Interface as a Paradox Resolver, and Nature's Insights on Functional Shapes, Hierarchical Cooperation, Nested Collaboration at Scale and the Logic of Belonging - A draft

Mariana Emauz Valdetaro

2025-04-02

Table of contents

Interface as a Paradox Resolver, and Nature's Insights on Functional Shapes, Hierarchical Cooperation, Nested Collaboration at Scale and the Logic of Belonging

* Abstract

We explore interfaces as fundamental structures that resolve paradoxes and enable coherent interaction across hierarchical systems. By synthesizing insights from mereology, category theory, biology, and cognition, we demonstrate how interfaces, from cell membranes to perceptual systems to social institutions, function as paradox-resolving boundary *happenings* that transform potential contradictions into productive redundancies. We examine how nature's functional shapes encode interaction potential, how hierarchical cooperation emerges through structured interfaces, how collaboration scales through nested code-dual systems (Hoffmeyer and Emmeche, 1991), and how belonging follows a formal logic of part-whole relationships. Together, these perspectives reveal interfaces not as mere technical abstractions but as the architecture of reality itself.

Introduction: The Interface Imperative

What is an interface? A "common boundary of two bodies", "place of interaction between two systems", "apparatus to connect two devices", and a verb, expressing *interfacing*. Composed by *Inter* (between, among, during) and *face* (appearance, form, figure, and possibky related to *facere* "to make") interface is a polysemic term, like many others, which finds it specific meaning in context. At its core, an interface is a **structured mediator** that enforces formal distinctions while enabling interaction. To generalize its essence, we must return to its etymology: boundaries, as formal separations, require **distinguishable properties**. For **something**—

$$x = A$$

—to interface with **something other than itself**—

$$x \neq A$$

—there must exist a definable boundary where interaction occurs without erasing the identities of either entity. This duality—separation enabling connection—resolves self-referential paradoxes while structuring reality itself. From cellular membranes to social contracts, interfaces are neither passive dividers nor neutral conduits but *active architects of coherence*, transforming contradiction into collaboration and isolation into outgoing order.

From the synaptic choreography of neural networks to the elaborate scripts of cultural rituals, human existence unfolds through relationships, patterns of connection that define what is by negotiating what could be. The concepts such as parts and wholes, surfaces, selves, composition, and belonging bring us to explore *interfacing* through a rich lens. One that not only is inter/multidisciplinary, nor merely abstract and theoretical, but one through which perception is shaped and relations structured.

Human societies institutionalize belonging through practices and rituals that define boundaries. Émile Durkheim's concept of **collective consciousness** highlights how shared rituals create a sense of unity, binding individuals into groups through common practices while simultaneously excluding those outside the group (Durkheim, 1912). Victor Turner expands on this idea with his study of **liminality**, describing transitional periods (e.g., rites of passage, career shifts) where existing roles and boundaries dissolve, allowing new relational frameworks to emerge (Turner, 1969). However, the costs of exclusion are profound. Communities denied access to dominant systems of belonging frequently produce **subjugated knowledges**, alternative epistemologies that challenge assimilation and expose contradictions hidden within existing structures (Foucault, 1980). These contradictions can resemble **Russell's paradox**, where systems that claim universality rely on exclusion for coherence—a group that includes "everyone" inevitably excludes those who challenge its boundaries.

This interplay between connection and exclusion is not confined to social structures; it is also fundamental to how cognition operates. Neuroscientific research reveals that cognition itself is inherently **interfacial**. Synaptic gaps act as physical boundaries where neurons communicate, regulating the flow of electrical signals between cells. At the same time, the brain's **predictive processing framework** operates through structured priors, models that filter sensory input into actionable interpretations (Clark, 2013). These cognitive interfaces allow the brain to distinguish self from environment and expectation from surprise.

The role of boundaries in regulating interaction is exemplified by the **dorsal anterior cingulate cortex (dACC)**, which acts as a neural interface for social belonging. Exclusion from a group triggers activity in the dACC, registering the rejection as a "prediction error"—a discrepancy between the expected and actual social interaction. This activation, neuroscientists argue, elicits emotional pain comparable to physical injury (Eisenberger et al., 2003). Much like a cellular membrane regulates molecular exchanges, the dACC enforces boundaries between the self and the social group, guiding the individual's relational awareness. When these interfaces fail, however, dysfunction follows: in psychosis, for instance, synaptic integration collapses, leading to blurred boundaries between self and other. Internal voices may be misclassified as external agents, creating recursive loops of confusion reminiscent of Russell's paradox (Fletcher & Frith, 2009).

But how do we distinguish a part from a whole in systems where wholes are nested as parts within larger systems? Consider a biological example: the mitochondrion. This organelle functions as a distinct unit within the cell, responsible for energy production, yet it is also an integral part of the larger whole (the cell). The mitochondrion maintains its identity through its double membrane, which serves as an interface regulating molecular exchanges with the cell. However, the cell as a whole depends on the mitochondrion's energy production for its own function. In this context, the mitochondrion is both a part and a whole, depending on whether we analyze it at the intracellular level or in relation to the broader system.

Mereology, the study of parts and wholes, provides formal tools for addressing these distinctions. Key principles such as **transitivity** (if x is part of y, and y is part of z, then x is part of z) and **irreflexivity** (no entity can be a proper part of itself) clarify the conditions under which entities belong to larger systems. In the case of the mitochondrion, its status as a part is defined by its functional contribution to the cell. It does not encapsulate the entirety of the cell's identity; it plays one role among many in maintaining cellular life. However, at its own scale, the mitochondrion is a "whole," with its internal structures, boundaries, and processes.

