DISSERTATION FOR THE DEGREE OF DOCTOR OF PHILOSOPHY (PHD)

The Nature of Consciousness, A Category Theoretical Proof of the Fermionic Mind Hypothesis

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List of Abbreviations

AD	Alzheimer's disease
AI	Artificial intelligence
FMH	Fermionic mind hypothesis
HFS	High-frequency stimulation
PFC	Medial prefrontal cortex
STS	Superior temporal sulcus
GWT	Global Workspace Theory
IIT	Integrated Information Theory

Definitions

Mental energy (intrinsic motivation): Mental energy is a long-term ability based on mental fluidity that allows trust, belief, and confidence (Di Domenico and Ryan, 2017).

Mental energy is related to intrinsic motivation, which predicts performance, learning, and creativity, and it plays a vital role in personality development and wellness across the lifespan (Ryan and Deci, 2000, 2017). Significantly, mental energy is the brain's structural quality; therefore, mental energy changes are associated with a thermodynamic cost.

Degrees of freedom: Degrees of freedom are the maximum number of logically independent values in a system. For example, the number of independent coordinates defines the possibilities of motion. In cognition, mental freedom refers to a person's possible behavior choices.

1 Introduction

"Who would believe that so small a space could contain the images of the whole universe?" — LEONARDO DA VINCI

The nature of the mind has been an intriguing puzzle throughout history. Modern neuroscience supports the materialist view that consciousness is the product of brain circuits (Churchland, 1981). Nevertheless, spectacular advances left the question of consciousness unanswered (Kandel et al., 2021).

Historically, significant breakthroughs have often come from cross-pollinating fields in the sciences. Physics, dealing with matter-energy interactions, is particularly well-positioned to enrich other fields. For example, perception can be represented as a thermodynamic cycle. Perception and attentional focus, the source of synaptic changes (Manohar et al., 2018; Inzlicht et al., 2018), turn learning and memory formation energetically costly (Crossley et al., 2023).

A complex interplay between the central nervous system, particularly the hypothalamus and peripheral systems, regulates the brain's immense glucose supply (Joly-Amado et al., 2012), where essential functions like ionic gradients, synaptic transmission, and signal transduction consume a substantial part of the total energy budget (Raichle & Gusnard, 2002). Therefore, consciousness relies on robust energy turnover (Pepperell, 2018). Stressors can lead to cognitive fatigue (Ampel et al., 2018) and corrupt immune and mental function (Cunnane et al., 2020; Picard et al., 2018).

1.1 Empirical Studies

Psychological studies, beginning with Selye's work (1970), demonstrate the environment's influence on mental evolution. The brain's homeostatic regulation to counteract environmental disturbances (Smitha et al., 2017) is based on emotional identification with the body (Guterstam, 2015). Even without stimuli, mind-wandering and introspection integrate sensory information into an abstract world model (Grieder et al., 2018; Musall et al., 2019; Tring et al., 2023).

Self-consciousness is encoded and contained in the brain's resting state's personal perspective (Qin & Northoff, 2011; Wolff et al., 2019). The resting-state network's extensive geodesic distance from primary sensory and motor regions allows information integration (Park & Blanke, 2019; Prentner, 2019); tightly controlled entropy and oscillation frequency regulation ensures resting coherence (Zanin et al., 2019; Kolvoort et al., 2020).

While fluctuations between low-frequency and beta local field potentials reflect a balance between automatic updates and the stability of conscious contents (Dwarakanath et al., 2023), evoked activations are purposeful and closely connected to stimuli (Orłowski & Bola, 2023). Cortical activity during sensory processing (Glomb et al., 2020) uncovers the spatial, temporal, and neurophysiological changes associated with different mental states and motivations.

The close correlation found in early free will experiments between volition and the brain's background electrical fluctuations (Libet, 1985) indicates that a stimulus' meaning and energy value depend on internal activities (Dempsey et al., 2022). The correlation between volition and the brain's background electrical fluctuations relates attitude to the brain's energy regulation with poignant questions on managing the perception cycle and the resting state recovery. Therefore, the thermodynamics of the perception cycle might play a role in attitude formation.

Despite our pride in our consciousness and logical nature, we have difficulty controlling our thoughts and emotions, which have an immense role in influencing our thoughts, judgments, and decisions. Moreover, emotions are a constant, although not always a conscious presence (Kobylińska et al., 2023), and part of the personality structure (Déli, 2020a.b). Their relationship to practically every body-regulatory system indicates their central homeostatic regulatory role. For example, interconnected regulatory pathways between emotion and thermoregulation (Grigg et al., 2021; Seebacher, 2020) integrate them into our physiology.

Neuroscience has yet to define emotions and how they operate. Nevertheless, positive and negative emotions can be distinguished based on their energy profiles (Kao et al., 2015; Pleeging et al., 2019; Surov, 2022). Neuroscience also uncovered that warped brain activation topologies (Knapen, 2021) slow our perception of time (Lehockey et al., 2018) in positive and negative emotions. In addition, emotions energy value or arousal is proportional to the dilation of time perception and motivation (Gladhill et al., 2022; Hosseini Houripasand et al., 2023).

Thus, the thermodynamics of perception might uncover emotions’ role in the brain’s homeostatic regulation, motivation, and volition and the nature of conscious experience.

1.2 Consciousness Models

Twenty-five years ago, the intellectual duel between neuroscientist Christof Koch and philosopher David Chalmers challenged the limits of human understanding regarding the nature of consciousness. The climax of this debate was a wager: Koch bet Chalmers a case of wine that, within 25 years, by 2023, researchers would identify a "clear" neural pattern underlying consciousness. This wager sparked a surge of interest in this perplexing topic.

The nature of consciousness, a puzzle that has perplexed philosophers for millennia, became a scientific challenge. Advancements in neuroimaging technologies, such as functional magnetic resonance imaging (fMRI), transcranial magnetic stimulation (TMS), and implanted brain electrodes, have since generated vast amounts of data. Although these data sets are processed and analyzed by sophisticated algorithms enhanced by artificial intelligence, a definitive neural correlate of consciousness remains undiscovered.

The absence of a breakthrough in identifying a neural correlate of consciousness may suggest our current approach is misguided. The limitations of traditional methodologies, heavily reliant on empirical data and computational analysis, are becoming apparent. These models are based on the biological brain’s information processing and cannot be generalized to large language models. To embrace interdisciplinary perspectives and transcend conventional scientific paradigms might require a paradigm shift.

The Koch-Chalmers wager, with its promise of a case of wine, has spurred research and sparked debates and discussions, shaping the direction of consciousness studies. Different disciplines, including philosophy, neuroscience, and psychology, have offered consciousness theories, indicating the unyielding human desire to unravel the mysteries of the mind. Two main theories, Global Workspace Theory (GWT) and Integrated Information Theory (IIT), have recently dominated the discussion.

GWT posits that local processes are unconscious (Baars, 1988; Dehaene and Changeux, 2011). When a local neuronal assembly reaches the activity threshold for broadcasting, a phenomenon known as 'ignition' occurs. This 'ignition' refers to the global broadcasting of information that reaches the brain's global workspace. It is a central concept in GWT, often linked to recurrent processing, for instance, in the frontoparietal cortex (van Vugt et al., 2018).

IIT interprets consciousness as the capacity to integrate information (Block, 2005; Nagel, 1974). The 'phi' (Φ), a quantifiable measure of integrated information, measures the level of consciousness. However, 'phi' is an abstract concept and difficult to measure, posing a significant limitation to the theory. A recent comparison study has shown both theories failure to explain consciousness (Ferrante et al., 2023; Melloni et al., 2023).

FMH incorporates current neuroscience, psychology, and physics understanding to build a comprehensive physical system theory governed by physical laws. It treats the brain as a thermodynamic system capable of intellectual growth by transforming information input by the sensory system. Moreover, the reversibility of the cognitive or perception cycle introduces a probabilistic or quantum behavior, allowing the mathematical framework of quantum mechanics to explain behavior and decision-making. Sensory stimuli drive bottom-up activation, while the resting state imposes a top-down self-referential stability. This regulatory duality causes our difficulty in controlling or retracing our thoughts and emotions. Possible research introduced in a later section can validate FMH.

Current consciousness models do not consider the results of psychology and behavioral science. These gaps are significant, but FMH remedies them by considering the results of psychology and social sciences and incorporating them into its framework. This method offers novel explanations with the hypothesis framework.

In addition, these theories cannot incorporate the emergence of artificial consciousness into their hypotheses. They also have trouble defining animal consciousness. FMH addresses both shortcomings. FMH's physical framework shows a path toward the possibility of artificial consciousness. It limits animal consciousness to emotion producers, mammals, and birds.

1.3 Mathematical Framework: A Category-Theoretical Perspective of Consciousness

Consciousness science serves as a bridge connecting neuroscience and psychology. Nevertheless, psychology and social sciences increasingly turn to physics, rather than neuroscience, to explain problems in cognition and human behavior. Thus, various physics frameworks provide superior cognitive science insights (Déli, 2020a,b; Goldenberg et al., 2018). For example, quantum cognition turned to quantum theory to explain the context dependence of memory, perception, and decision-making (Basieva et al., 2019; Chang et al., 2019; Dennett, 2018; Wendt, 2015). The fermionic mind hypothesis (FMH) follows this path but goes a step further. It recognizes the mind becomes an abstract structural and organizational mirror of the physical environment (Jeffery & Rovelli, 2020; Gruber et al., 2022; Tsao et al., 2018) by adopting a particle-like, fermionic organization (Deli, 2020a,b).

Mental adaptability and abstraction from experience suggest that the mind weaves input from the external environment onto stable internal mental representations and beliefs. FMH offers a coherent theory explaining the energy nature of emotions (Deli, 2020a,b). The mathematical formulation of a category can provide theoretical clarity to this idea by opening the door to rigorous cross-domain comparisons of consciousness.

