting higher dimensions that could, in theory, exist all around us.

This is the foundation of hyperdimensionality - the idea that the universe is made up of many dimensions, some of which are hidden because they are beyond the reach of our physical realm.

Hyperdimensionality ties into string theory, which states that reality is made up of infinitely small vibrating strings that are smaller than atoms, electrons or quarks.

As the strings vibrate, twist and fold, they produce effects in multiple unseen dimensions that give rise to all the particles and forces that we can observe, from particle physics to gravity.

'String theory is essentially a theory of hyperdimensionality,' Pravica said. 'It's looking at how the universe is put together on a sub-quantum scale.'

Pravica believes that our brains can tap into higher dimensions when in a dream state or performing deeply creating or intellectual tasks

Although we can observe the effects that these vibrating strings have on the physics of our dimension, we can't observe the hidden dimensions that they're vibrating in.

That is - we can't physically observe them.

But our consciousness may be able to tap into them, Pravica says.

Hyperdimensionality and string theory are widely accepted by physicists, but Pravica's idea of their relationship with consciousness is more controversial - especially because it blurs the lines between science and spirituality.

As an Orthodox Christian with a Ph.D. from Harvard, Pravica has found hyperdimensionality to be a way to bridge his scientific background with his religious beliefs.

For example, he believes Jesus may be a hyperdimensional being.

'According to the Bible, Jesus ascended into heaven 40 days after being on Earth. How do you ascend into heaven if you're a four-dimensional creature?' Pravica asked.

But being hyperdimensional could, theoretically, have allowed Jesus to move between our world and heaven - which may be a world of higher or infinite dimensions, he said.

Pravica's theory is based on a 'God of the gaps' perspective, where gaps in scientific knowledge are explained by divine intervention, said Stephen Holler, associate professor of physics at Fordham University.

He believes that this type of thinking is insufficient, and hampers the scientific inquiry needed to truly understand and explain ineffable phenomena like human consciousness.

'It's a poor explanation mechanism that arguably stifles the inquisitive nature required for good science and teaches that it's not okay to say, 'I don't know,'' Holler told Popular Mechanics.

He points out that our ability to mathematically manipulate higher dimensions is not proof that they actually exist, or that our consciousness can interact with them.

What's more, exploring these higher dimensions is impossible due to the limitations of our current technological capabilities.

Not even the most powerful particle accelerator in the world - the Large Hadron Collider (LHC) at CERN - can provide real proof that these dimensions exist.

The LHC smashes particles together at incredibly high speeds - up to the speed of light.

This allows physicists to study the fundamental building blocks of matter and energy and access infinitesimally small dimensions - even smaller than a single proton.

But even the LHC isn't able to reveal the high-dimensional strings that quantum physics predicts. To get that granular, physicists would need a much more powerful collider.

Without that concrete evidence, Holler says that hyperdimensionality 'borders on science fiction.'

But Pravica is optimistic that such technology could exist within his children's lifetime.

Until then, he will continue to support hyperdimensionality and his theory of how it relates to our consciousness.

'I see no point otherwise,' he said. 'Why study? Why live?'

Exploring consciousness with 'eureka' moments

For generations, researchers have been pondering the question of how and where consciousness is formed in the brain. Professor Ekrem Dere from Ruhr University Bochum, Germany, proposes a new approach to researching conscious cognitive information processing. He advocates defining phases of conscious cognitive processes on the basis of behavioral observations and learning curves. "Learning is often not a gradual process, but takes place in leaps and bounds; you could say that humans and animals experience sudden epiphanies every now and then," he says. "It's likely that these experiences are preceded by conscious processes."

Dere outlines his new approach, which might apply to both humans and animals, in an article published in the journal *Frontiers in Behavioral Neuroscience*.

Different levels of consciousness

Consciousness is not an all-or-nothing process. "There are different levels of consciousness, depending for example on whether we're sleeping or writing an email," says Ekrem Dere from the Mental Health Research and Treatment Center in Bochum, who is also a member of the Sorbonne Université in Paris. "At the upper end of this gradation, so to speak, we find conscious cognitive information processing that is required to deal with a complicated problem."

In order to study the neurobiological correlates of these processes using scientific methods, a human or animal must be presented with an experimental task that can only be solved with conscious cognitive information processing—it's crucial that there isn't a preconceived solution.

"In the long history of cognitive behavioral psychology, a great many such tasks have been developed," says Dere. "However, the main difficulty is that a human or animal may not use conscious cognitive information processing throughout the entire processing time."

Eureka moment is the time stamp

The researcher therefore suggests using learning curves to narrow down the phases of conscious information processing with regard to their timing. In these curves, performance in a specific task is plotted over time. "Learning performance often doesn't improve continuously, but rather by leaps or in stages," explains Dere. This so-called discontinuous learning after insight can serve as a time stamp.

"Conscious cognitive information processing must have taken place at this point and presumably also in the seconds leading up to it," says the psychologist. "Armed with this knowledge, we can use imaging or electrophysiological methods to observe the brain during conscious cognitive information processing by comparing the time periods immediately before the sudden increase in learning with earlier or later points in time during the processing of the task."

This would enable researchers to find out which mechanisms the brain uses in which region for conscious information processing.

More information: Ekrem Dere, Insights into conscious cognitive information processing, *Frontiers in Behavioral Neuroscience* (2024). DOI: 10.3389/fnbeh.2024.1443161 Provided by Ruhr-Universitaet-Bochum

Theory About the Multiverse Suggests That it May Even Hold the Key to Immortality

In 1979, physicist Alan Guth proposed 'cosmological inflation' as one of the most developed multiverse models to answer questions about the existence of a parallel universe that had been discussed since the early 1900s. He suggested that after the Big Bang, the universe expanded rapidly for a brief moment, creating a huge zoom effect that affected the cosmic microwave background and the distribution of galaxies.

Elaborating on the same, Neil Turok, a physicist at the University of Edinburgh, UK, toldBored Panda, "It was an approach that was born out of a certain sense of frustration with previous approaches. In my view, they had all become rather complicated and contrived, including my own approaches." He added, "I thought we could be on the verge of the next big revolution in theory. It would be inspired by the data, and by the failure of traditional paradigms. It would change our view of the universe."

Following Guth's proposal, many theories emerged including one from physicist Andrei Linde, who introduced chaotic inflation in 1983. This suggested that rapid expansion possibly occurred in different ways due to chaotic early conditions in the universe. Knewz.com noted that in 2013, the European Space Agency's Planck satellite map of the cosmic microwave background challenged inflation theory.

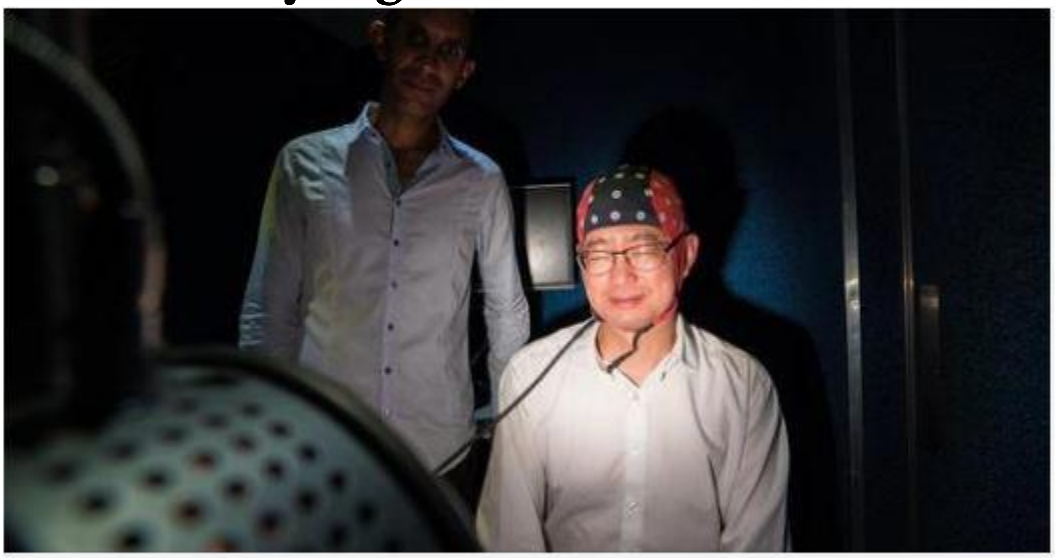
Since then, scientists have been inventing new methods to prove that there were parallel universes. Some argued in favor of the cyclic universe, which proposed that the universe went through endless cycles of formation and destruction. Additionally, Turok himself suggested a mirror universe theory in 2018, explaining that our universe had a twin where time moved backward.

According to theoretical physicist Alexander Vilenkin of Tufts University in Massachusetts, inflation didn't stop everywhere at the same time. Writing in Scientific American, he explained that when inflation stopped in one area, a new bubble universe was formed. He further wrote, "This picture of the universe, or multiverse, as it was called, explained the long-standing mystery of why the constants of nature appeared to be fine-tuned for the emergence of life. The reason was that intelligent observers existed only in those rare bubbles in which, by pure chance, the constants happened to be just right for life to evolve. The rest of the multiverse remained barren, but no one was there to complain about that."

Another theory that gained attention was Hugh Everett's 'Many-Worlds theory.' According to his theory, whenever an event had several possible outcomes, the universe split with every action. The theory surfaced more in the late 1990s through a thought experiment called 'quantum suicide,' which suggested that the Many-Worlds idea was theoretically possible. It was first suggested by physicist Hans Moravec in the 1990s and later expanded by Max Tegmark.

The experiment was created to test the idea of the 'many worlds' interpretation of quantum mechanics. Furthermore, the trials suggested that the person involved in the experiment would never experience death. This was because there would always be a version of the universe where they survived, making them 'quantum immortal.' Since then, physicists and mathematicians have continued to explore its implications. However, Many-Worlds was just one of several theories about the universe, and scientists were exploring more in search of a logical explanation.

Reality Is Just a Bunch of Hallucinations We Collectively Agree On



Reality Is Just a Bunch of Hallucinations We Collectively Agree On© Jade Small

When we think of hallucinations, we tend to associate them with unreal, distorted perceptions created by our minds. However, some experts argue that these visual illusions may be more connected to our everyday experiences than we realize. Neuroscientist Anil Seth, director of the Sackler Centre for Consciousness Science at the University of Sussex, suggests that hallucinations are not so different from what we commonly regard as reality.

What is Consciousness?

Anil Seth’s work focuses on understanding consciousness-an enigmatic and elusive concept. He defines it as the experience of being aware, explaining that while there is “something it is like to be” a living organism, such as a mouse, there's no comparable experience for inanimate objects, like a coffee mug. Through his research, Seth aims to uncover how our brains create this state of awareness and how it shapes our perception of the world around us.