A category is defined as a collection of objects with morphisms between them. Stripping objects to their defining qualities and abstract structures reveals their fundamental properties, which aids a deeper understanding. Therefore, category theory can uncover connections between seemingly unrelated fields, such as neuroscience, psychology, general relativity, quantum theory, and beyond (Anderson, 2021; Ehresmann & Gómez-Ramírez, 2015; Phillips, 2022).

Central to category theory is the Yoneda lemma, which allows for equivalence between two objects, A and B, up to isomorphism, based on their relationships with other objects within a category (Tsuchiya & Saigo, 2021a). We can gain revealing insights by comparing their relationships with other objects, even in the case of complex and elusive subjects. This concept can be particularly beneficial for multifaceted concepts, like consciousness, which has defied a universally accepted definition.

The bird's eye view provided by category theory can assess the shared characteristics of consciousness and elementary particles to uncover their fundamental relationships. The Yoneda lemma can test the validity of the FMH and offer a solid mathematical foundation for the relational understanding of the fermionic mind hypothesis.

2 Aims

This dissertation furthers the understanding of the nature of consciousness based on FMH by using the tools of physics and mathematics. In mathematics, category theory can verify consciousness' relationship to physical principles and laws, providing a framework for proof of the FMH.

I focused on the following points in my study of the nature of consciousness:

- Perception: What are the energy-information consequences of perception?
- The resting state: What is the role of the resting state in energy regulation and behavior?
- Emotions: How can emotions produce motivation, and what is their role in cognition?
- Category theory: What can the Yoneda lemma's global perspective teach us about consciousness?

3 Materials and Methods

This dissertation examines consciousness based on its physical characteristics. Cognition is founded on interacting with the external environment via the sensory system, representing an energy-information exchange. The above relationship permits the thermodynamic consideration of the cognitive cycle, where sensory information fuels intellect generation. I used the Kullback-Leibler divergence (DKL) to uncover how much learning takes place. DKL is a type of statistical distance: a measure of how one probability distribution p is different from a second, reference probability distribution q. Learning is a cognitive updating caused by a stimulus, a statistical distance represented as a surprise between the current and expected output. It is deemed that, like the gravity field governs particle movement, temporal orientation defines our cognitive freedom. Temporal orientation rests with the resting state.

I examined the role of the resting state in energy regulation and behavior. In perception, the resting state's autonomic maintenance is fundamental and ensures a closed thermodynamic cycle. As a result, consciousness is a temporal, complexity-generating system. Memory forming ensures a wide variety of reference frames. Moreover, the stability of the resting state requires the presence of emotions. I examined emotion regulation from an energetic perspective, how emotional experiences change the perception of time, and how it relates to their action-producing power (Remmers & Zander, 2018; Rudd et al., 2012).

In the context of theoretical neuroscience, I modeled consciousness using category theory by considering consciousness as a physical system. In this context, consciousness forms morphisms analogous to fermions. Category theory, which studies structures and their relationships, offers a panoramic perspective that can demystify connections between diverse disciplines, uncovering similarities or equivalence between them. Category theory, like cognitive science, is concerned with modeling the (compositional) structure of some “domain” of interest. Category theory can differentiate between different reference frames.

3.1 The Yoneda Lemma’s Global Perspective

At the core of category theory lays the Yoneda lemma. In category theory, the Yoneda lemma can prove the equivalence of two objects A and B in a category by proving the analogy of their relationships to other objects (Tsuchiya & Saigo, 2021a). Applying category theory and the Yoneda lemma to the fermionic mind hypothesis establishes a mathematical foundation elucidating the relational interplay between consciousness and material systems. This innovative framework can verify the hypothesis by aligning harmoniously with existing empirical evidence.

This dissertation employs the Yoneda lemma, a foundational result in category theory. The Yoneda lemma is a key theorem in category theory that relates objects in a category to sets of morphisms from these objects to other objects in the category. It allows for a deeper understanding of consciousness based on analogies to physical processes through morphisms, providing a new perspective on the cognitive process.

The Yoneda lemma can prove the equivalence of two objects A and B in a category by proving the analogy of their relationships to other objects. It states that for any category C and any objects A and B in C, the set of natural transformations from the hom-functor Hom(_,A) to Hom(B,−) is isomorphic to the set of morphisms Hom(B,A).

The essence of the Yoneda lemma is that their relationships fully define objects. For example, the social contacts people have are unique to them. The application of this understanding solved the inverted spectrum problem in visual science. The inverted spectrum hypothesis holds that there might be someone whose linguistic behavior is just like ours but whose color experiences are systematically inverted: what he experiences when he looks at red objects is what we experience when we look at green objects and vice versa (Cohen, 2001).

The Yoneda lemma solves the inverted spectrum problem. The inverted spectrum hypothesis holds that there might be someone whose behavior is normal but whose color experiences are systematically inverted: his experience of red is the same as the color experience of green for everyone else and vice-versa. The Yoneda lemma shows that identifying colors by their unique distance from each other on the color spectrum map solves the inverted spectrum problem (Tsuchiya & Saigo, 2021b). Therefore, two colors are identical if and only if their connections to different colors are identical, which is only possible if they are the same colors.

3.2 Model Formulation

Category of Neural Networks: We define a category C where: Objects are conscious minds. Morphisms define relationships based on physical principles.

Hom-Functor: For a set of functors, the hom-functor Hom(_,A) maps a set of fermionic characteristics to consciousness through morphisms.

Application of Yoneda lemma: By the Yoneda lemma, the functor map of consciousness is isomorphic to Hom(_,A) fermions. Thus, how physical laws determine consciousness characteristics can be fully understood by studying the physical morphisms of fermions.

Representation of Time Dynamics: Time dynamics can be represented by functors and morphisms between time points. I used diagrams to represent objects, morphisms, and natural transformations in the categories F and C. I generated time-series plots and commutative diagrams to visualize the dynamics of consciousness analogies.

The dissertation shows that consciousness and fermions have identical connection maps to fundamental physical theories, such as quantum mechanics, and show similar organizations. In conclusion, the Yoneda lemma can provide a deeper insight into consciousness' representational and dynamic properties. This categorical approach opens new avenues for exploring consciousness’ function, providing a robust mathematical framework for the theoretical consideration of consciousness.

3.3 Possible testing of the hypothesis

Modern computers are based on a stored-program concept introduced by John Von Neumann. In this stored-program concept, programs and data are stored in a separate storage unit called memories, making the computer built with this architecture easier to reprogram. According to FMH, the resting state’s temporal manifold and the perception cycle form consciousness. The same architecture might be a requirement for artificial consciousness.

Based on Landauer's principle, we can study the neural system’s energy relationships in dish brain organoids. Landauer’s principle (1961), a basic principle of the thermodynamics of information processing, holds that any logically irreversible manipulation of information, such as the erasure of a bit or the merging of two computation paths, must be accompanied by a corresponding entropy increase in non-information-bearing degrees of freedom of the information-processing apparatus or its environment. Similarly, computer simulations can investigate emotions and energetic correlations, making testable predictions about perceptual, cognitive, and control tasks.

Testing the grip strength, puzzle-solving ability, and generosity before and after mental challenges or games can indicate mental energy changes. The expectation is that winners would show an increase in grip strength due to an endothermic shift in mental energy. In contrast, losers would show grip strength, creativity, generosity, and problem-solving ability loss.

4 Results

Based on the perception cycle, resting state, and emotional regulation data, I formulated a novel hypothesis, the FMH. Using the Yoneda lemma from category theory, I proved that consciousness is homomorphic to fermions.

4.1 Perception: The Brain's Energy Relationships

The energy cost of synaptic changes integrates the brain into the environment's broader energy and information cycle. I used this novel assumption to analyze the thermodynamic cost of perception, attentional focus, learning, and motivation (Appendix). I gained detailed insights into the brain's dynamic integration with the environment.

4.2 The Resting State in Energy Regulation and Behavior

In analyzing the brain's entropic relationships, I concluded that the brain's autonomous resting balance is analogous to an equilibrium position. Therefore, based on Shannon's information entropy, the perception cycle’s direction relates to temporal directionality. Endothermic cycles produce future orientation, whereas past orientation confines exothermic cycles (Figure 1); see Table I. I interpreted the cycle’s direction as intrinsic angular momentum, with the endothermic cycle representing up spin and an exothermic cycle forming down spin.

Table I. The physiological consequences of different brain states The thermodynamic and psychological implications of basic emotions.

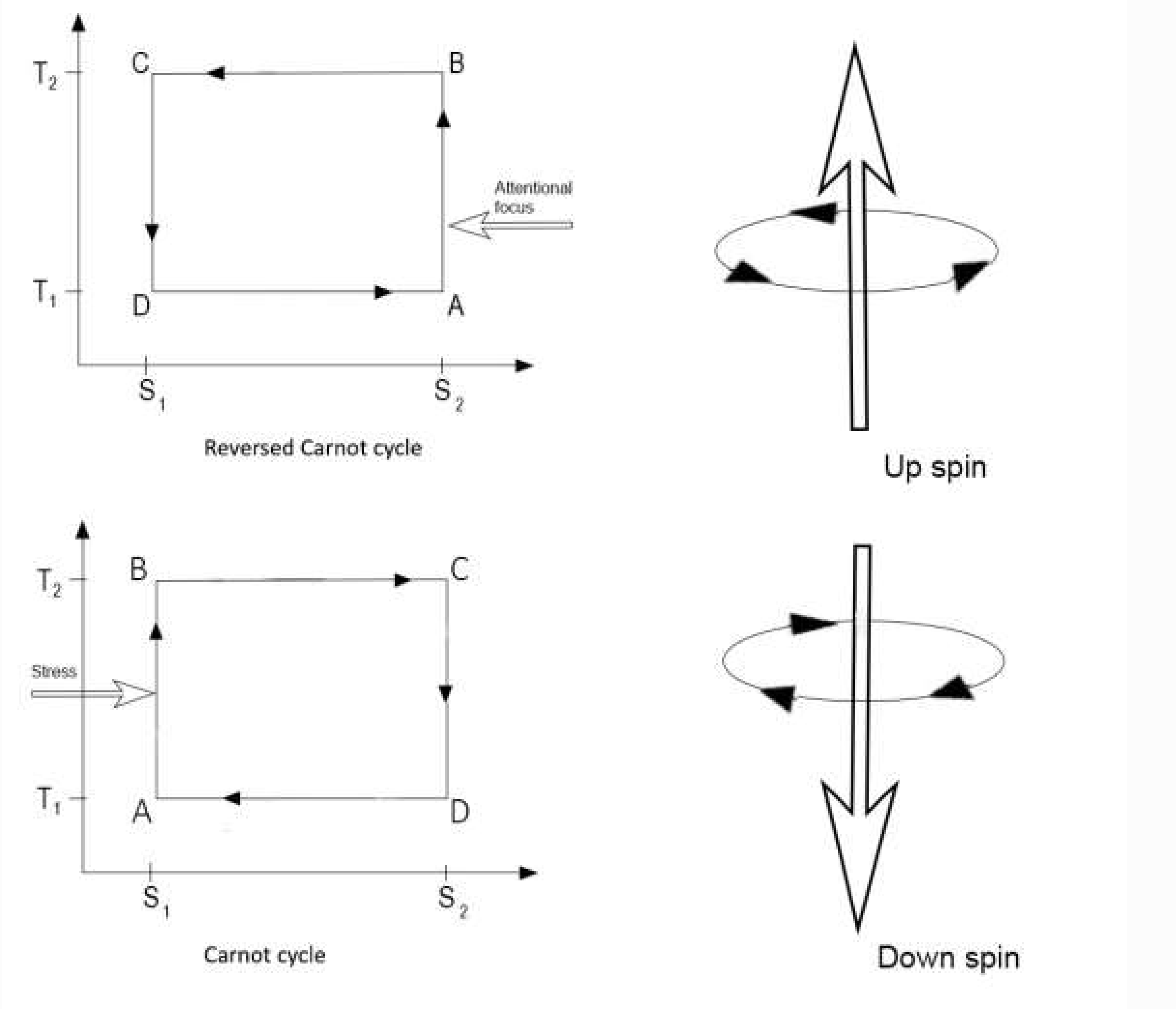
	Reversed Carnot cycle **High entropy resting state**	**Carnot cycle** **Low entropy resting state**
Mental state	Positive emotions	Negative emotions
Activations	Information poor	Information rich
Subjective sense of time expands	The wealth of time inspires confidence	Time pressure causes impatience
Degrees of freedom	Expanding	Loss
Thermodynamic consequences	Endothermic cycle: absorbs energy and entropy	Exothermic cycle: dumps energy and entropy
Consequences for the organism	Intellect	Mental and immune problems

4.3 Emotions Regulate the Cognitive Cycle by forming Motivation

Emotions serve the brain's thermodynamic regulation and homeostatic balance by producing attitude, a context-dependent and involuntary action-producing force. In this context, emotional valence is an instant feeling, with positive states representing preference and negative ones, aversion. Likewise, mathematical study of the reversed Carnot cycle (preference) indicates energy accumulation and future focus (Appendix). Inversely, exothermic, low entropy states (aversion) reduce synaptic complexity and limit cognitive freedom. The process dissipates energy via criticism, destructive behavior, or violence (Table II).

Table II. The characterization of material fermions and the temporal mind

	Matter fermion	**Temporal fermion (consciousness)**
Unity	The smallest unit of matter	The smallest unit of intellect
Thermodynamic outcome	Exothermic cycle → arrow of time	Endothermic cycle → future orientation
Corresponding field	Gravity	Social, temporal manifold
Lorentz transformation	Time dilation	Dilation of time perception
Pauli exclusion principle	Material structure	Social hierarchy
Constancy	Stable particle	A constant sense of self
Quantum characteristics	Wave-particle duality	Wave-particle duality



Reversed Carnot cycle

Up spin

Carnot cycle

Down spin

Figure 1. The thermodynamic origin of spin Perception as a thermodynamic cycle (left). The endothermic reversed Carnot cycle absorbs energy from the environment to enhance mental energy, forming an up spin (top right). The exothermic Carnot cycle degrades mental energy by radiating heat toward the environment, developing a down spin (bottom right). (Reproduced with permission from Déli and Kisvarday, 2020).

4.3.1 Temporal Orientation: The Orthogonality of Sensory Reality and Cognition

The nature of consciousness, whether a continuous stream of experiences, emotions, or thoughts occurring at specific moments, has been a longstanding and intriguing question among philosophers, psychologists, and neuroscientists. However, there is a significant duration of unconscious processing before conscious perception and awareness emerge. Moreover, despite our continuous flow of experiences, we remember episodes as discrete sequences of events and see the future as steps on the temporal measuring stick of our imagination, which is consistent with discrete processing. Thus, consciousness shows continuous and discrete qualities and a framework that reflects both and, in this way, might represent how we perceive the world around us.

For example, directly manipulating attention postdictively, i.e., at short time delays (Shen et al., 2020), influences choice. Therefore, cognition is not instantaneous, moment-by-moment consciousness constructions but incorporates information after perception by the so-called postdictive effect. In the above example, substantial periods of continuous unconscious processing precede discrete conscious percepts (Herzog et al., 2020).

Next, the cognitive process was studied as a source of duality. Conscious experience is intrinsically tied to the "now," representing an unbroken stream of awareness, seamlessly transitioning from one moment to the next. Nevertheless, each present moment uniquely represents discrete conscious experiences of successive "nows" that become memories. This twofold nature of consciousness signifies a constant shift in focus, where observation changes its underlying parameters, making it impossible to grasp—analogous to the observer effect. In quantum mechanics, the observer effect is the change of an observed system by observation. It also suggests that measurement causes the discrete collapse of the wave function, the so-called wave-particle duality.

Although category theory is based on highly abstract definitions and theorems, it organizes around the commuting square in various contexts. Its main idea views cognition as a computational processing system that produces cognitive representations via various paths. These different paths represent a shift in focus.

The lens of a "monoid" can effectively examine the concept of conscious duality. A monoid can encompass multiple morphisms, each representing the ongoing flow of consciousness. In a monoidal category where only the identity morphism exists, the arrow returns to itself, symbolizing the continuous unfolding or extension of conscious experience (Figure 2).

$$id_a \circ f = f = f \circ id_a$$

The concept of consciousness as a monoid closely aligns with the brain's ability to coalesce disparate and disorderly information into a unified perception (Tring et al., 2023). Unity aligns along a temporal arc (Smallwood et al., 2021) that endows intellect with a remarkable predictive ability (Northoff et al., 2019). "Therefore, time touches the eternal now at each moment,…disappears moment by moment and is born moment by moment… as a continuity of discontinuity (Nishida, 1948, p. 342, after Taguchi & Saigo, 2023)." Similarly, with time, consciousness stays constant yet continuously updates, shaping our social insights, thoughts, and actions (Smitha et al., 2017; Wolff et al., 2019).

Morphisms of consciousness can be viewed from the perspective of the monoid, where the morphism is always from the same object to the same object. "One morphism and another, one morphism and itself, can all be composed because the morphism of a monoid has only one object, which means that all morphisms ('passages') are connected at the same object ('now') because their starting points (domains) and endpoints (codomains) are the same objects (Taguchi & Saigo, 2023)." The flow of consciousness perpetually remains in the same place because it originates from the same object as their domain and returns to it as their codomain. In essence, the dynamic, streaming aspect of the present corresponds to the diverse morphisms within a monoid. In contrast, the static, standing aspect aligns with the unique object of the monoid. This monoid framework effectively captures consciousness' intricate structure, encompassing its ever-changing and constant facets (Figure 3).

Now, I return to the orthogonality question. The brain's spatial data compression formulates an orthogonal sensory temporal hologram (Saaty and Vargas, 2017), representing an orthogonal projection onto the two-dimensional cortical surface (Déli, 2020a,b). In neuroscience, the hippocampus' place cells transform spatial relationships into a temporal projection (Shimazaki, 2020), with the intermediate hippocampal CA1 serving the spatial aspects and the dorsal hippocampal CA1 serving the temporal aspects of episodic memories (Barker et al., 2016), and coordinate collective behavior.

The arrow of time, a fundamental concept in physics, demonstrates a profound connection to the rate of entropy generation (Lucia & Grisolia, 2020). In essence, the arrow of time concept states that spontaneous processes move a system toward equilibrium. Surprisingly, the brain's ability to consistently form endothermic processes entails entropy generation by enhancing the degrees of freedom (Shi et al., 2019; Yang et al., 2019). The brain’s dominant regulation is a predictive organization occurring in the time dimension. Consciousness' predictive nature contrasts general relativity, where gravity is a spatial field. Therefore, intellect is an orthogonal orientation vis-à-vis material structure, where entropy generation represents complexity and order.