Exploring Perception in a New Way

At the Sackler Centre, Seth and his interdisciplinary team use cutting-edge technology like virtual reality, computational science, and brain imaging to delve into the mysteries of consciousness. Their goal is ambitious: to form a unified theory of perception that explains how we see, hear, and experience time. Seth believes that our perceptions are not just the result of passive observation, but rather an active construction by our brains, influenced by both electrical impulses and previous experiences.

The Thin Line Between Reality and Hallucination

Seth's perspective on reality is as thought-provoking as it is revolutionary. He suggests that our conscious experience is, in many ways, a controlled hallucination. The brain receives sensory signals, processes them, and predicts what's happening based on prior knowledge. This means that much of what we perceive as “reality” is shaped by our brains filling in gaps with past experiences. The main difference between this and a hallucination, Seth argues, is that society collectively agrees on these experiences and labels them as reality.

Early Fascination with Consciousness

Seth's journey into the world of neuroscience and consciousness began early. Growing up in Oxfordshire, England, he became captivated by the subject at 19, while studying math and physics at Cambridge University. Reading books like *The Emperor's New Mind* by Roger Penrose and *Consciousness Explained* by Daniel Dennett opened his eyes to the complexities of the mind, though he felt something was missing in these explanations. This curiosity propelled him into a lifelong study of how consciousness works.

The Influence of Nobel Laureate Gerald Edelman

Seth's research deepened when he joined the Neurosciences Institute in San Diego, working with Nobel Prize-winning biologist Gerald Edelman. Edelman's groundbreaking theory of Neural Darwinism emphasized the biological basis of consciousness, arguing that genetics and environment shape how neurons in the brain interact and evolve. This experience was pivotal for Seth, as it allowed him to study consciousness in a scientific context, and he even built robots designed to mimic human brain functions to solve visual problems.

Building a Multidisciplinary Team

In 2006, Seth returned to the UK to establish his laboratory at the University of Sussex. There, he assembled a team that included not only neuroscientists but also philosophers and computational scientists. His work required a unique blend of scientific and philosophical knowledge, as he sought to understand how the brain constructs our sense of self and the world around us. The lab’s diverse methodologies-including VR experiments-have allowed them to explore a wide range of questions about perception, reality, and even the nature of the soul.

The Intersection of Philosophy, Faith, and Consciousness

Seth's exploration of consciousness doesn't stop at science; it also crosses paths with philosophy and religion. He has engaged with Buddhists, Hindus, Christians, and others to understand how different cultures and faiths view consciousness. For example, while Western religions often treat the soul as a separate entity that moves from one body to another, Eastern traditions tend to view it as a more intricate concept. This cross-cultural perspective has enriched Seth's understanding of consciousness, though he remains frustrated by the lack of concrete data in these broader discussions.

Mental Health and Consciousness

On a personal level, Seth's study of consciousness has helped him grapple with his own mental health challenges. He has experienced depressive episodes throughout his life and has found that understanding how emotions and perceptions are constructed has helped him break free from negative thought patterns. By recognizing that reality is something the brain actively creates, Seth has been able to change his relationship with his thoughts. He hopes that his research will eventually lead to a better understanding of mental health disorders like schizophrenia, which could revolutionize how these conditions are treated.

Conclusion: The Future of Consciousness Research

Though Seth and his team have made significant strides in studying consciousness, there are still many unanswered questions. Why do humans experience consciousness, and why do some people have certain experiences while others don't? Seth acknowledges that the journey is far from over. Despite the challenges, he remains deeply connected to his work, which influences both his professional and personal life. As research continues, the answers to these questions could have profound implications for our understanding of the human mind and the machines we create. By exploring the boundaries of consciousness, Seth's research is not only shaping the future of neuroscience but also helping us better understand ourselves and the world we live in.

People think in many dimensions at the same time, study finds

Seeing the world around you may feel effortless. You open your eyes and can quickly distinguish people, animals, and objects in your surroundings.

Traditionally, scientists believed that the main goal of perception was to recognize and categorize these objects. However, new research suggests that the process might be more complex than previously thought.
A study led by the Max Planck Institute for Human Cognitive and Brain Sciences, the Justus Liebig University in Germany, and the National Institutes of Health in the USA indicates that brain activity during object recognition is influenced by various behaviorally important factors, not just categorization.

The traditional view of the brain's visual system suggested that when you see an object, your brain breaks it down into basic features—such as color, shape, and texture—and then reassembles these features to help you recognize and categorize it.

The brain activity of study participants was measured in the MRI scanner over 15 sessions while they saw over 8,000 different images of 720 objects. (CREDIT: MPI CBS)

According to this view, the ultimate aim is to assign an object to a specific category, like recognizing that a dog is an animal. However, Martin Hebart, a group leader at the Max Planck Institute and professor at Justus Liebig University, explains that their findings challenge this idea.

He states, "Our results have shown that recognition and categorization are important goals of our vision, but by no means the only ones." Hebart adds that behaviorally relevant signals are found at all stages of visual processing, and these signals extend beyond mere recognition.

The researchers used a computational model to explore the way objects are represented in the brain. They identified 66 different dimensions based on behavioral data gathered from more than 12,000 participants.

These dimensions do more than just help categorize an object as, for example, a dog or an animal. They also explain various attributes like color, shape, and the typicality of an object—such as how typical a dog is as a representative of the animal category.

This broader set of dimensions allows a deeper understanding of how the brain perceives and makes sense of the environment. Hebart notes, "This allowed us to explain much better how our brain enables us to perceive the objects in our environment and understand their meaning."

The study examined the brain activity of three participants, who were shown over 8,000 different images of 720 objects while in an MRI scanner.

An fMRI encoding model of object dimensions underlying human similarity judgements. (CREDIT: MPI CBS)© The Brighter Side of News

First author Oliver Contier describes the results: "When the participants saw a rocket, for example, we were able to measure from the brain activity that their visual system not only recognized that it was a rocket or that a rocket is a vehicle, but also that it is grey and elongated, has to do with fire, can fly, or sparkles."

This demonstrates that the brain does not only recognize and categorize objects; instead, it processes a wide array of characteristics, engaging all perceptual processing stages.

This richer, multidimensional approach to understanding visual perception offers insights into how people make sense of what they see. Martin Hebart explains that their work reveals a "multidimensional framework that is consistent with the rich and diverse behavioral relevance of objects."

Regional tuning profiles across 66 object dimensions and representative images for selectivity of each region of interest in visual cortex. (CREDIT: MPI CBS)© The Brighter Side of News

Unlike a focus purely on categorization, this approach better captures the broad spectrum of human behavior and the complexity of interacting with the visual world. By considering multiple dimensions, the study shows how perception is not just about knowing "what" something is, but understanding a broader array of attributes that give it meaning in a variety of contexts.

Ultimately, this new perspective on vision can help explain human behavior more effectively than the traditional categorization-focused view. Whether recognizing an object, understanding its properties, or predicting how it might interact with its surroundings, the human visual system is far more dynamic than previously thought.

The findings underline the importance of behaviorally relevant features, which include not just the identity of objects but also qualities like form, function, and context.

This approach provides a clearer understanding of how people navigate the visual complexities of everyday life. Instead of the brain working purely to sort objects into categories, each visual experience involves interpreting numerous dimensions simultaneously.

This insight offers a more complete picture of how perception works, shedding light on how individuals perceive, interpret, and respond to their environment.

The mystery of consciousness shows there may be a limit to what science alone can achieve

Credit: Pixabay/CC0 Public Domain© Provided by Phys.org

The progress of science in the last 400 years is mind blowing. Who would have thought we'd be able to trace the history of our universe to its origins 14 billion years ago? Science has increased the length and the quality of our lives, and the technology that is commonplace in the modern world would have seemed like magic to our ancestors.

For all of these reasons and more, science is rightly celebrated and revered. However, a healthy pro-science attitude is not the same thing as "scientism," which is the view that the scientific method is the only way to establish truth. As the problem of consciousness is revealing, there may be a limit to what we can learn through science alone.

Perhaps the most worked out form of scientism was the early 20th-century movement known as logical positivism. The logical positivists signed up to the "verification principle," according to which a sentence whose truth can't be tested through observation and experiments was either logically trivial or meaningless gibberish. With this weapon, they hoped to dismiss all metaphysical questions as not merely false but nonsense.

These days, logical positivism is almost universally rejected by philosophers. For one thing, logical positivism is self-defeating, as the verification principle itself cannot be scientifically tested, and so can be true only if it's meaningless. Indeed, something like this problem haunts all unqualified forms of scientism. There is no scientific experiment we could do to prove that scientism is true; and hence if scientism is true, then its truth cannot be established.

In spite of all of these deep problems, much of society assumes scientism to be true. Most people in the UK are totally unaware that "metaphysics" goes on in almost every philosophy department in the country. By metaphysics, philosophers don't mean anything spooky or supernatural; this is just the technical term for philosophical, as opposed to scientific, enquiry into the nature of reality.

Truth without science

How is it possible to find out about reality without doing science? The distinguishing feature of philosophical theories is that they are "empirically equivalent," which means you can't decide between them with an experiment.

Take the example of my area of research: the philosophy of consciousness. Some philosophers think that consciousness emerges from physical processes in the brain—this is the "physicalist" position. Others think it's the other way around: consciousness is primary, and the physical world emerges from consciousness. A version of this is the "panpsychist" view that consciousness goes all the way down to the fundamental building blocks of reality, with the word deriving from the two Greek words pan (all) and psyche (soul or mind).

Still others think that both consciousness and the physical world are fundamental but radically different—this is the view of the "dualist." Crucially, you can't distinguish between these views with an experiment, because, for any scientific data, each of the views will interpret that data in their own terms.

For example, suppose we discover scientifically that a certain form of brain activity is correlated with the conscious experience of an organism. The physicalist will interpret this as the form of organization which turns non-conscious physical processes—such as electrical signals between brain cells—into conscious experience, whereas the panpsychist will interpret it as the form of organization which unifies individual conscious particles into one larger conscious system. Thus we find two very different philosophical interpretations of the same scientific data.

If we can't work out which view is right with an experiment, how can we choose between them? In fact, the selection process is not so dissimilar from what we find in science. As well as appealing to experimental data, scientists also appeal to the theoretical virtues of a theory, for example how simple, elegant and unified it is.

Philosophers too can appeal to theoretical virtues in justifying their favored position. For example, considerations of simplicity seems to count against the dualist theory of consciousness, which is less simple than its rivals in so far as it posits two kinds of fundamental stuff—physical stuff and consciousness—

whereas physicalism and panpsychism are equally simple in positing just one kind of fundamental stuff (either physical stuff or consciousness).

It could also be that some theories are incoherent, but in subtle ways that require careful analysis to uncover. For example, I have argued that physicalist views of consciousness are incoherent (although—like much in philosophy—this is controversial).

There is no guarantee that these methods will yield a clear a winner. It could be that on certain philosophical issues, there are multiple, coherent, and equally simple rival theories, in which case we should be agnostic about which is correct. This would in itself be a significant philosophical finding concerning the limits of human knowledge.