Regarding the arrow of time, the two examined systems are antithetic. In contrast to physical systems, the brain’s high entropy resting state represents a potential where the possible configurations are synonymous with cognitive complexity and intellect. In category theory, orthogonality defines relationships between objects and morphisms within categories. For example, in the category of sets, two sets are considered orthogonal if they have an empty intersection. In a class of morphisms X in a category C, the orthogonal complement of X within C is a class of morphisms Y in C. These morphisms Y in C are such that for each morphism f: X→Y in C×C, there is a unique morphism g: A→B in C such that f is orthogonal to g. Therefore, for a composable pair of morphisms (f,m), there is an operation ∘ called "composition" that makes the morphism m∘f called the "composite of m and f." Likewise, for the composable pair of morphisms (e,g), the operation ∘ called "composition" makes the morphism g∘e called the "composite of g and e." The domain of m∘f and g∘e coincide with the domain of d, and the codomain of m∘f and e∘g coincide with the codomain of d.

$$\begin{tikzcd}
A \arrow[r, "e"] \arrow[d, "f"'] \arrow[dr, "d"] & B \arrow[d, "g"] \\
C \arrow[r, "m"'] & D
\end{tikzcd}$$

Two morphisms e: A→B and m: C→D are orthogonal if for any f: A→C and g: B→D, there exists a unique morphism d: A→D such that m∘f=g∘e.

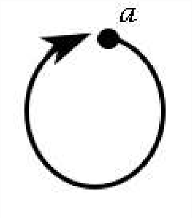


Figure 2. Consciousness (*a*) as a monoid The arrow represents the identity morphism.

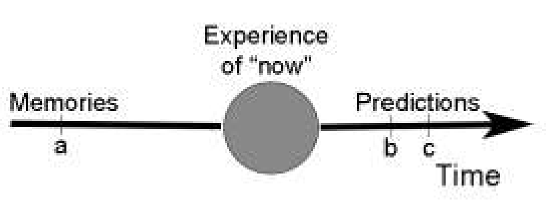


Figure 3. Consciousness as a continuous and discrete temporal flow Memory and expectation materialize at discrete temporal locations marked: time points a,b,c.

4.4 The Homomorphism of Consciousness and Fermions: The Yoneda Lemma, a Category-Theoretical Perspective

There is a structural correspondence between probabilistic and discrete outcomes in the domains of consciousness and fermions. Composition produced new relationships: $y_0 \circ x_0 = n$ and $y \circ x = n$, demonstrating that consciousness and fermions are isomorphic (Figure 4) regarding wave-particle duality.

$$\begin{tikzcd}
 & Q \arrow[dl, "x_0"'] \arrow[dr, "x"] \arrow[dd, Rightarrow, "n"'] & \\
F \arrow[dr, "y_0"'] & & C \arrow[dl, "y"] \\
 & P &
\end{tikzcd}$$

Figure 4. The isomorphism of consciousness and fermions regarding wave-particle duality Quantum mechanics Q and particle-like P behavior, fermions F consciousness C, paths $y_0 \circ x_0 = n$ and $y \circ x = n$

From the above, I established a source category A with wave-particle duality (Figure 5) and a target category B, comprising consciousness C and fermions F. The category B can be mapped to A via Functors. Functors F and C connect the source category A to target category B. This process leads to a commutative diagram in which all directed paths with the same start and endpoints lead to the same result, verifying the isomorphism of categories.

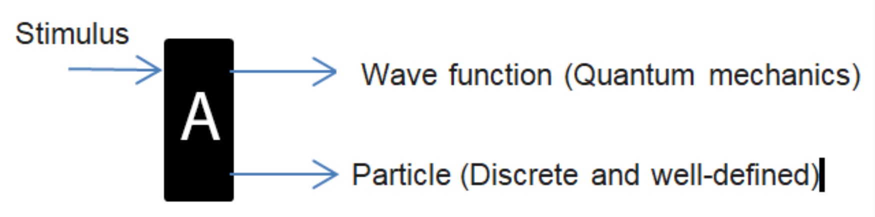


Figure 5. The wave-particle duality of Source Category A

Specifically, functor F connects object Q in the source category A to object F(q) in B, and functor C maps object Q to C(q) in B (Figure 6). Similarly, functor F connects object P to F(p), while Functor C connects P to C(p). Natural transformation α connects the Functor F and C. The morphisms between F and C form a commutative diagram. Natural transformations α between F and C will pick, for every q, a morphism αq between F(q) and C(q), and for every p, a morphism αp between F(p) and C(p). In other words, a natural transformation is a family of morphisms parameterized by objects in B.

$$\begin{tikzcd}
 & F & C \arrow[l, "\alpha"'] \\
Q \arrow[d, Rightarrow, "f"'] & F(q) \arrow[r, "\alpha_q"] \arrow[d, "F(f)"'] & C(q) \arrow[d, "C(f)"] \\
P & F(p) \arrow[r, "\alpha_p"'] & C(p)
\end{tikzcd}$$

Figure 6. A structure-preserving mapping between two functors The morphism f from a quantum system (Q) to discrete particle-like behavior (P) in source category A (left). Fermions (F) and consciousness (C) are part of target category B (right). Measurement turns the quantum behavior to particle-like, from F(q) to F(p) and C(q) to C(p). Natural transformation αq emerges from F(q) to C(q) and αp from F(p) to C(p).

Another set of morphisms f, connect Q to P in A, and the functors F(f) and C(f) connect F(q) and F(p), and C(q) and C(p), respectively. These four morphisms in B form a diagram. The commutation of that diagram is the naturality condition that a natural transformation must fulfill:

$\alpha p \circ F(f) = C(f) \circ \alpha q$

The commuting square of arrows forming a structure-preserving mapping between two functors (Figure 6) abstracts the details of the relationships (morphisms) between the sets and their structures. A natural transformation maps objects to morphisms and morphisms to (commutative) diagrams. These properties state that our examined objects (consciousness and fermions) manifest the universal property of wave-particle duality. Therefore, consciousness is categorically isomorphic to particles in category B.

Finally, I established homomorphism (hom). Homomorphism is a structure-preserving mapping, where hom H(C,F) is the hom set. This mapping exposes an object's internal structure by its relationships, analogous to scattering studies delineating the atomic structure. In this case, each element in fermion set F maps to a unique component of consciousness set C, and vice versa, and the function covers the entire range of each set. Therefore, consciousness (C) and fermions (F) are equivalent in the categorical sense (Figure 7). A functor f from C to F is a mapping that associates each object in C to an object in F. Although we looked at three fundamental fermionic characteristics, the conclusions also apply to others (unity, permanence, and half-spin). Considering their orthogonality, consciousness (C) is homomorphic to fermions (F) in the context of category theory. In other words, by adopting the fermionic organization, the brain gave rise to consciousness, an intelligent temporal system. However, the relationship is not invertible; fermions have no consciousness.

f: C → F
C: f(QC, Unity, Emotional forces, Particle-like)
F: f(QM, Unity, Fundamental forces, Particle)

$Hom_C(\_,\mathbf{A}) = Hom_F(\_,\mathbf{A})$.

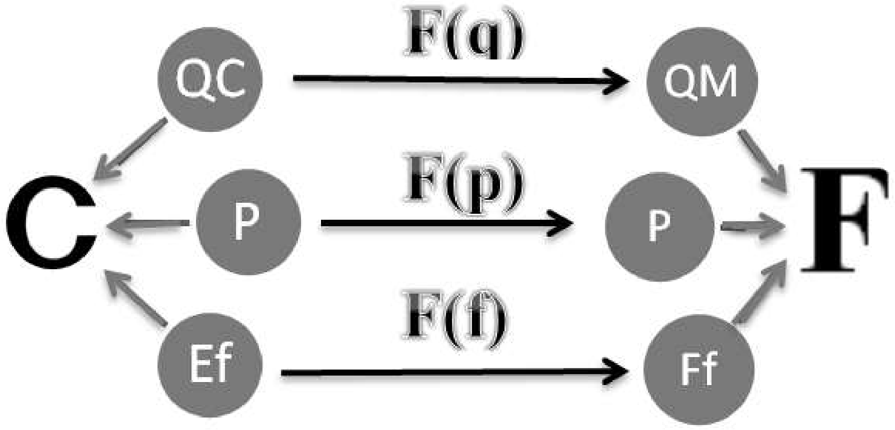


Figure 7. Applying the Yoneda lemma Consciousness (C), fermion (F), quantum consciousness (QC), quantum mechanics (QM), Particle (P), Emotions (Ef), and fundamental force (Ff). Functiors F(q), F(p), and F(f) preserve structural correspondence between objects in categories C and F.

5 Discussion

5.1 Unity

Our biological dependence on air, water, rest, and food requires a "temporal integration" (Tsao et al., 2018), where faster frequencies nest within the more powerful, slower ones (Ahmed et al., 2020). For example, in an eye-closed resting state, delta (1–4 Hz) is the “phase-modulating” band, and all other frequencies (4–40 Hz) are “amplitude-modulated” (Wolff et al., 2019). This energy integration is at the basis of transcendental, non-computable, subjective, and ungovernable thought processes (Kolvoort et al., 2020), coalescing into unity (Prentner, 2019; Deli, 2020a,b). Unity is necessary for the first-person experience of learning, speech, thinking, and muscle coordination.

The neural system's shared regulation organizes incoming sensory information into a coherent mental construct. Interhemispheric fibers between homologous brain regions form a continuous electromagnetic field, supporting large-scale cortical unified waves on the cortical surface (Alexander et al., 2019). Complementary projections of multisensory modalities integrate into a unified object/event representation (reviewed by Chen and Spence, 2017) and functional organization (Moutoussis, 2017). Even when presented with confusing or chaotic information, our brains formulate a unified first-person perception, supporting an abstract mental world model (Musall et al., 2019; Tring et al., 2023).

In quantum systems, each option has "amplitude," but the observational outcome materializes out of the wave function’s possibilities (Selesnick & Piccinini, 2018). Likewise, conscious perception is never fractured: ambiguity forces a non-deterministic, quantum-like fluctuation between two options, images, ideas, or concepts, such as the two depths representation of the Necker cube (Einhäuser et al., 2008). Binocular rivalry alternates between the perceptions of the two sensory fields, such as the two eyes (Tong et al., 2006) or the two nostrils (Zhou & Chen, 2009).

Although stroke generally lesions one hemisphere, the entropy reduction extends to the contralateral hemisphere (Bastos et al., 2015). However, separating the two hemispheres causes the famous split-brain experience, with different mental contents, intentions, and personalities (Pinto et al., 2017). Further dividing the brain destroys consciousness, underscoring its structural wholeness. Because particles represent the smallest unit of matter, the mind represents the smallest unit of intellect (Déli, 2020a; Parmentier et al., 2010).

5.2 Quantum and Relativistic Characteristics of Human Thought

The dynamic intrinsic activation patterns and fluctuations in the cortex profoundly influence arousal (Anderson et al., 2019), surpassing the impact of external stimuli (Dempsey et al., 2022). The wave-like characteristics of these fluid and vague thoughts, emotions, and concepts settle into discrete convictions and beliefs (Herzog et al., 2020), akin to the complementarity principle in quantum physics (Basieva et al., 2019). This way, the mind's abstract world model flexibly adapts to different situations and experiences.

Quantum cognition uses the mathematical principles of quantum theory to explain comprehension and decision-making (Deli, 2020a,b; Khrennikov, 2020; Tring et al., 2023; Wolff et al., 2021). The indistinguishable intrinsic properties of fermions, such as charge, mass, and spin, find emotional analogies, allowing us to identify with others and form comparisons.

Fermions' ability to form stable objects is due to their adherence to the Pauli exclusion principle, which prevents them from simultaneously occupying the same quantum state within an atom, causing their resistance to compression. This is analogous to the human tendency for competition, contradiction, and criticism, the source of territorial needs in the animal world and societal hierarchical structures (Saaty and Vargas, 2017; Wato et al., 2020). Therefore, the quantum qualities become the foundation for classical behavior.

5.3 The role of temporal orientation in perception

Understanding the relationship between space, time, and mental states is one of the biggest challenges in neuroscience, according to Gruber et al. (2022). The brain’s temporal organization originates from the biological dependence on air, water, rest, and food (Tsao et al., 2018). Learning, speech, thinking, and muscle coordination rely on ordered associations that differentiate past, present, and future (Ahmed et al.,2020); see Table II. The hippocampus’ place cells transform spatial relationships into a temporal projection (Shimazaki, 2020), with the intermediate hippocampal CA1 serving the spatial aspects and the dorsal hippocampal CA1 serving the temporal aspects (Barker et al., 2016).

Orthogonal, large-dimensional random vectors represent holographic projection (Makey et al., 2019). Similarly, spatial information compression (Tsao et al., 2018) generates an orthogonal, high-fidelity Cartesian mental manifold (Saaty and Vargas, 2017; Di Domenico et al., 2018), representing a hologram on the two-dimensional cortical surface

(Déli, 2020a; Déli & Kisvárday, 2020). The resting, non-computable, personal, and often ungovernable thought processes give rise to a subjective, transcendental, and privileged first-person experience (Kolvoort et al., 2020; Wolff et al., 2019).

Self-consciousness is inherently tied to temporal integration across different time scales, presumably including the individual's retrospective lifetime (Wolff et al., 2019; Kolvoort et al., 2020). Memory is a predictive organization (Dabaghian, 2019) that serves temporal continuity (Northoff et al., 2019; Wolff et al., 2019), the grounding of self-identity, and a coherent self-narrative (Smitha et al., 2017). The endothermic thermodynamic cycle supports energetic and ordered states such as creativity, novelty, and future orientation. At the same time, the "arrow of time" shows a deep connection to the entropy generation rate and the loss of work potential, as Chatterjee and Iannacchione (2020) and Lucia and Grisolia (2020) have discussed. The arrow of time is the temporally irreversible consequence of the second law of thermodynamics, occurring in non-equilibrium systems via irreversible net fluxes between underlying states (Seif et al., 2021).

Optimizing action repertoire between the past and the future inspires work potential, freedom of action, focus, and control, as Zanin et al. (2019), Déli and Kisvarday (2020), and Biderman et al. (2020) have suggested. The stationary action's temporal equivalent is a stationary temporal trajectory of predictive intelligent processing (Dabaghian, 2019; Debatin, 2019). The self-regulating, predictive mind optimizes behavior between the past and the future, following the principle of least action for physical systems.

Resting activation time symmetry increases in pathologic conditions such as depression, mania, psychosis, or schizophrenia, as Kolvoort et al. (2020) and Stringer et al. (2019) have reported. For example, in major depression, cognitive impairment correlates with resting-state symmetry, monotony (Wolff et al., 2018), and entropy reduction (Wang, 2020). Because there is no quick-fix treatment for the above conditions, the corruption of mental energy and lack of motivation are conducive to poor outcomes and low quality of life (Kopec et al., 2019; Sizemore et al., 2018).

Cognitive inference is generated by shifting electric current polarities between the neocortex and the limbic system (Deli et al., 2018; Rastmanesh et al., 2022; Tozzi et al., 2017; Peters et al, 2017), ensuring minimal energy conformation during state transitions (Pepperell, 2018). The brain's perception cycle evolves the mind into an abstract mirror of the environment through Bayesian updating, supporting the view that mental evolution parallels the environment.

The direction of the perception cycle can be reversed, resulting in exothermic energy loss, according to Roberts (2019). The contrasting psychologies can be represented by a soldier racing toward an enemy or running away in panic. However, there is a caution against the literal understanding of time reversal. The orthogonal position represents uncertain back-and-forth vacillations, canceling mental progress: the coward hesitates. In the following, I investigate how the perception of time formulates motivation.

5.3.1 The Cognitive Cycle as Psychological Spin

The Stern–Gerlach experiment's inhomogeneous magnetic field produces the specific quantized values (up and down spin) of the particles' angular momentum (Peleg et al., 2010), an essential elementary particle characteristic. Recent work has demonstrated that emotions are complex and culturally influenced by multi-dimensional brain activity profiles (Torres et al., 2020; Suhaimi et al., 2020), correlate to positive or negative emotional valence (Hesp et al., 2021), an instant feeling of preference or aversion (Pleeging et al., 2019; Surov, 2022). The reversible perception cycle naturally leads to a spin interpretation (Deli and Kisvarday, 2020; Deli et al., 2021, 2022). For instance, attitude, a context-dependent and involuntary action-producing motivator, shows similarities to spin (Babaev et al., 2018; Bechler et al., 2019), which can override rational thinking. Like the half-integer spin of the electron determining atomic structure, psychological spin determines societal hierarchy (Deli, 2023; Wato et al., 2020; Magee and Smith, 2013).

As shown earlier, the exothermic cycle forms low-entropy (representing down spin) and dissipates energy (Deli and Kisvarday, 2020; Deli et al., 2021) (Table 1) via vigilance (Manohar et al., 2018), criticism, destructive behavior, or violence. Inversely, long-term potentiation reduces resting synaptic complexity (Kaiser et al., 2016) and entropy (Déli et al., 2021; Lin et al., 2022), causing repetitious, monotone thinking (Wang, 2020). The pessimistic past focus (Gustavson et al., 2018; Zanin et al., 2019) can reinforce itself, forming anger or sadness (Chen et al., 2023). Exothermic work production discharges energy through aggravation (Saxe et al., 2018), violence, regret, remorse, rumination, and shame (Stanghellini et al., 2016; Vries, 2017). It leads to insecurity (Meeusen et al., 2020), which can negatively affect IQ (Gao et al., 2022; Goldsmith et al., 2020); refer to Figure 4.

Mistakes represent a failure to move forward, whereas achievement, healthy behavior, and planning (Li et al., 2018) require future focus (Deli et al., 2018; Deli, 2020b; Shannon, 1948). The reversed Carnot cycle requires high entropy resting state (Gao et al., 2022), which is linked to fluid intelligence (Yang et al., 2019; Keshmiri, 2020; Wang, 2021), openness (Zmigrod et al., 2019), and creativity (Shi et al., 2019), and purpose (Ryan & Deci, 2017; Van Cappellen et al., 2018). Future focus increases the degrees of freedom (Deli & Kisvarday, 2020; Deli et al., 2022) (Table I). Positive focus (Manohar et al., 2018; Déli et al., 2021) and reward processing require thalamic neurotensin production and release (Li et al., 2018).

5.3.2 Dilation of time perception

Sensory representation studies produce warped spatial topologies throughout the brain (Knapen, 2021). Moreover, intense emotions, such as awe or anxiety, increase the subjective perception of time. In positive states, detail-scarce activations encompass broader cortical areas (Machado & Cantilino, 2016), allowing associative representations and greater neural efficiency (Velasco et al., 2019). The slowing down is time abundance (Mitchell et al., 2015), allowing confidence (Makarevskaya, 2018), satisfaction (Carmona-Halty et al., 2019), generosity, and trust (Connelly et al., 2017).

The brain's complex processes involve nonlinear, competitive, dynamic interactions among various neural regions (Zmigrod et al., 2019). The entropy-absorbing, endothermic operation of the reversed Carnot cycle, which boosts future focus (Shannon, 1948; Kolvoort et al., 2020), is particularly energy-hungry (Lynn et al., 2021).

Emotions are powerful motivators that can alter our perception of time to facilitate action. However, not the emotions themselves but the transition to emotional states can make time feel like it is standing still (Wang & Lapate, 2023). Once we start taking action, time perception diminishes, allowing for better focus and permitting the flow experience, where time seems to pass faster than usual (Failing & Theeuwes, 2016). Studies on behavioral activation systems (BASs) have found overestimation bias scores for positive stimuli (Lehockey et al., 2018). Similarly, the anticipation phase leads to the perception that time passes more rapidly in positive and negative states (Gable & Poole, 2012; Gable et al., 2022).

Although motivation contracts time perception, positive and negative withdrawal motivation decelerate time perception, emphasizing that the motivational direction, not affective valence and arousal, drives temporal shifts (Gable & Poole, 2012; Gable et al., 2022). Likewise, novel stimuli or rewards inflate the perception of time durations, known as the 'oddball effect' (Failing & Theeuwes, 2016).