Philosophy can be frustrating because there is so much disagreement. However, this is also true in many areas of science, such as history or economics. And there are some questions on which there is a modest consensus, for example, on the topic of free will.

A tendency to mix up philosophy with a growing anti-science movement undermines the united front against the real and harmful opposition to science we find in climate change denial and anti-vax conspiracies.

Like it or not, we can't avoid philosophy. When we try to do so, all that happens is we end up with bad philosophy. The first line of Stephen Hawking and Leonard Mlodinow's book "The Grand Design" boldly declared: "Philosophy is dead." The book then went on to indulge in some incredibly crude philosophical discussions of free will and objectivity.

If I wrote a book making controversial pronouncements on particle physics, it'd be rightly ridiculed, as I haven't been trained in the relevant skills, haven't read the literature, and haven't had my views in this area subject to peer scrutiny. And yet there are many examples of scientists lacking any philosophical training publishing very poor books on philosophical topics without it impacting their credibility.

This might be sounding bitter. But I genuinely believe society would be deeply enriched by becoming more informed about philosophy. I have hope that we will one day move on from this "scientistic" period of history, and understand the crucial role both science and philosophy have to play in the noble project of finding out what reality is like.

What Happens to Your Brain When You Meditate Every Day?

Improved memory, attention, and learning? Yes, please!

People who meditate regularly swear by it, but others are often skeptical of it, thinking it's a little, you know, woo-woo.

But what if we told you that meditation is actually a powerful way to train your brain to be calmer and sharper? That scientific studies have shown that meditating regularly can alter brain shape, size, and function?

“Meditation can actually create structural changes in the brain. It has been shown to increase gray matter in the brain, particularly in areas related to learning, memory, emotion regulation, and perspective,” says Mirela Loftus, MD, PhD, medical director at Newport Healthcare.

Based on the amount of scientific evidence supporting meditation, every doctor would be prescribing it if it were a pill, says Gary Soffer, MD, an integrative medicine specialist at Yale Medicine.

Let's dive in and take a look at what meditating regularly does to your brain.

At a Glance

Meditating regularly changes the brain in several ways. It alters brain waves, increases gray matter, and improves connectivity within the brain. The cherry on top? It also boosts feel-good chemicals like dopamine and serotonin.

Together, these changes make us happier, calmer, and sharper. As a result, we're better equipped to handle stress, stay focused on tasks, and experience a greater sense of well-being in our daily lives.

What Meditating Every Day Does to Your Brain

While meditation is an ancient practice, science is still unlocking the full spectrum of its benefits. A surge in research over the past few decades has investigated meditation's effects on both the brain and body.

Electroencephalography (EEG) and structural/functional magnetic resonance imaging (MRI) techniques have been used to map the brain and study the effects of meditation on the brain.

Increases Gray Matter

Meditation increases gray matter in the brain, particularly in areas related to learning, memory, emotion regulation, and perspective, says Dr. Loftus. In fact, imaging studies show that meditation increases the size and volume of the brain, due to increased gray matter concentration.

Strengthens the Prefrontal Cortex

Regular meditation is linked to increased thickness of the prefrontal cortex, which is associated with higher-order brain functions such as awareness, concentration, memory, and decision-making, Dr. Loftus explains.

MRI scans have found that in addition to increasing the gray matter in the prefrontal cortex, meditation also improves the neural connectivity and cognitive function in this area.

Improves Neuroplasticity

Neuroplasticity is the brain's ability to change and rewire itself based on new information and experiences. Meditation increases neuroplasticity by improving neural connectivity patterns across different regions of the brain.

By enhancing connectivity between different brain regions, meditation can improve cognitive functions, information processing, and emotional regulation, says Dr. Loftus.

Boosts Dopamine and Serotonin

Dopamine and serotonin are neurotransmitters, or chemical messengers in the brain. Meditation is linked to a larger quantity of positive neurotransmitters like serotonin and dopamine in the brain, says Dr. Soffer.

Apart from regulating functions like sleep, growth, and metabolism, these chemicals play an important role in maintaining our emotional equilibrium, by making us feel positive and happy.

Alters Brain Waves

Meditation not only calms our blood pressure, respiratory rate, and heart rate, it also alters our brain waves. This helps us relax, concentrate, and process information better.

Those who practice meditation regularly often exhibit higher levels of gamma brain waves, which are associated with heightened perception, problem-solving, and consciousness, says Dr. Loftus.

Decreases the Size of the Amygdala

The amygdala, which is responsible for the fight-or-flight response, tends to shrink in people who meditate regularly, says Dr. Loftus. Research shows that this significantly reduces our stress levels.

Benefits of Meditation

As a result of these changes in the brain, meditation offers us several mental, emotional, and cognitive benefits. Research shows us that it can improve:

- Mood
- Emotional regulation
- Self-awareness
- Attention
- Concentration
- Memory
- Spatial abilities
- Execution function (thinking, planning, decision-making)
- Conflict resolution
- Mindfulness
- Relaxation
- Self-compassion
- Stress
- Sleep
- Pain
- Anxiety

- Depression
- Insomnia
- Post-traumatic stress disorder (PTSD)

Mindful Moment

Need a breather? Take this free 3-minute meditation to calm down quickly—or choose from our guided meditation library to find another one that will help you feel your best.

How to Meditate Every Day

The best way to reap the benefits of meditation is to incorporate it into your daily routine and practice it every day. The benefits can be vast if you stick to the practice, says Dr. Soffer.

Here's how you can make daily meditation a habit:

- **Start small:** You can start with just a few minutes every day. Even five minutes of meditation can be helpful. As you get more comfortable with it, you can work your way up to longer sessions.
- **Find a time that works for you:** Choose a specific time of day that works best for you, whether it's first thing in the morning, during your lunch break, or before bed. Consistency helps in forming a habit.
- **Pick a quiet spot:** Choose a place where you can sit comfortably and won't be interrupted. It could be a swing on your porch, a cozy chair in your room, or even a quiet corner in your office.

- **Set the ambience:** If you like, you can set the ambience for your meditation session by dimming the lights, playing gentle soothing music, and lighting a scented candle.
- **Set an intention:** Before you start meditating, set a clear intention or goal for your practice. It could be to reduce stress, increase focus, or simply take a break from your busy day.
- **Use a guided meditation program:** If you're new to meditating and not sure how to go about it, it can be easier to start with a guided meditation program that takes you through the steps. There are several free programs available online—you can choose the one that best fits your needs and your schedule.
- **Focus on your breath:** Use your breath to anchor you to the present. If your mind wanders to other things, gently bring your focus back to your breath.
- **Reflect on the practice:** After you finish, take a moment to reflect on your session. What did you feel and learn? If you like, you can write down your thoughts in a journal.
- **Be patient with yourself:** Building a new habit takes time. Be patient with yourself on this journey. Don't get frustrated if your mind wanders or if you miss a day. Some days will be easier and others will be harder.

Related: The 7 Best Meditation Apps of 2024

Sample Meditations to Try

If you want to get started with meditation, these are a few types you can try.

Breath Awareness Meditation

Breath awareness meditation simply involves focusing your attention on your breath. Here's how to do it:

- Sit comfortably and close your eyes.
- Taking deep breaths, bring your attention to your breath. Pay attention to the way the air comes in through your nose, fills up your stomach, and goes out again.
- If your attention wanders, gently bring it back to your breath.
- Do this for as long as you like. When you're done, open your eyes slowly.

Body Scan Meditation

Body scan meditation involves bringing your attention to each part of your body and consciously relaxing it, one at a time. Here's how to do it:

- Lie down on your back and close your eyes.
- Bring your attention to your toes, breathing into them and relaxing them. Notice any sensations you feel without trying to change anything.
- Slowly move your focus to your feet, ankles, calves, knees, thighs, and so on, up to the top of your head.
- After you finish scanning your entire body, take a few deep breaths and open your eyes.

Loving-Kindness Meditation

Loving-kindness meditation involves sending kind thoughts to yourself, your loved ones, and the world around you. Here's how to do it:

- Get comfortable, close your eyes, and take a few deep breaths.
- Send kindness to yourself. You can repeat silently, "May I be happy. May I be healthy. May I be safe."
- Extend kindness to your loved ones. Think of someone you love and repeat, "May you be happy. May you be healthy. May you be safe."
- Expand kindness to others. Gradually extend these wishes to a neutral person, someone you have difficulty with, and finally to all living beings.

Walking Meditation

If you find sitting still difficult and prefer movement, walking meditation may be for you. Here's how to do it:

- Find a quiet space to walk comfortably back and forth.
- Walk slowly, paying attention to the sensations in your feet as they make contact with the ground.
- Coordinate your breath with your steps, inhaling and exhaling with each step.
- Notice any thoughts that come to you, letting them go and returning your focus to walking.
- Turn around and continue walking mindfully when you reach the end of your space.

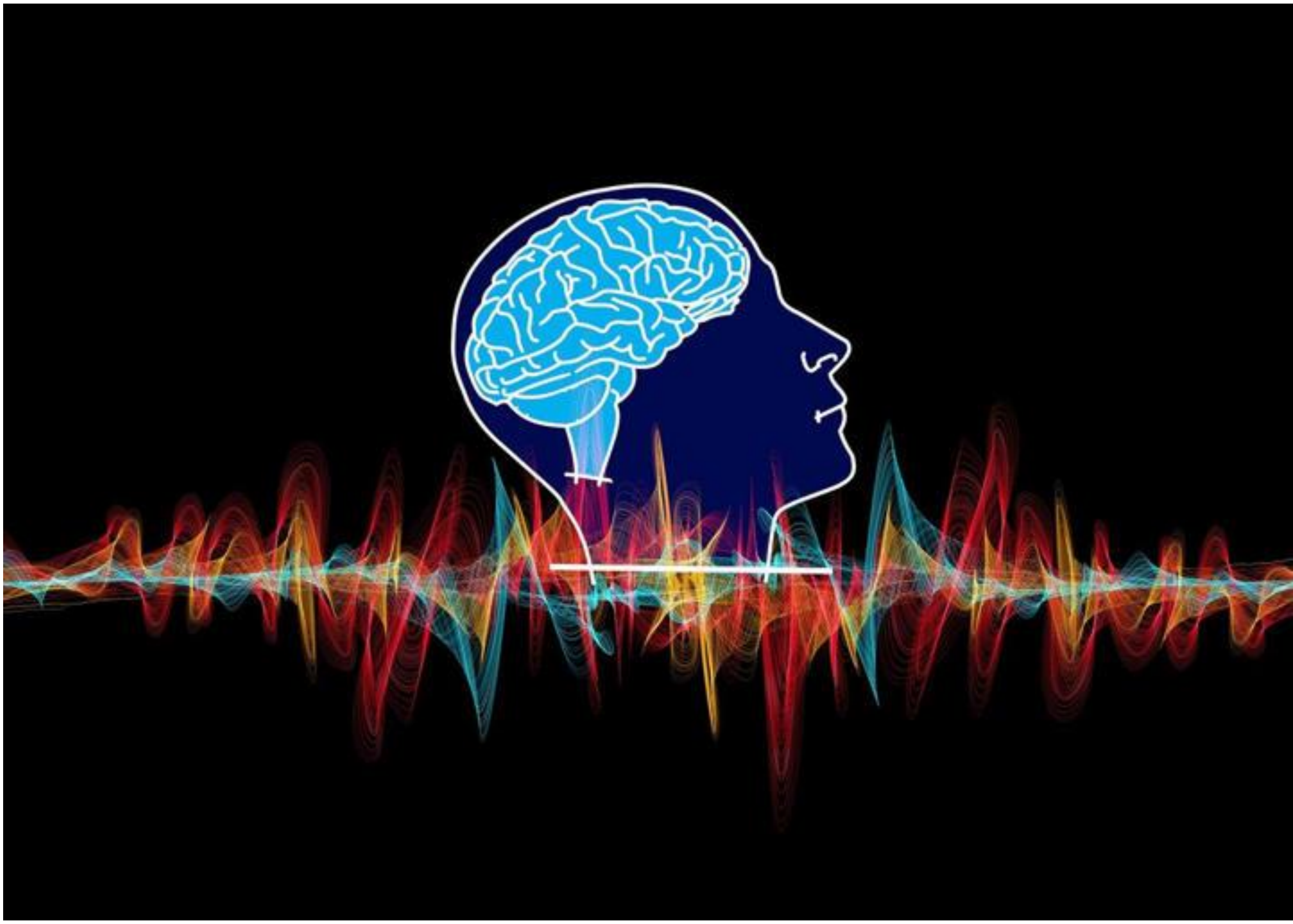
- When you’re done, stand still, take a few deep breaths, and reflect on the experience.

Related: [How to Practice Music Meditation]

Key Takeaways

While meditation may seem simple on the surface, its impact on the brain is quite profound. Incorporating it into your daily routine can improve your attention, memory, mood, and stress levels. You can start slowly with just a few minutes a day, working your way up to longer sessions over time. Just do your best to be regular with it!

Alpha, beta, theta: What are brain states and brain waves? And can we control them?



Credit: Pixabay/CC0 Public Domain© Provided by Medical Xpress

There's no shortage of apps and technology that claim to shift the brain into a "theta" state—said to help with relaxation, inward focus and sleep.

But what exactly does it mean to change one's "mental state"? And is that even possible? For now, the evidence remains murky. But our understanding of the brain is growing exponentially as our methods of investigation improve.

Brain-measuring tech is evolving

Currently, no single approach to imaging or measuring brain activity gives us the whole picture. What we "see" in the brain depends on which tool we use to "look." There are myriad ways to do this, but each one comes with trade-offs.

We learnt a lot about brain activity in the 1980s thanks to the advent of magnetic resonance imaging (MRI).

Eventually we invented "functional MRI," which allows us to link brain activity with certain functions or behaviors in real time by measuring the brain's use of oxygenated blood during a task.

We can also measure electrical activity using EEG (electroencephalography). This can accurately measure the timing of brain waves as they occur, but isn't very accurate at identifying which specific areas of the brain they occur in.

Alternatively, we can measure the brain's response to magnetic stimulation. This is very accurate in terms of area and timing, but only as long as it's close to the surface.

What are brain states?

All of our simple and complex behaviors, as well as our cognition (thoughts) have a foundation in brain activity, or "neural activity." Neurons—the brain's nerve cells—communicate by a sequence of electrical impulses and chemical signals called "neurotransmitters."

Neurons are very greedy for fuel from the blood and require a lot of support from companion cells. Hence, a lot of measurement of the site, amount and timing of brain activity is done via measuring electrical activity, neurotransmitter levels or blood flow.

We can consider this activity at three levels. The first is a single-cell level, wherein individual neurons communicate. But measurement at this level is difficult (laboratory-based) and provides a limited picture.

As such, we rely more on measurements done on a network level, where a series of neurons or networks are activated. Or, we measure whole-of-brain activity patterns which can incorporate one or more so-called "brain states."

According to a recent definition, brain states are "recurring activity patterns distributed across the brain that emerge from physiological or cognitive processes." These states are functionally relevant, which means they are related to behavior.

Brain states involve the synchronization of different brain regions, something that's been most readily observed in animal models, usually rodents. Only now are we starting to see some evidence in human studies.

Various kinds of states

The most commonly-studied brain states in both rodents and humans are states of "arousal" and "resting." You can picture these as various levels of alertness.

Studies show environmental factors and activity influence our brain states. Activities or environments with high cognitive demands drive "attentional" brain states (so-called task-induced brain states) with increased connectivity. Examples of task-induced brain states include complex behaviors such as reward anticipation, mood, hunger and so on.

In contrast, a brain state such as "mind-wandering" seems to be divorced from one's environment and tasks. Dropping into daydreaming is, by definition, without connection to the real world.

We can't currently disentangle multiple "states" that exist in the brain at any given time and place. As mentioned earlier, this is because of the trade-offs that come with recording spatial (brain region) versus temporal (timing) brain activity.

Brain states vs. brain waves

Brain state work can be couched in terms such as alpha, delta and so forth. However, this is actually referring to brain waves which specifically come from measuring brain activity using EEG.

EEG picks up on changing electrical activity in the brain, which can be sorted into different frequencies (based on wavelength). Classically, these frequencies have had specific associations:

- gamma is linked with states or tasks that require more focused concentration
- beta is linked with higher anxiety and more active states, with attention often directed externally
- alpha is linked with being very relaxed, and passive attention (such as listening quietly but not engaging)
- theta is linked with deep relaxation and inward focus
- and delta is linked with deep sleep.

Brain wave patterns are used a lot to monitor sleep stages. When we fall asleep we go from drowsy, light attention that's easily roused (alpha), to being relaxed and no longer alert (theta), to being deeply asleep (delta).

Can we control our brain states?

The question on many people's minds is: can we judiciously and intentionally influence our brain states?

For now, it's likely too simplistic to suggest we can do this, as the actual mechanisms that influence brain states remain hard to detangle. Nonetheless, researchers are investigating everything from the use of drugs, to environmental cues, to practicing mindfulness, meditation and sensory manipulation.

Controversially, brain wave patterns are used in something called "neurofeedback" therapy. In these treatments, people are given feedback (such as visual or auditory) based on their brain wave activity and are then tasked with trying to maintain or change it. To stay in a required state they may be encouraged to control their thoughts, relax, or breathe in certain ways.

The applications of this work are predominantly around mental health, including for individuals who have experienced trauma, or who have difficulty self-regulating—which may manifest as poor attention or emotional turbulence.

However, although these techniques have intuitive appeal, they don't account for the issue of multiple brain states being present at any given time. Overall, clinical studies have been largely inconclusive, and proponents of neurofeedback therapy remain frustrated by a lack of orthodox support.

Other forms of neurofeedback are delivered by MRI-generated data. Participants engaging in mental tasks are given signals based on their neural activity, which they use to try and "up-regulate" (activate) regions of the brain involved in positive emotions. This could, for instance, be useful for helping people with depression.

Another potential method claimed to purportedly change brain states involves different sensory inputs. Binaural beats are perhaps the most popular example, wherein two different wavelengths of sound are played in each ear. But the evidence for such techniques is similarly mixed.

Treatments such as neurofeedback therapy are often very costly, and their success likely relies as much on the therapeutic relationship than the actual therapy.

On the bright side, there's no evidence these treatment do any harm—other than potentially delaying treatments which have been proven to be beneficial.

According to Quantum Physics, Death Might Be an Illusion

What happens after we die? While many believe that death is the end, quantum physics suggests that it might not be as simple as we think.

In fact, it could be an illusion. This idea challenges everything we know about life and death. By looking at concepts like the interconnectedness of all things and the nature of consciousness, here's to a whole new perspective on life after death.

Biocentrism Challenges Our Understanding of Death & Life

Dr. Robert Lanza, a leading expert in biotechnology, plays a major role in this idea. He's the Chief Scientific Officer at the Astellas Institute for Regenerative Medicine, where he studies stem cells and how they can be used to treat diseases.

Before this, Dr. Lanza focused on researching embryonic stem cells and cloning, working with both animals and humans. He is also an adjunct professor at Wake Forest University School of Medicine in North Carolina.

According to biocentrism, death might not be what we think it is. Instead of seeing death as the end of life, this theory suggests that it could be an illusion, something created by the way we perceive the world.

The idea is that time and space, as we understand them, are not fixed. Our awareness of these concepts might shape what we experience as life and death.

The theory doesn't deny that our physical bodies die, but it suggests that our experience of death might not be the final event we think it is.

By studying stem cells and regenerative medicine, Dr. Lanza is working to explore how life can be extended or even renewed. His research into cloning and stem cells shows that the boundaries of life might not be as clear-cut as we once believed.

If we can manipulate biological processes, it suggests that life—at least the biological part of it—could be much more flexible than we realize.

So, in the context of biocentrism, death is not the end, but an illusion shaped by how we perceive the world. This shifts the way we might think about life, consciousness, and even the universe itself. It challenges everything you've known about life and death and opens up a whole new way of looking at existence. (ref)

Heisenberg's Uncertainty Principle

Building on the idea of biocentrism, Heisenberg's Uncertainty Principle gives us another way to think about death as an illusion. You might be familiar with the idea that, in quantum physics, things don't always behave the way we expect them to.

Heisenberg's Uncertainty Principle tells us that we can't know everything about a particle at once—specifically, we can't know both its exact position and speed at the same time. The more precisely we know one, the less we can know about the other. (ref)

Now, you might wonder how this connects to the idea that death is an illusion. This principle suggests that the universe is not as predictable as we once thought.

The world operates in a way that is uncertain, unpredictable, and constantly shifting. Just like with quantum particles, our understanding of life and death might be based on limited knowledge.

If death is something that happens when our bodies stop functioning, it seems like a clear and final event. But what if, just like the uncertainty of quantum particles, death isn't as fixed as it seems? What if the way we understand death is shaped by our limited perception of time and space?

Think about it: in the quantum world, things can exist in multiple states at once, and only when we observe them do they "choose" a state. This could suggest that our perception of life and death is similar—it might depend on how we observe it.

If consciousness itself plays a key role in shaping our reality, as biocentrism suggests, then death could be something we don't fully understand because we haven't figured out how to "observe" it in a different way.

The "Many Worlds" Theory

Now, let's take this idea even further with the Many Worlds Theory, which could also support the idea that death is an illusion.

Sean Carroll, a theoretical physicist and philosopher, believes that the many-worlds theory is the simplest way to understand quantum mechanics. According to this theory, there is one wave function for the entire Universe.

When something happens in our world, the other possible outcomes don't disappear. Instead, new worlds are created where each possibility becomes real.

Carroll calls this approach "courageous" because of its simplicity and logic. These other worlds exist alongside ours, but they are so hidden they might as well be empty. (ref)

So, when you face a choice or even a life-or-death situation, every possible outcome occurs in a separate, parallel universe. For example, if you were in a dangerous situation and could either live or die, the theory says that in one world, you might survive, while in another, you might die.