Therefore, emotionally arousing experiences result in proportional increases in time estimations (Lehockey et al., 2018). For example, awe expands time perception through its perceptual vastness and temporal abundance of the present moment (Rudd et al., 2012). Similarly, satisfaction enhances the visual experience's perceived duration (Failing & Theeuwes, 2016), particularly in natural environments (Davydenko & Peetz, 2017). Moreover, relaxing experiences inspire generosity and appreciation.

Underestimation of interoceptive time perception can diminish the processing of salient bodily stimuli. At the same time, overestimations can depend on an individual's ability to perceive bodily information accurately (Di Lernia et al., 2018).On the other hand, pain, stress, or monotony can make time feel even slower. The temporal distance is longer for neutral-to-negative image transitions forming temporal dilation with the onset of an adverse event (Wang & Lapate, 2023). The extent of the negative-picture-induced temporal dilation in memory correlated with dispositional negativity across individuals. Stress is a psychological pressure that induces stagnation by slackening time flow (Wise et al., 2017; Remmers & Zander, 2018). The sense of permanence (time perception) makes stress exponentially challenging, causing impatience (Hollis et al., 2015) and impulsivity (Gladhill et al., 2022; Hosseini Houripasand et al., 2023), and the fight or flight response.

In conclusion, the domination of internal activation during perception initiates a skewed perception of time. In turn, the process of dilating time perception requires an energy investment and leads to the energy nature of motivation. The slowing of time perception in both positive and negative conditions shows analogies to the laws of physics in general relativity, indicating that the brain adopted the laws of physics in its operation.

5.4 Discussion of Mental Energy

In the words of Conant and Ashby (1970), "Every good regulator of a system must be a model of that system." The mind can produce a meaningful response to a stimulus because sensory processing generates an intelligent environment model through nonlinear, competitive, and dynamic interactions between neural regions (Zmigrod et al., 2019).

The ability to manage emotions and mitigate fatigue (MacCann et al., 2019), defined by emotional intelligence or mental energy (Kong et al., 2019), is the brain's structural quality (Dabaghian, 2019; Debatin, 2019), analogous to potential energy in physics (Figures 6 and 7). Although it may be challenging to establish in other fields, mental energy is the primary predictor of runners' finish time (Nicolas et al., 2019; Rubaltelli et al., 2018) (Figures 6 and 7). Significant achievements result from a persistent and goal-directed effort, mental discipline, and the willingness to work hard for rewards (Inzlicht et al., 2018) (Figure 8).

Mental plasticity and goal orientation can nurture self-confidence (Ryan et al., 2016; Yang et al., 2018) and a can-do attitude, inspiring creativity, success, and longevity even in the face of challenges and conflict (Inzlicht et al., 2018; Ryan and Deci, 2017). Reward and goal expectations can push performance beyond the limitations of fatigue (Manohar et al., 2018). Lack of mental energy related to dopamine and norepinephrine transmission and binding can be a significant barrier to achievement (Meeusen et al., 2020).

In the constantly changing environment, temporal coherence and mental progress (Kolvoort et al., 2020; Sugimura et al., 2021) might be a fundamental psychological requirement for cognitive function, social relationship quality, and achievement (Du et al., 2019; Phan et al., 2019). The brain’s thermodynamic exploration indicates no shortcuts to mental progress.

Even when the results are barely noticeable, the endothermic process provides emotional stability, resilience, and persistence for coping with personal and professional challenges (Chang et al., 2016) (Figure 8). The energy needs of the endothermic cycle and the compounded nature of attitude and disposition (Pleeging et al., 2019) demand that education is supportive and inspiring (Crawford et al., 2020; Neal et al., 2018). Moreover, understanding the thermodynamic consequences of emotions could improve mental disease treatments and prevention (Pulido & Ryan, 2020).

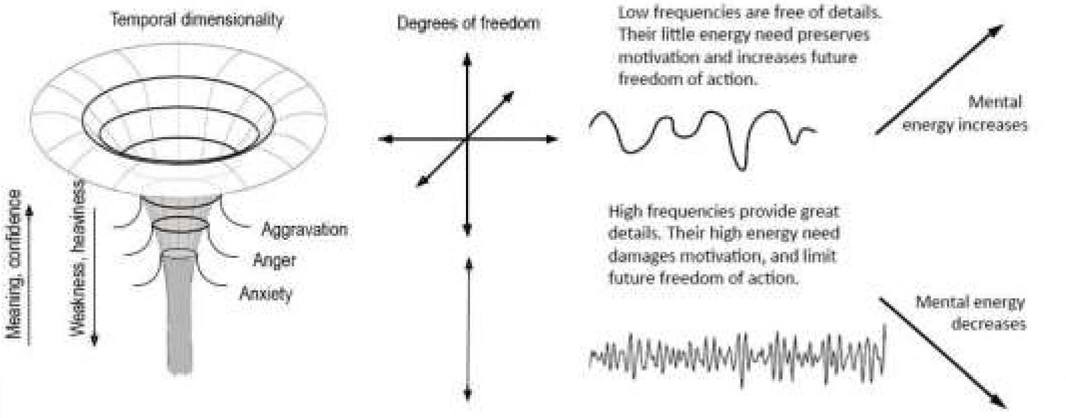


Figure 8. The effects of emotions on mental freedom Positive emotions and meaning expand freedom (top). On the other hand, the higher energy needs of aggravation, anger, and anxiety constitute stress, which wastes time and energy, causing mental rigidity (bottom). The resulting decisions decrease the future freedom of action. (Figure is courtesy of Deli, 2020a).

5.4.1 Corrupted Decision-making

Peter Kropotkin (1902), in the late 19th century, observed that animals displayed cooperation and generosity when resources were abundant but resorted to conflict when supplies were scarce. Stewart and Plotkin's (2012) and Connelly et al.'s (2017) studies supported his observation. Poverty can lead to cognitive stress, as evidenced by prefrontal gamma rhythms (Gao et al., 2022; Trevisiol et al., 2017), which can cause feelings of insecurity and hopelessness. Additionally, reduced psychological freedom can lead to deterministic outcomes, denying individuals free will (Goldsmith et al., 2020). There is a close link between mental and physical health (reviewed by Koban et al., 2021). Therefore, safe and dignified population structures promote generosity, cooperation, and intellect, as suggested by Tkadlec et al. in 2020. The thermodynamic understanding of perception shows that managing emotions is like operating a car engine. Mental effort and focus are essential to the brain's functionality; much like fuel economy is to a car engine (Schoeller et al., 2018; Saarimäki et al., 2017). Chronic stress impairs the reward/motivation system (Padamsey et al., 2022). When the will is compromised, maintaining constructive attention can be challenging (Keller et al., 2019; Meeusen et al., 2020).

Low self-esteem, anxiety, and depression are mental quick-sand that block courage and will (Wise et al., 2017; Meeusen et al., 2020). Conflicts elicit valence judgments and physiological arousal (Inzlicht et al., 2018), indicating emotions' functional integration within the brain's energy architecture.

Dopaminergic suppression inhibits the left insula and cognitive flexibility regions, such as putamen and cerebellum (Hua et al., 2020), causing the mesolimbic anhedonic stress response (Baik, 2020). The indirect pathway striatal neurons’ D2 dopamine receptors hyperpolarize the cell in response to dopamine. Introspective socio-affective network hyperconnectivity boosts self-focus (Berkman, 2018), reducing degrees of freedom (Sanacora et al., 2022); see Table 1. Interestingly, hyperconnectivity of the superior temporal sulcus (STS), a brain region crucial in social processing, is associated with lower interpersonal warmth and increased emotional reactivity (Fredericks et al., 2018). Increased reactivity increases the risk of late-onset AD, even at one point. Moreover, AD patients have higher global connectivity within the right anterior insula and STS.

Impaired emotional regulation (Sizemore et al., 2018) is associated with depressive symptoms (Wade-Bohleber et al., 2020). For example, anxiety patients showed increased connectivity in a resting-state network (Gehrt et al., 2022) while processing emotional stimuli.

The loss of freedom inflicts a cognitive burden and enhances psychiatric disorder risk and treatment resistance (Sydnor et al., 2021). Damage to emotional regulation (Mitchell et al., 2015) can corrupt social behavior and IQ (Goldsmith et al., 2020).

Dendritic atrophy in the medial PFC and hypothalamus (Sanacora et al., 2022) causes hippocampal sharp-wave ripple—cortical spindle coupling (Steadman et al., 2020). Low entropy insecurity (Lin et al., 2022) and cognitive vulnerability (Grieder et al., 2018) is proportional to depression severity (Wang, 2020; Wise et al., 2017). In depression, the time-symmetric low resting entropy parallels rigidity (Stringer et al., 2019) and past orientation (Zanin et al., 2019; Wolff et al., 2018).

5.5 The fermionic mind hypothesis

Twenty-five years ago, Christof Koch, the neuroscientist, and David Chalmers, the philosopher, argued whether consciousness, which philosophers have wrestled with for millennia, was scientifically tractable, resulted in the now famous bet. Koch bet Chalmers a case of wine that within 25 years—that is, by 2023—researchers would discover a “clear” neural pattern underlying consciousness.

Thanks in part to the publicity by Koch and Chalmers, more researchers than ever are trying to solve the puzzle of consciousness. The plethora of data from functional magnetic resonance imaging, transcranial magnetic stimulation, and electrodes implanted inside brains have been analyzed by artificial intelligence-augmented algorithms to no avail. However, the problem might be that we approach consciousness from the wrong perspective.

The emergence of artificial intelligence and the potential of artificial consciousness indicate that we should not seek consciousness in the biological brain but in its physical organization. My work treats the brain’s interaction with its environment as the source of intellect. Moreover, it combines experimental work, such as quantum consciousness, into a theoretical framework of physics. These physics tools embed the brain in its physical environment and provide a fermionic structure.