All these different versions of you exist in separate worlds, but they're all happening at the same time, just in different realities.

Schrödinger's Cat

Schrödinger's Cat, devised by physicist Erwin Schrödinger in 1935, is a famous thought experiment in quantum physics. This might also support the idea that death is just an illusion.

Imagine you have a cat inside a sealed box. Along with the cat, there's a radioactive atom that has a 50% chance of decaying and releasing poison. If the atom decays, the poison will kill the cat. If it doesn't decay, the cat stays alive. (ref)

In the world we see around us, the cat is either alive or dead, depending on whether the atom has decayed. But in quantum physics, things are not so clear-cut. Before we open the box and look, the cat is both alive and dead at the same time.

This is because the atom can be in both a decayed and not-decayed state at once. It's only when you open the box and observe the cat that it "chooses" a state—alive or dead.

The key here is that in quantum physics, the act of observation determines the outcome. Before you check, the cat exists in a mix of both states. This could mean that reality, including life and death, isn't as fixed and certain as we think. It's only when we observe something that it "becomes" real to us.

If we apply this to death, it might mean that death isn't an absolute, unchangeable event. Instead, it could be like the cat in the box—alive and dead at the same time, depending on how we perceive it.

Carl Jung, Quantum Physics & the Spiritual

Image Credit: ETH Library, Public domain, via Wikimedia Commons

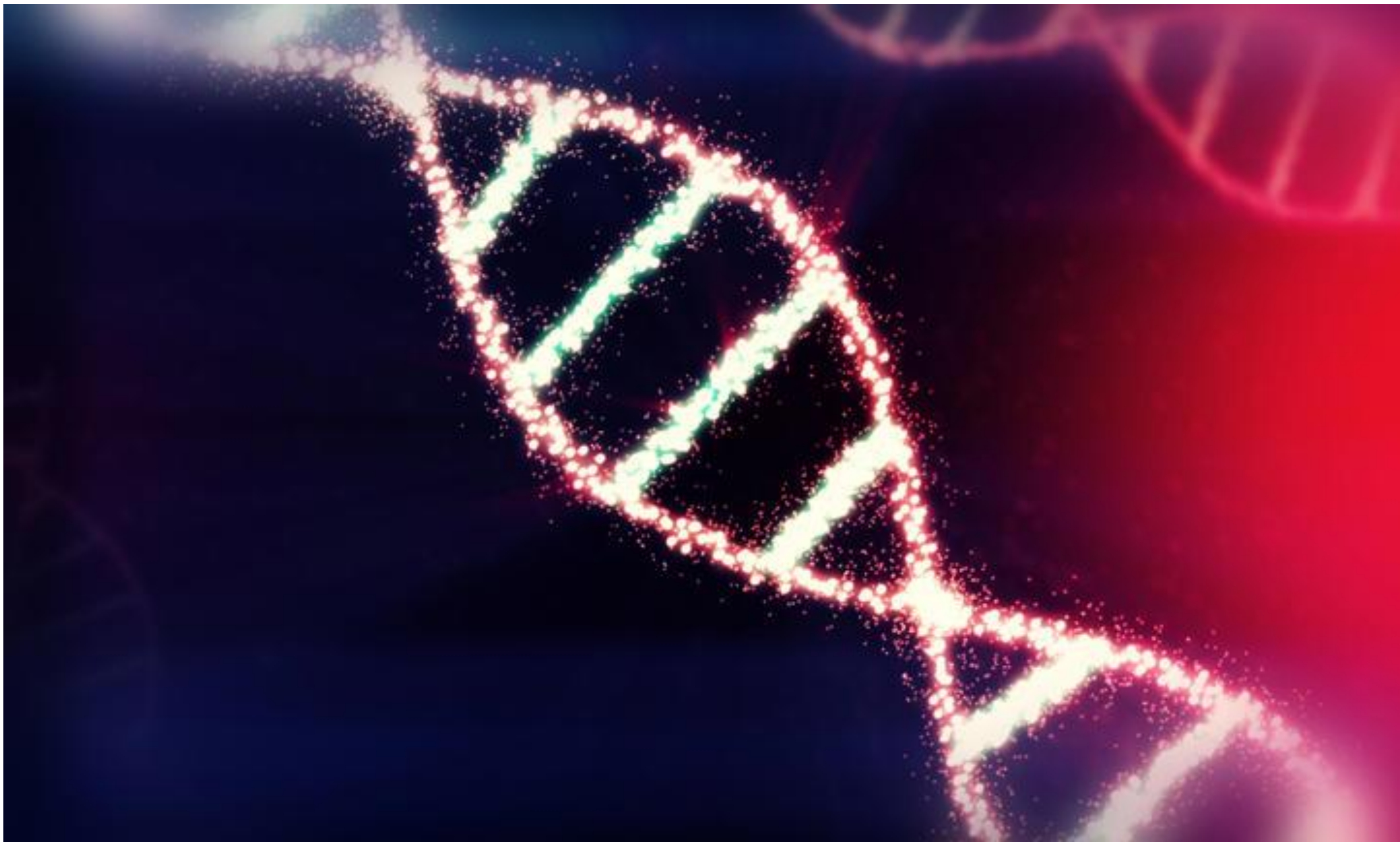
Researchers examined Carl Gustav Jung's theories suggesting that a non-physical realm made up of forms, which, though invisible, can appear in the physical world and influence it. In a published paper, they argue that the physical world comes from this realm of potential, where forms become physical or mental. (ref)

So, is death not as final as it seems? Just as forms in the unconscious can appear in physical reality, consciousness may continue to exist in different states even beyond physical death.

By blending Jung's psychological theories with quantum physics, we are presented with a view of existence that is far more interconnected and continuous than the traditional view of death as a finality. These concepts challenge the way we typically think about life and death. While we may never fully understand the mysteries of life and death, quantum physics suggests that there could be much more to our existence than we realize.

Yes, humans are still evolving

Noted public figures like David Attenborough have previously claimed that human evolution is over, but many researchers studying human evolution firmly disagree. We know that humans have altered our environment in innumerable ways–changing the very air, water, and soil that we rely on as the most successful "ecosystem engineers" on Earth. It can be easy, [...]



Every person is born with about 70 new genetic mutations on average, which aren't derived from their parents'.© Credit: blackdovfx/Getty Images

Noted public figures like David Attenborough have previously claimed that human evolution is over, but many researchers studying human evolution firmly disagree. We know that humans have altered our environment in innumerable ways–changing the very air, water, and soil that we rely on as the most successful "ecosystem engineers" on Earth. It can be easy, amid all that change, to assume that we've conquered biology and eliminated the effects of evolution and natural selection on our species. But that's not what the science says.

"Of course humans are still evolving," says Jason Hodgson, an anthropologist and evolutionary geneticist at Anglia Ruskin University in England. "All living organisms that are in a population are evolving all the time."

"Humans are definitely still evolving," agrees John Hawks, a paleoanthropologist at the University of Wisconsin-Madison.

"Humans are still evolving, as are virtually all other populations of organisms," says Stephen Stearns, an emeritus professor of ecology and evolutionary biology at Yale University.

Yet the way that evolution acts on our species may not be what you imagine. In biological terms, evolution is a change in gene variant (a.k.a. "allele") frequency in a population over time. It is not a force directing a species' trajectory towards a certain goal. However, biologists can still observe human evolution in action and identify recent examples of it.

How does evolution happen?

Before we get into the research, it's important to understand how evolution works. There are a handful of ways organisms can evolve. Every person is born with about 70 new genetic mutations on average, which aren't derived from their parents'. Once emerged, mutations can be passed onto subsequent generations, thereby changing population-level allele frequency. There's drift, where randomness influences what gene variants are passed on in what proportions–this unfolds the quickest in small populations. There's gene flow, where individuals and populations migrate, bringing their genetic material to new places. Sexual selection happens when people mate non-randomly (which accounts for most of human mating).

Then there's natural selection–often conflated with evolution itself–where environmental conditions that impact survival and reproduction dictate what alleles are most likely to persist through future generations. Counter to drift, natural selection happens faster in larger populations, says Hodgson, as beneficial alleles are more likely to emerge when there are more people around. "This is the largest the human population size has ever been, so this is probably to some extent the greatest change for natural selection to act in humans," he adds.

Through all of these above mechanisms, humans evolved from our last common ancestor with our two closest living relatives–chimpanzees and bonobos. We did not evolve from these great apes, but rather from a lineage of now extinct primates which diverged from the predecessor of chimpanzees and bonobos from a shared point. Long before *Homo sapiens* were a branch on the tree of life, previous divergences led to primates and mammals and vertebrates. Slowly, over billions of years, evolution has diversified all organisms from the last universal common ancestor. Our bodies still carry the evidence of our species' evolutionary past. For instance, in our now useless (or "vestigial") tail bones and appendixes.

And all of the above mechanisms are still at play in humans today, though our societal organization and sheer numbers may have altered which ones are acting the quickest, in what populations, and in what ways. Big evolutionary changes impacting conspicuous traits, like the loss of tails, happen very slowly, but there is still less apparent change being wrought all the time.

The oft-stated belief that modern medicine has eliminated natural selection "is not a serious view," says Hodgson, because it relies on many untrue assumptions. For instance that we've resolved all health issues with science or that access to healthcare and contraception is equal. In reality, "it's not even close to being equal," he emphasizes. Therefore, there is also unequal reproduction and unequal survival and people everywhere remain exposed to all manner of selective mechanisms.

Concurrently, there's also other drivers of human evolution that are likely unique to our species, at least in their intensity. In many instances, our cultures influence with whom, how, and if people reproduce, note both Hodgson and Hawks. Those things also go on to affect the frequency of gene variants across time.

"We are maybe somewhat tweaking the course of evolution, but it doesn't at all mean we're stopping it from happening," says Hakhamanesh Mostafavi, an associate professor of genetics and genomics at New York University

How do we know evolution is still happening?

Many studies of humans' genetic past provide illustrative examples of evolution in action. There's the rise of malarial resistance in Madagascar, linked to the proliferation of a specific gene variant in the population, as described in 2014 research from Hodgson. That example of evolution, he says, occurred within the past 2,000 years–very recent on the order of evolutionary time.

There's the emergence and spread of alleles that enable adult lactose digestion in some Middle Eastern, European, and African populations, following the spread of herding. "Even within the past 1,000 years, lactase persistence as an allele is increasing," Hawks says.

And even more recently than that–in the last century–Stearns and his research colleagues attributed height decreases and other population-level changes to natural selection in a classic 2010 study of people in Framingham, Massachusetts, based on a data collection endeavor begun in 1948.

Studies of large genomic datasets also reveal changes that wouldn't otherwise be observable on a trait-level. A 2022 paper identified two small changes in the human genome, responsible for creating functional proteins, which emerged since our species split from other primate lineages.

In a 2017 study led by Mostafavi, he and his colleagues examined gene differences between age groups in the UK Biobank, a repository of about half a million British peoples' genetic and health data. They were looking for widespread alleles that were less common among older people, and therefore likely linked with longevity and survival. Across the whole dataset, they only found two such gene variants–one related to heavy smoking in men and one related to Alzheimer's risk. Despite the fact that many differences in health are genetic, there were relatively few identifiable, harmful single gene variants circulating in the study population. Which means evolution likely already filtered out those genes.

"The absence [or more deleterious alleles] is a strong suggestion for selection," says Mostafavi. The two genes that were identified in the study are liable to be filtered out with additional time as well, he says. The fact that they're currently common might mean that they've only recently become harmful.

The type of evolution demonstrated in Mostafavi's research is purifying selection: The removal of harmful mutations from a population over time. It's less flashy than selection in favor of beneficial traits, but it's much more common.

Another common form of not-so-flashy selection is stabilizing selection, where extremes remain rare, in favor of a tendency towards the middle ground. Birth weight and human height are standard examples of where stabilizing selection acts, he says.

"Maybe we don't always see stabilizing [and] purifying selection, maybe they're not obvious… but we know for a fact that many human [traits] are somehow kept at some optimum," indicating that both forms of natural selection remain ongoing.

So what are we evolving into?

"Most people want to know, 'are we directionally changing as a species into something else?' That is: Is there a destination at the end of this?" says Hawks. The answer, at least on the timescale scientists can study it, is unclear.

Evolution is a process, not an outcome, and it doesn't always happen linearly. "Today's environments are changing really fast in various ways. We don't know for sure which changes will be sustained over time, so we don't know what changes might add up to anything. [Many] changes might reverse and go the opposite direction just as quickly as they evolved in the last generation or two," Hawk adds.

"I personally think that our genetics are going to continue to change, probably at an accelerated rate," he says, "but I do not have a good basis for predicting how."

What does neurotypical, neurodivergent, and neurodiverse mean?

- Neurotypical
- Neurodivergent
- Neurodiversity
- Which term is better?
- Benefits
- Summary

The word “neurotypical” describes someone who thinks and processes information in ways that are typical within their culture. They tend to learn skills and reach developmental milestones around the same time as their peers.

In contrast, the term “neurodivergent” describes someone who processes information in a different way. Autistic people and those with attention deficit hyperactivity disorder (ADHD) and similar conditions sometimes identify as neurodivergent.

These words can be a way of moving discussions away from focusing on a disease or mental health disorder, implying instead that people simply have a different way of understanding and interacting with the world.

However, some argue that the term “neurodiversity” is better still. This word refers to various ways that individuals think and behave. Rather than frame one way as typical and the other as atypical, “neurodiversity” embraces a continuum of possibilities.

In this article, we will look at what it means to be neurotypical and neurodivergent and explore some traits that share associations with these words. We will also look at neurodiversity and its benefits.

What does neurotypical mean?

The term neurotypical describes someone who thinks and processes information in an expected way for their culture and setting.

Some characteristics that people associate with neurotypical development include:

- reaching developmental milestones at a similar time to other children, such as learning to speak
- having social or organizational skills that are similar to someone’s peers
- being able to tolerate some sensory discomfort, such as loud noises, without much difficulty
- being able to adapt to changes in routines
- being able to focus in class or at work for prolonged periods
- having varied interests or hobbies typical for the person’s age

A neurotypical person does not necessarily have all of these traits or have them in all situations to identify as neurotypical.

For example, some people without autism may feel overwhelmed by certain sensory experiences, such as being in a crowd. Some children also have delays in learning speech or other skills that are not a result of any diagnosis.

The meaning "neurotypical" is also subjective, to an extent. What people consider typical can vary according to context.

For example, a 2018 studyTrusted Source comparing data from the United States, India, and Japan looked at the characteristics doctors use to distinguish autistic from allistic — or nonautistic — people. Researchers found that while many traits were consistent across groups, others depended on the culture.

What does neurodivergent mean?

The term "neurodivergent" describes people who process information and behave in a way that differs from the actual or perceived norms of a particular culture. It is a way to discuss diagnoses, such as autism, in a way that does not frame it as a problem or an illness.

According to the United Kingdom charity ADHD Aware, 30–40% of the population are neurodivergent. As with the term "neurotypical," though, the term has no fixed meaning.

Neurodivergence comes in many forms. People with the following may consider themselves neurodivergent:

- **ADHD:** People with ADHD oftenTrusted Source have high levels of energy, which may cause hyperactivity and difficulty sitting still at school or work. Therefore, staying focused or organized can also be difficult. However, these traits can also mean people with ADHD are spontaneous and dynamic.

- **Learning disabilities:** Learning disabilities affect how someone learns or takes in information. For example, dyslexia affects a person's ability to read, while dysgraphia affects handwriting and fine motor skills. People with these diagnoses are not unintelligent or incapable of learning — in fact, they often have average or above-average intelligence. However, they can benefit from learning in different ways.
- **Autism:** Autism affects how someone processes sensory information and how they think and communicate. For example, an autistic individual may be very sensitive to certain sounds and noises or have trouble reading social cues. Others may have very specific, in-depth interests. The effects vary greatly from person to person.
- **Tourette's syndrome:** People with Tourette's syndrome have a neurological condition that causes them to make involuntary movements or sounds, known as tics.
- **Synesthesia:** Individuals with synesthesia experience the senses in different ways. They may see colors or shapes when they hear music or taste certain flavors when they hear words. They may only experience this in their "mind's eye," or externally in the world around them.

Some consider rare forms of giftedness to be part of neurodivergence too. For example, people with hyperthymesia have a highly accurate memory of their own life experiences.

Does neurodivergence include mental health?

The above diagnoses are not mental health conditions — they are neurodevelopmental in origin. They come with long term traits that do not change over time.

However, some people consider mental health conditions to be part of neurodivergence because they can also change how someone thinks and behaves. People with these conditions can also face some of the same challenges, such as feeling misunderstood or experiencing stigma.

However, mental health conditions have some characteristics that make them distinct:

- **Quality of life:** Being neurodivergent does not necessarily reduce quality of life. In the right circumstances, people who identify as such can lead fulfilling lives. However, a supportive environment does not prevent mental health conditions from affecting quality of life.
- **Identity:** For many, neurodiversity is part of their identity. Some may also feel this way about their mental health condition. In some situations, this viewpoint could cause harm. For example, seeing anorexia as a lifestyle or identity can mean people do not seek treatment, which could be fatal.
- **Treatment:** Finally, many mental health conditions are treatable and can improve significantly with support and therapy. The same is not true for autism, learning disabilities, and other types of neurodivergence. Though there is no cure for these diagnoses, appropriate support can help people learn the skills they find challenging.

ADHD Aware states that eventually, some long term conditions that people consider psychological, such as schizophrenia or antisocial personality disorder, may ultimately become part of the concept of neurodivergence or neurodiversity.

The more scientists discover how these conditions work, the more the language will evolve.

What is neurodiversity?

Neurodiversity refers to the wide spectrum of ways that people think. It frames differences in cognition as variations, all of which are equally normal and valuable.

The concept became popular in the 1990s, when sociologist Judy Singer proposed that autism arises from the brain working differently from nonautistic individuals. She also highlighted that this is not a fault but a difference. Neurodiversity has since become a movement, changing how people see autism and other diagnoses.

Neurodiversity advocates may still use the terms “neurotypical” and “neurodivergent” to identify where they are on the neurodiversity spectrum or talk about others. However, everyone is included in neurodiversity, regardless of how their brain functions.

Which terms are better?

There are mixed opinions on whether the terms “neurotypical” and “neurodivergent” are helpful.

Some feel that “neurotypical” is an accurate reflection of how many people understand the world and social interactions in a similar or typical way.

The word can also reflect the privileges from which neurotypical people can benefit. Because their peers consider them “typical,” people who fall into this category often have an easier time in school, the workplace, and relationships.

However, others say that calling one group “typical” reinforces the idea that while some people think typically, others think atypically. A 2021 paper argues that this is both scientifically inaccurate and harmful.

The authors say that diversity in how people think is a natural product of evolution and that it is natural for human brains and bodies to vary. To consider one type of cognition “typical” ignores this fact.

How a person identifies and describes themselves is ultimately a personal choice. Generally, it is a good idea to use the terms an individual prefers.

What are the benefits of neurodiversity?

Supporters for neurodiversity believe that variations in thinking are beneficial to society, adding different perspectives and ideas. Teaching children about neurodiversity may:

- reduce fear about the way their brain works or how they differ from others
- encourage them to see differences as normal and natural
- teach them about being aware of harmless behaviors, such as stimming
- help cultivate healthy self-esteem
- empower children to advocate for their needs, for example, if they are have reading difficulties in class
- feel confident about their unique abilities

On a personal level, the benefits for adults are very similar. Learning about neurodiversity can change how people see themselves or those around them.

On a broader scale, acceptance of neurodiversity may:

- help parents and caregivers understand and care for their children
- help teachers understand how best to educate children with a range of needs
- encourage employers to hire neurodiverse people, reducing unemployment
- increase positive representations of neurodiversity in the media
- decrease stigma, bullying, and discrimination

Summary

The word “neurotypical” refers to people who have brains that function in a similar way to most of their peers. Individuals who are neurotypical develop skills, such as social or organizational skills, at around the same rate as others their age. They can also tolerate change, disruption in routines, and distractions without too much difficulty.

In contrast, people who consider themselves neurodivergent have brains that function differently. They may have a diagnosis such as ASD, ADHD, dyslexia, or Tourette’s syndrome. Neurodivergence comes in many forms, and they affect people with these diagnoses differently.

'Noisy' autistic brains seem better at certain tasks. Here's why neuroaffirmative research matters

Autism is a neurodevelopmental difference associated with specific experiences and characteristics.

For decades, autism research has focused on behavioral, cognitive, social and communication difficulties. These studies highlighted how autistic people face issues with everyday tasks that allistic (meaning non-autistic) people do not. Some difficulties may include recognizing emotions or social cues.

But some research, including our own study, has explored specific advantages in autism. Studies have shown that in some cognitive tasks, autistic people perform better than allistic people. Autistic people may have greater success in identifying a simple shape embedded within a more complex design, arranging blocks of different shapes and colors, or spotting an object within a cluttered visual environment (similar to Where's Wally?). Such enhanced performance has been recorded in babies as young as nine months who show emerging signs of autism.

How and why do autistic individuals do so well on these tasks? The answer may be surprising: more "neural noise."

What is neural noise?

Generally, when you think of noise, you probably think of auditory noise, the ups and downs in the amplitude of sound frequencies we hear.

A similar thing happens in the brain with random fluctuations in neural activity. This is called neural noise.

This noise is always present, and comes on top of any brain activity caused by things we see, hear, smell and touch. This means that in the brain, an identical stimulus that is presented multiple times won't cause exactly the same activity. Sometimes the brain is more active, sometimes less. In fact, even the response to a single stimulus or event will fluctuate continuously.