The environment’s information flow continuously bombards the sensory system (Deli et al., 2018; Fry, 2017). The environment's increasing entropy regulates the flow of this sensory information—the second law of thermodynamics. Nevertheless, a continuous flow of intuitions and feelings creates an exceptionally unified perception and generates a holographic consciousness.

Therefore, the evolution of intellect did not introduce new physical laws. Instead, the intelligent mind was created by ingeniously mapping existing physical principles onto neural structures (Gruber et al., 2022). This internalization of physics principles allows us to intuitively interact with and control our environment (Schoeller et al., 2018). The unique self-awareness of the mind—the awareness of being an observer—is rooted in the "particle-like" isolation of what can be referred to as the "resting state."

Within this framework, perception is a cyclical and reversible model. Perception's thermodynamic consequences—endothermic or exothermic cycles—represent energy direction analogous to the intrinsic angular momentum or particle spin. This recognition explains why the mathematical tools developed for quantum mechanics have effectively explored questions in psychology and social sciences. In this cycle, the interplay between stimulus and cognition gains temporal orientation due to the cycle's thermodynamic directionality. Thus, physical principles underlie the perception process. Consequently, consciousness is a self-regulating "temporal fermion" (Table II), ensuring survival (Deli, 2021a.b) through interactions motivated by emotions, such as hunger and fear (LeDoux and Brown, 2017). By dilating our perception of time (Déli, 2020a,b), these emotions can be the potent driving forces behind our motivation.

Emotions extraordinary action-producing power gives rise to the belief in free will. However, free will is limited to choosing the direction of the thermodynamic cycle. Therefore, emotions act as the fundamental forces of motivation (Déli, 2020a,b). However, in contrast to photons, which are responsible for space dilation, emotions dilate the perception of time.

In learning and decision-making, the cognitive shift occurs suddenly and discretely, often following practice periods, as governed by bifurcations in neural dynamics (Sridhar et al., 2021), representing opposing learning gradients between past and future behavioral paths. The quantum character of the perception cycle and the quantized nature of self-consciousness (Wolff et al., 2019) illuminate the mind's dual nature, analogous to the wave-particle duality.

Interestingly, this dualistic nature of the mind—oscillating between chaotic, probabilistic perception and a stable, field-like resting state—could offer insights into some of the most perplexing questions about human psychology. Our framework thus aligns with Lakatos' criteria by providing fresh perspectives via four key propositions: 1) The brain's self-regulation is anchored in a resting balance. 2) A quest for thermodynamic equilibrium drives emotional responses. 3) Dilation of time perception can trigger either urgency or relaxation, resulting in contrasting motivation. 4) Decisions crystallize discrete beliefs and sense of self.

The Hungarian-born science philosopher Imre Lakatos believed that the merit of a scientific theory lies in its ability to offer novel insights. This principle also guided me in my research. FMH generates new explanations and insights into the brain's workings: 1) The self-regulation forms a thermodynamic cycle centered on the resting balance. 2) The evoked cycle's search for thermodynamic balance motivates response through emotions. 3) Time perception generates motivation via the sense of urgency or relaxation. 4) Category theory can verify the main points of FMH. 5) Remarkably, the laws of nature can apply to consciousness.

5.6 Characterizing Consciousness Using the Yoneda lemma

Two objects are isomorphic if and only if their functors are isomorphic, i.e., they have the same structure. Akin to particle stability in physics, consciousness is a dynamic equilibrium that maintains cognitive constancy in the face of ever-changing circumstances. The fermionic model can capture the structure of the world by structural correspondence; that is, the relations between entities in perception states map to relations between entities in the representation domain (Figure 7).

Memories lend temporal orientation to consciousness, which represents orthogonal conditions vis-à-vis fermions. Despite their orthogonal orientation, they follow classical and quantum features, allowing the tools of quantum mechanics, electromagnetism, and relativity to describe their operations. Consciousness and fermions have identical connection maps and, therefore, isomorphic structures.

Consciousness models invoking the Yoneda lemma in the theory of categories and functors for their mathematical justification may initiate more research into psychological and behavioral problems.

5.7 Implications and Applications of the Hypothesis

Understanding the nature of consciousness carries profound implications across various fields, ranging from philosophy and neuroscience to artificial intelligence and ethics. In philosophy, questions about the relationship between the mind and the body could clarify the Mind-Body Problem, whether consciousness is purely a physical process or if it involves something non-material. FMH shows that consciousness is physical and governed by physical laws. This understanding can influence our identity and view of ourselves, providing deeper insight into human behavior. The FMH also sheds new light on the nature of free will and our ability for conscious control.

In neurology, FMH can offer new insights into brain diseases, and neural adaptation and reorganization after brain injuries. FMH can improve understanding of emotional health and provide treatment for mental conditions. The thermodynamic considerations of consciousness can enhance treatments for mental health disorders, such as depression, as a problem of energy regulation.

FMH can provide the tools to build artificial general intelligence and test its existence in current systems by providing a consciousness benchmark. It can also aid human-computer interaction by making technology more intuitive and aligned with human experiences.

FMH can inspire new ways to measure consciousness presence, informing debates about personal autonomy, consent, and individual rights. Consciousness insights can inform ethical decisions regarding brain death, vegetative states, and end-of-life care.

Current school curricula often antagonize students, who feel left out and unmotivated. FMH can inform education by providing individually tailored tools to motivate students to achieve their personal best. It can help design an education system that attracts students by focusing on their individual and emotional development. It guarantees personal satisfaction and happiness and promotes a more harmonious and faster-progressing society. Regarding the legal system, FMH can tailor punishments that aid the rehabilitation of criminals.

FMH has implications for meaning and purpose. It can influence existential questions about the meaning and purpose of life and the place of intellect in the universe. It can provide a bridge between science and spirituality. Finally, FMH can improve moral considerations on how we view and treat non-human animals.

Ultimately, FMH goes beyond scientific exploration. It carries profound philosophical implications by emphasizing the deep connection between consciousness and the physical universe. According to FMH, consciousness isn't a separate entity but intricately woven into the fabric of physical reality. The particle-like, homeostatic wholeness and unity are consciousness's unique, inalienable character:

1. The duality of consciousness leads to probabilistic decision-making but preserves the stability of the self.
2. The thermodynamics of cognition leads to difficulty controlling our thoughts and emotions. Therefore, thought suppression, conscious attempts to stop thinking about a particular idea, is counterproductive (Lappalainen et al., 2021; Wenzlaff & Bates, 2000). The thermodynamics of cognition reveals the role of acceptance in forming an endothermic state and promoting cognitive flexibility.

3. The neural system's adoption of the physical laws gives rise to a fermionic system, confirming the universality of physical laws.
4. The theory builds on psychological observations and provides ways to improve mental and psychological problems. It also explains which animals have consciousness (mammals and birds) and provides a possible path for generating artificial consciousness.

5.8 Comparison of Consciousness Models

In contrast to other leading consciousness theories, which approach consciousness through a phenomenological perspective, FMH uses a physics approach. It shows that physical laws, such as the energy input of stimulus and the principle of stationary action, can direct brain activations in forming a cognitive cycle and resting stability. This physicalism causes our inability to direct and control our thoughts and emotions, for example. Thus, FMH does not contradict but supersedes current consciousness theories, such as the GWT and IIT.

5.8 Limitations and Future Work

FMH explains the subjective experience and thought processes resulting from stimulus activation and recovery of the resting state. It can account for the dynamic, spontaneous, and continuously changing conscious experience. However, FMH remains agnostic about how different brain regions and neural circuits contribute to conscious experience. Moreover, thermodynamic calculations supported by measurements of the mental energy changes during the cognitive cycle are computationally intensive and not yet feasible with current technology. Although it can offer new treatment options for mental conditions, brain diseases, such as schizophrenia and PTSD, require further studies.

There are financial limitations, which can be overcome by collaboration with leading laboratories. I believe that once the FMH gathers more attention through conferences and publications, new avenues for testing its proposal will be possible, making its broader acceptance possible.

However, FMH cannot be accepted step by step; it requires a radical departure from current directions in consciousness science. The needed paradigm shift represents perhaps the greatest obstacle to its acceptance in neuroscience and psychology.

6 Conclusions

This work introduces a novel consciousness hypothesis, FMH, offering a radical connection between physics and consciousness. It suggests that the principles governing the smallest building blocks of matter, fermions, are mirrored in the workings of the mind.

FMH builds a bridge between neuroscience, psychology, sociology, and economics by proposing a physical foundation for them all. It posits that intelligent behavior stems from an abstraction of the environment encoded in our synaptic memories. These memories allow us to make predictions, and any discrepancies between those predictions and reality trigger emotions, which motivate us to act. This principle mirrors the fundamental interactions that govern the physical world.

The hypothesis goes further, suggesting a crucial role played by the recurring resting state. This state establishes a distinct, particle-like detachment from the environment while maintaining a consistent psychological identity throughout life.

By adopting the organizing principles of the physical environment, the brain develops a particle-like structure, such as unity and indivisibility, with fermionic traits, such as half spin. "Fermion" and "consciousness" represent the smallest known components of matter and intellect, respectively, shedding light on the physical underpinnings of intellect. Unlocking the physical basis of consciousness, as FMH proposes, could revolutionize our approach to artificial intelligence.

We used the Yoneda lemma to validate the homomorphism (structural similarity) between consciousness and fermions. The emergence of intellect through an endothermic process within memory-forming systems may represent a universal principle in the natural world, offering a pathway for artificial consciousness.

Ultimately, FMH goes beyond scientific exploration. It carries profound philosophical implications by emphasizing the deep connection between consciousness and the physical universe. According to FMH, consciousness isn't a separate entity but intricately woven into the fabric of physical reality.