Neural noise in autism

There are many sources of neural noise in the brain. These include how the neurons become excited and calm again, changes in attention and arousal levels, and biochemical processes at the cellular level, among others. An allistic brain has mechanisms to manage and use this noise. For instance, cells in the hippocampus (the brain's memory system) can make use of neural noise to enhance memory encoding and recall.

Evidence for high neural noise in autism can be seen in electroencephalography (EEG) recordings, where increased levels of neural fluctuations were observed in autistic children. This means their neural activity is less predictable, showing a wider range of activity (higher ups and downs) in response to the same stimulus.

In simple terms, if we imagine the EEG responses like a sound wave, we would expect to see small ups and downs (amplitude) in allistic brains each time they encounter a stimulus. But autistic brains seem to show bigger ups and downs, demonstrating greater amplitude of neural noise.

Many studies have linked this noisy autistic brain with cognitive, social and behavioral difficulties.

But could noise be a bonus?

The diagnosis of autism has a long clinical history. A shift from the medical to a more social model has also seen advocacy for it to be reframed as a difference, rather than a disorder or deficit. This change has also entered autism research. Neuroaffirming research can examine the uniqueness and strengths of neurodivergence.

Psychology and perception researcher David Simmons and colleagues at the University of Glasgow were the first to suggest that while high neural noise is generally a disadvantage in autism, it can sometimes provide benefits due to a phenomenon called stochastic resonance. This is where optimal amounts of noise can enhance performance. In line with this theory, high neural noise in the autistic brain might enhance performance for some cognitive tasks.

Our 2023 research explores this idea. We recruited participants from the general population and investigated their performance on letter-detection tasks. At the same time, we measured their level of autistic traits.

We performed two letter-detection experiments (one in a lab and one online) where participants had to identify a letter when displayed among background visual static of various intensities.

By using the static, we added additional visual noise to the neural noise already present in our participants' brains. We hypothesized the visual noise would push participants with low internal brain noise (or low autistic traits) to perform better (as suggested by previous research on stochastic resonance). The more interesting prediction was that noise would not help individuals who already had a lot of brain noise (that is, those with high autistic traits), because their own neural noise already ensured optimal performance.

Indeed, one of our experiments showed people with high neural noise (high autistic traits) did not benefit from additional noise. Moreover, they showed superior performance (greater accuracy) relative to people with low neural noise when the added visual static was low. This suggests their own neural noise already caused a natural stochastic resonance effect, resulting in better performance.

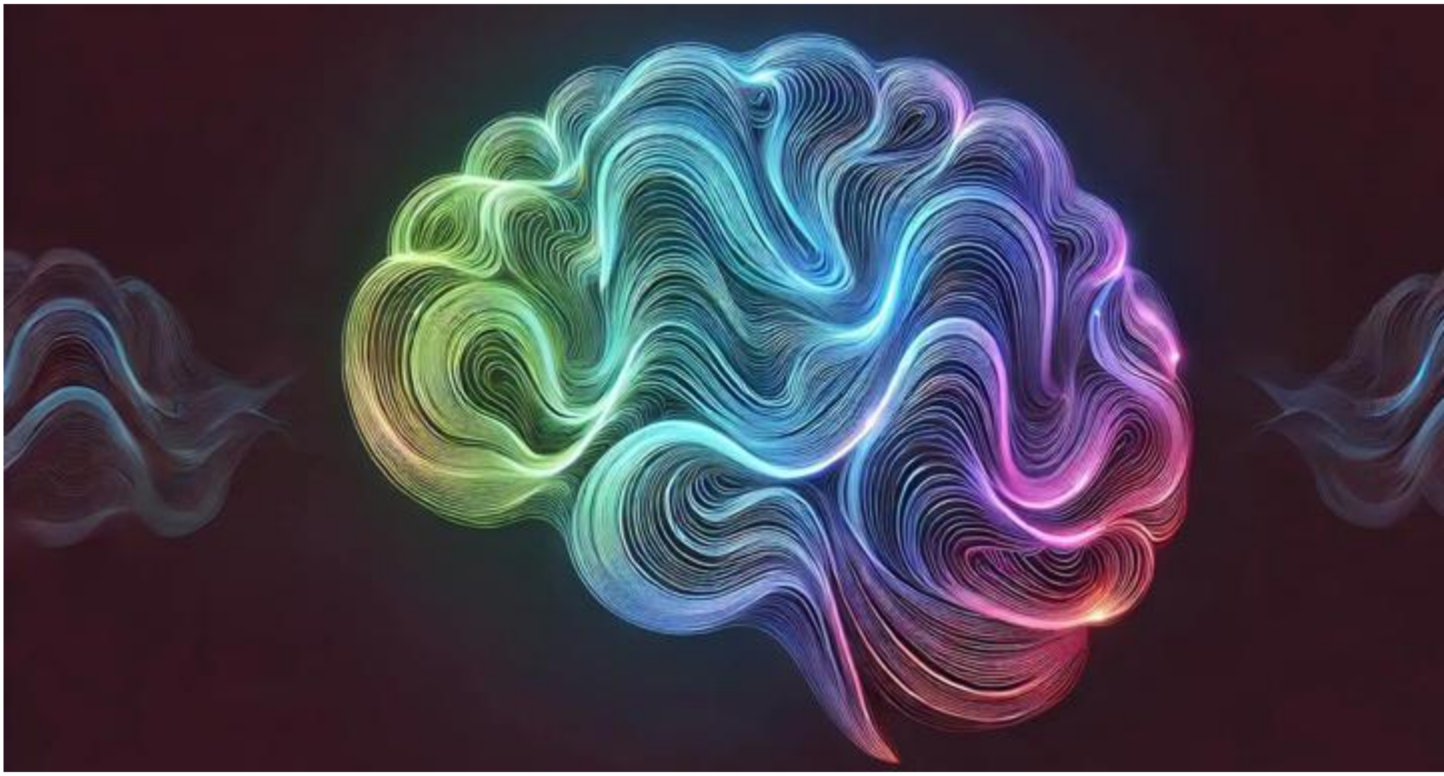
It is important to note we did not include clinically diagnosed autistic participants, but overall, we showed the theory of enhanced performance due to stochastic resonance in autism has merits.

Why this is important?

Autistic people face ignorance, prejudice and discrimination that can harm well-being. Poor mental and physical health, reduced social connections and increased "camouflaging" of autistic traits are some of the negative impacts that autistic people face.

So, research underlining and investigating the strengths inherent in autism can help reduce stigma, allow autistic people to be themselves and acknowledge autistic people do not require "fixing." The autistic brain is different. It comes with limitations, but it also has its strengths.

Dynamic brain connectivity distinguishes conscious and unconscious states



(Photo credit: DALL·E)© PsyPost

Our brains are remarkably dynamic, constantly shifting between states of activity that reflect our thoughts, perceptions, and awareness. A new study published in *Communications Biology* suggests that this dynamism is key to distinguishing between consciousness and unconsciousness. Researchers found that the brain "explores" a diverse range of connectivity patterns when we are awake, but during states like deep sleep or anesthesia, the brain becomes more predictable and rigid, its functional activity corresponding more closely with its structural wiring.

Consciousness—our ability to experience, perceive, and respond to the world—has long been one of the most puzzling topics in neuroscience. Researchers have sought reliable, objective markers to distinguish between conscious and unconscious states, both to deepen our understanding of awareness and to improve clinical tools for diagnosing and managing conditions like comas or anesthesia.

Brain connectivity can be classified into two types: *structural* connectivity and *functional* connectivity. Structural connectivity refers to the physical wiring of the brain, the fixed networks of neurons and pathways that form its architecture. Functional connectivity, on the other hand, reflects the brain's activity patterns, showing how different regions work together dynamically at any given moment.

Previous research has shown that the brain's functional connectivity constantly shifts between different configurations, reflecting various cognitive processes. The new study aimed to address whether the shifting patterns of functional connectivity could reliably differentiate between conscious and unconscious states by focusing on brain dynamics in people who were awake, under general anesthesia, or in deep sleep.

"Consciousness remains one of the most intriguing topics in neuroscience—something deeply fundamental and yet not fully understood," explained study authors Alain Destexhe and Rodrigo Cofré, who are both affiliated with the Paris-Saclay Institute of Neuroscience.

"We are broadly interested in the whole spectrum of consciousness states, from the unconscious states to those induced by psychedelics. Our interest lies in unraveling the dynamic functional mechanisms that underlie conscious awareness and how they differ when consciousness is perturbed. Resting-state functional MRI (fMRI) gives us a unique way to observe the brain in action, allowing us to capture spontaneous activity and its transitions, which may reflect deeper processes related to consciousness."

For their study, the researchers analyzed fMRI data from two datasets. The first involved 16 healthy participants scanned during three states: awake, under general anesthesia (using the intravenous drug propofol), and after recovery. The second dataset included 18 healthy participants scanned during wakefulness and deep sleep (N3 stage).

The analysis focused on "phase coherence," which measures how synchronized different brain regions are at any given moment. This approach enabled the researchers to identify recurring patterns of brain activity and track their transitions over time. Using statistical clustering techniques, these patterns were grouped into distinct categories, or “states,” for each condition. The frequency and distribution of these states were then analyzed across conscious and unconscious conditions.

To characterize brain dynamics, the study employed two key measures. Shannon entropy quantified the diversity of brain activity patterns, with higher entropy indicating a broader repertoire of states. Structure-function coupling assessed how closely the brain’s functional activity aligned with its physical wiring, as determined by structural MRI. The researchers also used a Markov chain model to evaluate the likelihood of transitions between states, providing insights into the stability and flexibility of brain dynamics in various conditions.

The results revealed significant differences in brain dynamics between conscious and unconscious states. During wakefulness, the brain exhibited a diverse and flexible repertoire of activity patterns, reflected in high Shannon entropy. These patterns were less reliant on the brain’s structural connectivity, indicating that the conscious brain explores states independent of its physical wiring. Frequent transitions between states during wakefulness underscored the dynamic and adaptable nature of the conscious brain.

In contrast, unconscious states, such as those induced by general anesthesia or deep (N3) sleep, showed reduced diversity in brain activity patterns. Shannon entropy was significantly lower, indicating that the brain explored a narrower range of states. Additionally, functional activity in unconscious states closely aligned with the brain’s structural connectivity, suggesting that the unconscious brain relies more on its anatomical wiring. Transitions between states were also less frequent, reflecting a more rigid and repetitive dynamic.

“In simple terms, our brain’s activity patterns are far more dynamic when we’re awake and conscious,” Destexhe and Cofré told PsyPost. “These rich dynamical patterns of brain connectivity appear to be essential for awareness. Under anesthesia or deep sleep, however, the brain is still very active but relies on less dynamic patterns, closer to the anatomical connectivity, and shows fewer transitions. These findings bring us closer to identifying objective and reliable indicators of consciousness, which could one day help us better understand and even track awareness in clinical settings.”