7 **Summary**

One of the most puzzling questions in neuroscience is how the neural system gives rise to emotions and consciousness. In the present work, I used the physics lens of the fermionic mind hypothesis to investigate the above questions.

Life is a highly complex organization, yet part of the energy cycle of the environment. Perception represents a reversible thermodynamic cycle, which maintains the resting equilibrium. As emotions motivate the recovery of the resting state, the neural system can accumulate energy via the endothermic reversed Carnot cycle or lose energy via an exothermic process.

Although the reversible and probabilistic perception formulates a quantum system, decisions, and beliefs are discrete and unified, creating particle-like stability. The above quantum-classical divide is reminiscent of wave-particle duality. The Yoneda lemma provides an elegant mathematical proof of FMH, showing the homomorphism of consciousness and fermions. Our improving intuition about the brain's intelligent computations may allow new treatments for mental diseases and inspire novel applications in robotics and AI.

8 Összefoglaló

Az idegtudomány egyik legnagyobb rejtélye az érzelmek és a tudat eredete. A disszertációm ezeket a kérdéseket célozza a fermionikus elme hipotézis (FMH) alapján. FMH a fizikai alapokra helyezi a tudat vizsgálatát. Felismeri például hogy az összetett szerveződésű biologiai rendszerek környezet energia ciklusának részei. Az észlelés egy reverzibilis termodinamikai ciklus, amely az agy önszabályzásán keresztül fenntartja az agy nyugalmi egyensúlyát. Az érzelmek, mint a motiváció erői, döntően részt vállalnak ennek a nyugalmi állapotnak a fenntartásában.

Az észlelés ciklusa megfordítható. A nyugalmi állapot egyensúlyának a fenntartása során az idegrendszer energiát halmoz fel az endoterm ciklus révén, vagy energiát veszít egy exoterm folyamat során. Az észlelési ciklus reverzibilitása kvantumrendszereknek megfelelő véletlenszerüséghez vezet, ezért a kvantummechanika módszerei számos tudathoz kapcsolódó jelenséget képesek megmagyarázni. A döntések azonban részecskére emlékeztető stabilitást vezetnek be. Ezért a tudati folyamat a hullám-részecske dualitásra emlékeztető kvantum-klasszikus megosztottságot mutat.

Az elmélet bizonyitására a Yoneda lemmát használtam a kategória elméletből. A Yoneda lemma elemzésével azt találtam hogy a tudat fermionikus tulajdonságokat mutat, és a fizikai törvényeknek van alávetve. Az FMH elegáns matematikai bizonyítéka alátámasztja a tudat és a fermionok homomorfizmusát.

Az tudat megértése új terápiás lehetőségek feltárását kínálja a mentális betegségek kezelésére, valamint forradalmi alkalmazásokhoz vezethet a robotika és a mesterséges intelligencia területén.

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10 Appendix:

The Kullback-Leibler divergence (DKL) is a type of statistical distance represented as a surprise between the current output and the expected output. DKL represents the amount of learning required from the current knowledge p to reach knowledge q. When the distribution does not change with the change in the model parameters, the cost function is 0.

In the endothermic brain, the discrete DKL is defined as follows: X = discrete random variable in brain signal space X. $p(x) \geq 0$, $q(x) > 0$ = probability distribution of x, where p(x) = probability distribution of observed brain signal x, q(x) = probability distribution of estimated brain signal x.

$$D_{KL}((p(x) \parallel q(x)) = \sum_{x \in X} p(x) \ln \frac{p(x)}{q(x)} \geq 0 \qquad (1)$$

where $ln\frac{p(x)}{q(x)}$ is the novelty of the information. Learning depends on $D_{KL} \geq 0$, and when q = p, no learning occurs.

Instead of asking how much learning occurs between p and q, we can look for the cognitive updating caused by a stimulus, F (the free energy). S is the entropy, and T is the social temperature as defined by frequencies, $dS = \frac{\delta Q}{T}$, therefore

$$F = <F> - TS \qquad (2)$$

where <F> is the expected meaning (intellect). High social temperature increases the stimulus surprise potential, which is its ability for arousal. The system's free energy is proportional to the sensory information's surprise value relative to expectation. As the system moves toward equilibrium, the free energy is minimized. In the endothermic case, the resting entropy increases during stimulus processing, absorbing free energy. The Boltzmann distribution expresses the probability that a system will be in a state p_i as a function of the intellect (energy) and the social temperature, showing an inverse relationship between aggravation (T) and intelligent behavior as follows.

$$p_i \propto \exp\left(-\frac{kF_i}{T}\right) \qquad (3)$$

where k is the Boltzmann constant. The system evolves through a Markov process.

$$F(q) - F(p) = kT\, D_{KL} \quad (4)$$

where F(q) is the free energy for q and F(p) is the free energy in p. The system's free energy is proportional to the sensory information's surprise value relative to expectation. From Equation (2), we can express the energy requirement of learning

$$\frac{dp_i}{dt} = (F_i - < F >)\, p_i \quad (5)$$

$$\frac{d}{dt} D_{KL} = -\sum_i (F_i - < F >) q_i \quad (6)$$

where $\sum_i (F_i - < F >) p_i$ is the average "relevance" of an incoming stimulus, and D_{KL} is how much information is left to learn by going from p to q. Equation (6) shows the relevance compared to the equilibrium position p_i. Information with greater surprise changes the brain more significantly. Language, reading, mathematics, and the arts have exponentially increased the information density humans can access. It supports the intuitive notion that we never learn if exposed to the same information.

11 Keywords

Consciousness, fermionic mind hypothesis, thermodynamics, perception cycle, psychological spin, emotions,

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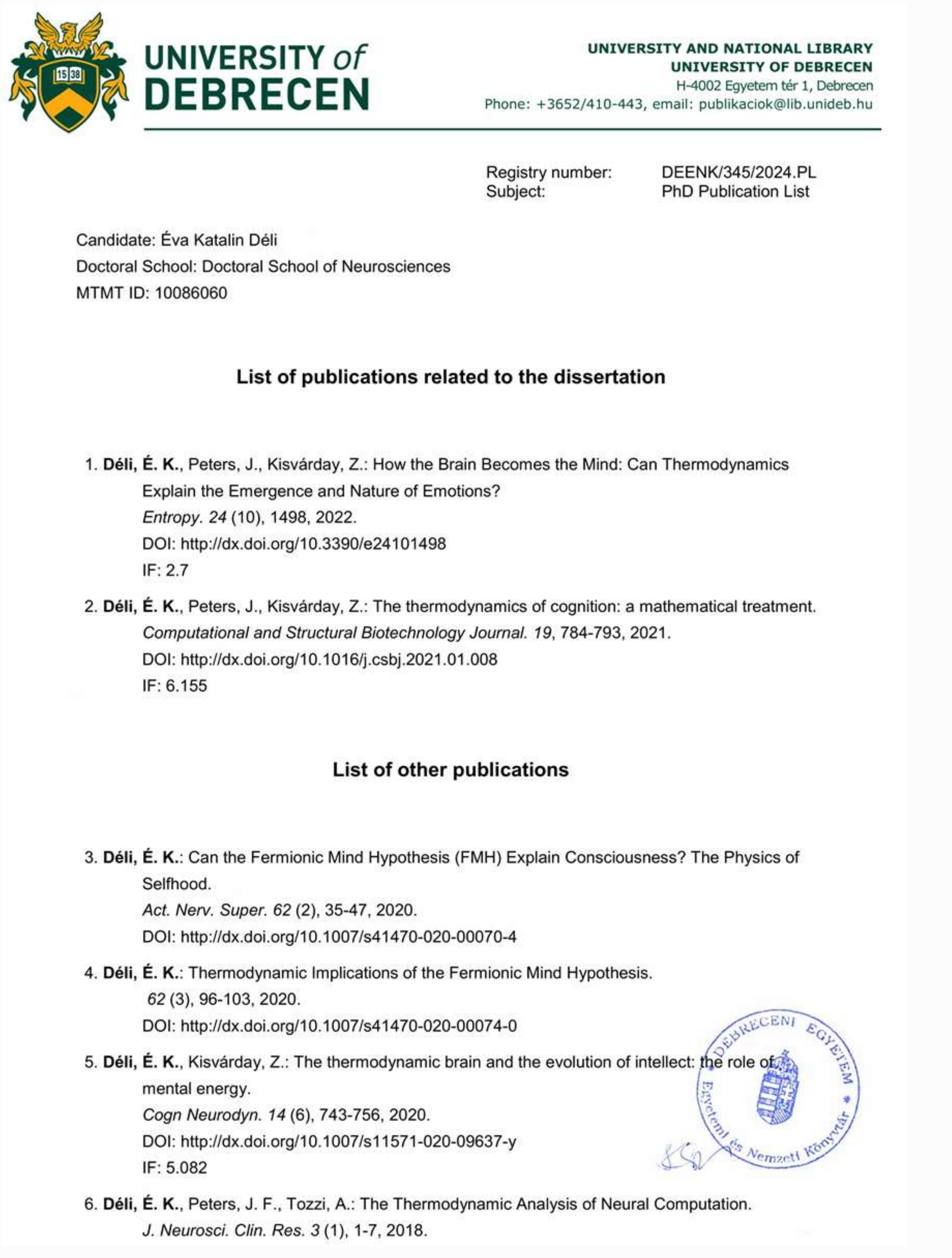
13 List of own publications



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List of publications related to the dissertation

1. **Déli, É. K.**, Peters, J., Kisvárday, Z.: How the Brain Becomes the Mind: Can Thermodynamics Explain the Emergence and Nature of Emotions?
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List of other publications

3. **Déli, É. K.**: Can the Fermionic Mind Hypothesis (FMH) Explain Consciousness? The Physics of Selfhood.
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