Interestingly, the researchers observed that certain activity patterns typically associated with unconsciousness occasionally appeared during wakefulness, and vice versa. This finding suggests that consciousness may exist on a spectrum, with overlapping features between states of awareness and unawareness. Despite these overlaps, the overall findings consistently demonstrated that rich and dynamic brain activity is a hallmark of consciousness.

"We were surprised by the robustness and generalizability of our results," the researchers said. "Additionally, we were surprised to find that certain connectivity patterns more associated with unconsciousness can appear in small bursts even when we're awake, and vice versa. This suggests that consciousness isn't necessarily an all-or-nothing state; rather, it may be a fluid spectrum with overlapping features, raising intriguing questions about the boundaries between states of awareness and unawareness."

As with all research, the study includes some limitations. The data came from two different research groups using distinct scanning and preprocessing methods, which may have introduced variability. Additionally, the study focused on one anesthetic, and the effects of other drugs on brain dynamics remain unexplored. Deep sleep, which involves more than just a loss of consciousness, may also introduce complexities not fully addressed in this study.

"While our method is robust and seems applicable across different states such as general anesthesia and deep sleep, there are still limitations in how data is collected and preprocessed in different studies," Destexhe and Cofré explained. "For example, differences in data acquisition settings and preprocessing techniques can introduce subtle variability. Additionally, while we studied the effects of one anesthetic (propofol), other drugs may have different effects on brain dynamics."

Future research could expand these findings by exploring other unconscious states, such as those induced by different anesthetics or psychedelics. Using alternative brain imaging techniques could also provide complementary insights. Ultimately, the goal is to develop universal markers of consciousness that can be applied in diverse clinical and research contexts.

"Long-term, we hope to develop generalizable markers of consciousness that could be used across various clinical scenarios, from general anesthesia monitoring to assessments of consciousness in patients with brain injuries," Destexhe and Cofré said. "We're also interested in exploring other imaging methods like EEG, which may offer additional insight into the brain's conscious and unconscious states. We would also like to generalize our results further to psychedelic states."

"This study underscores the centrality of the brain's dynamic patterns to consciousness. A deeper understanding of these dynamics holds promise not only for advancing scientific knowledge but also for practical medical applications, such as assessing brain states in patients with traumatic brain injuries or comatose states, or for monitoring the depth of anesthesia and altered states under psychedelics. Ultimately, we hope this work inspires further research to extend these methods across additional species, alternative anesthetics, and diverse data acquisition techniques."

The study, "Dynamical structure-function correlations provide robust and generalizable signatures of consciousness in humans," was authored by Pablo Castro, Andrea Luppi, Enzo Tagliazucchi, Yonatan S. Perl, Lorina Naci, Adrian M. Owen, Jacobo D. Sitt, Alain Destexhe, and Rodrigo Cofré.

Your consciousness could travel multiverse when you dream, claim scientists

Your consciousness could travel multiverse when you dream, claim scientists

Scientists have suggested that dreams sometimes act as portals to alternate realities, connecting a person to another version of themselves in a parallel world.

“Dreams have been historically perceived as mirrors reflecting our conscious waking life, laden with symbolic representations of our desires, fears, and experiences,” they claimed in their research article.

“Conversely, a riveting conjecture exists that dreams might also function as conduits to alternative dimensions or elevated states of consciousness, suggesting a more profound and expansive role than traditionally conceived," they added.

This hypothesis takes inspiration from the "many worlds interpretation of quantum theory," which is sometimes also referred to as the multiverse theory.

It suggests that for a quantum event, there are multiple possibilities or outcomes. Each of these outcomes plays out in separate universes. So, for example, if you played a football match, your team may have won in this universe, but in some other universe, your team may have lost the game.

The authors suggest that in dreams, one can travel to these other universes. However, this isn't the the primary scientific basis they used to support their hypothesis.

Can dreams overcome physical limits?

According to David Leong, who is the first author of the article and an honorary professor at Charisma University in Turks and Caicos, when a person sleeps and dreams, it might be possible his consciousness crosses the boundaries of space and time.

This is because, during sleep, a person's consciousness is in the least contact with his logical brain, reality, and physical senses. Notably, scientists still don't know much about human consciousness, and its limitations.

It is possible consciousness also experiences something like quantum entanglement — a phenomenon that suggests that two particles can affect each other's states irrespective of the distance between them.

It might be possible that consciousness is also capable of affecting people across parallel universes. "This leads to a re-conceptualization of consciousness as a more expansive and interconnected entity with the potential to navigate a multiverse of experiences," the authors said.

Moreover, different versions of a person might have a shared collective unconscious, a concept proposed by psychologist Carl Jung in the early 1900s. Jung used this concept to refer to a part of the mind shared by all humans, containing instincts, memories, and ideas that are passed from one generation to another.

“Dreams could be the psyche’s means of tapping into this collective unconscious, exploring and experiencing the shared human narrative that extends beyond the personal,” the research article added.

However, these are all possibilities and there is no real empirical evidence confirming that a person can indeed travel to alternate realities in dreams.

Not all dreams take you to the multiverse

Leong suggests that recurring vivid dreams with strong emotions and memories are the ones that can probably take people to their alternate versions in parallel worlds.

“Say you have a repetitive dream of being stuck in high school. While it may reflect unresolved psychological themes, such as feelings of stagnation or anxiety about personal growth, it could also indicate that in another reality, you are still in high school, dealing with the same challenges your waking self has moved beyond,” remarked Leong, as reported by *Popular Mechanics*.

Meanwhile, other dreams that a person experiences might still be the result of their subconscious mind’s perception of the memories, experiences, fears, emotions, and desires they have.

For now, there’s no way to prove whether the proposed hypothesis is right. However, recurring dreams with vivid imagery and strong emotional resonance may warrant further examination, as they could potentially offer clues about experiences in alternate realities.

The research article is published in *Qeios*

Humanity May Reach Singularity Within Just 6 Years, Trend Shows

By one unique metric, we could approach technological singularity by the end of this decade, if not sooner.

- A translation company developed a metric, Time to Edit (TTE), to calculate the time it takes for professional human editors to fix AI-generated translations compared to human ones. This may help quantify the speed toward singularity.
- An AI that can translate speech as well as a human could change society.

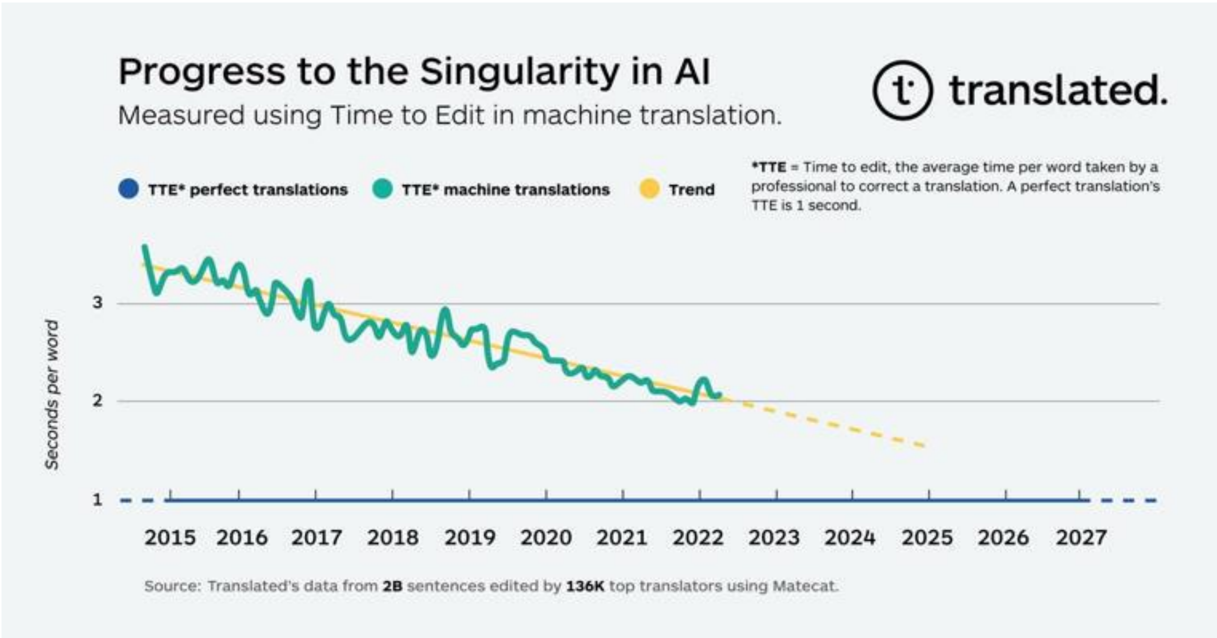
In the world of artificial intelligence, the idea of "singularity" looms large. This slippery concept describes the moment AI exceeds beyond human control and rapidly transforms society. The tricky thing about AI singularity (and why it borrows terminology from black hole physics) is that it's enormously difficult to predict where it begins and nearly impossible to know what's beyond this technological "event horizon."

However, some AI researchers are on the hunt for signs of reaching singularity measured by AI progress approaching the skills and ability comparable to a human.

One such metric, defined by Translated, a Rome-based translation company, is an AI's ability to translate speech at the accuracy of a human. Language is one of the most difficult AI challenges, but a computer that could close that gap could theoretically show signs of Artificial General Intelligence (AGI).

"That's because language is the most natural thing for humans," Translated CEO Marco Trombetti said at a conference in Orlando, Florida, in December 2022. "Nonetheless, the data Translated collected clearly shows that machines are not that far from closing the gap."

The company tracked its AI's performance from 2014 to 2022 using a metric called "Time to Edit," or TTE, which calculates the time it takes for professional human editors to fix AI-generated translations compared to human ones. Over that 8-year period and analyzing over 2 *billion* post-edits, Translated's AI showed a slow, but undeniable improvement as it slowly closed the gap toward human-level translation quality.



Data showing speed to singularity© Translated

On average, it takes a human translator roughly one second to edit each word of another human translator, according to Translated. In 2015, it took professional editors approximately 3.5 seconds per word to check a machine-translated (MT) suggestion—today, that number is just 2 seconds. If the trend continues, Translated's AI will be as good as human-produced translation by the end of the decade (or even sooner).

"The change is so small that every single day you don't perceive it, but when you see progress … across 10 years, that is impressive," Trombetti said on a podcast. "This is the first time ever that someone in the field of artificial intelligence did a prediction of the speed to singularity."

Although this is a novel approach to quantifying how close humanity is to approaching singularity, this definition of singularity runs into similar problems of identifying AGI more broadly. And while perfecting human speech is certainly a frontier in AI research, the impressive skill doesn't necessarily make a machine intelligent (not to mention how many researchers don't even agree on what "intelligence" is).

Whether these hyper-accurate translators are harbingers of our technological doom or not, that doesn't lessen Translated's AI accomplishment. An AI capable of translating speech as well as a human could very well change society, even if the true "technological singularity" remains ever elusive.