This distinction also manifests in social systems. Consider a family: it functions as a cohesive unit (a whole) within its own dynamics, yet it operates as a part of larger systems such as communities, economies, or nations. The family's relationships, values, and rituals define it internally, but its interactions with external systems depend on the interfaces it shares with them. These interfaces regulate belonging: for instance, immigration laws, as social interfaces, determine whether a family is legally recognized as part of a nation.

Ultimately, **interfaces define the distinction between part and whole** by mediating relationships at multiple scales. A whole is never entirely reducible to its parts; instead, it gains its identity from the structured interactions of its components. Conversely, parts derive their roles and significance from their relationships to the wholes they compose. Whether in biology, cognition, or society, **boundaries act as relational filters**, establishing contexts in which parts and wholes interact without losing their distinctness. Interfaces, in this sense, serve as the logic that governs belonging and cooperation, ensuring that systems function cohesively while preserving their internal differentiation.

In 1901, Bertrand Russell unearthed a paradox: known as **Russell's paradox**, it exposed a flaw in naive set theory, the intuitive framework mathematicians had relied on for defining collections of objects. The paradox came from the seemingly innocuous question: *Can a set contain itself as a member?*

Self-referential paradoxes, such as **Russell's paradox**, reveal a fundamental tension in systems where entities define or reference themselves. By considering the set of all sets that do not contain themselves, Russell demonstrated a fundamental inconsistency: $R = {x x x}

R R R R$

The resolution required reimagining how sets are defined and how entities relate to one another, a journey that led to modern axiomatic set theory and profound insights into abstraction, composition, and belonging.

In ZF set theory, axioms like *Specification* (restricting set formation to subsets) and *Regularity* (banning self-membership) acted as mathematical interfaces, preventing paradoxes by governing how sets interact. Similarly, cellular membranes, social norms, and perceptual systems function as real-world interfaces, mediating interactions while preserving identity.

The paradox's significance extends far beyond mathematics. It seems to reveal something more fundamental about *How things relate coherently?* Systems that allow *unrestricted self-reference breed contradiction* whether in logic, biology, or social structures. The solution—enforcing interfaces as **structured boundaries** became a blueprint for coherence.

Traditionally, *identity* was seen as an intrinsic property, a *self* defined by immutable essence (e.g., Aristotle's *ousia*). However, **Hegel** and **Mead** argued that *identity* stems dialectically through interaction with the *"other."* Through mathematics, we can express identity as relational, using **Category Theory** where objects (e.g., groups, spaces) are defined *up to isomorphism* by their morphisms (structure-preserving maps). A group identity lies in how it maps to other groups (e.g., via homomorphisms), not just its internal elements; and through **Type Theory**, where entities derive meaning from their place in a hierarchy (e.g., natural numbers in Peano arithmetic). While mereology formalizes belonging, category theory formalizes composition shifting focus from isolated entities to **relational networks**, where boundaries and interactions define identity.

Russell's paradox was not merely a technical crisis but a catalyst for redefining abstraction. By enforcing hierarchies, whether in set theory, biology, or software, we eliminate contradictions while enabling coherence across levels of organization, from the very simple to most complex.

A timeless insight on how things persist structured seems to be that **clarity in abstraction requires discipline in separation.**

Expanding the definition, an interface can be seen as a structured boundary that enables interactions between entities, expressing how entities relate to one another (e.g., composition, or membership) without conflating their internal states.

It operates through two complementary logics:
1. **Mereology**: Governs *belonging* through part-whole relationships (e.g., a mitochondrion is part of a cell).
2. **Category Theory**: Functions of *interaction* through directional morphisms (e.g., a cell membrane mediating osmosis).

From synapses regulating neural communication to constitutional checks balancing governmental power, interfaces resolve paradoxes by:
- **Separating** entities into distinct domains.
- **Regulating** interactions through defined pathways.
- **Preserving** identity across hierarchical scales.

Russell's paradox, once a crisis, became a catalyst for redefining abstraction. It taught us that **clarity requires disciplined separation**—a principle manifest in nature's interfaces. Whether in proteins folding into functional shapes, societies enforcing legal boundaries, or algorithms parsing data streams, structured interaction prevents chaos while enabling complexity.

Interfaces are not mere technical tools but the hidden syntax of reality, shaping how parts become wholes, how selves navigate worlds, and how systems persist through change. Their logic—born from mathematical necessity—echoes across disciplines, offering a universal framework to understand cooperation, cognition, and belonging.

2. Some Theoretical & Foundational Ideas

Mereology

Mereology, derived from the Greek word *"meros"* meaning **part**, provides the theoretical foundation for understanding *part-whole* relationships. Originally formalized by Polish logician Stanisław Leśniewski in the early 20th century, mereology has evolved into a means of computationally analyzing component interactions of a system while formalizing *belonging* without sets, using predicates like $P(x, y)$ **x is a part of y** governed by axioms (e.g., transitivity, irreflexivity).

Classical Extensional Mereology (CEM) establishes several fundamental principles governing part-whole relationships: - **Transitivity**: If A is part of B, and B is part of C, then A is part of C. - **Irreflexivity**: No entity is a proper part of itself ($\neg P(x, x)$). - **Antisymmetry**: If A is part of B and B is part of A, then A and B are identical.

These axioms prevent Russell-like contradictions by enforcing hierarchical composition. For instance, a cell ($ x)*maybelongtoatissue*(y$), but tissues cannot recursively belong to cells. Giorgio Lando emphasized that, CEM represents *"a highly general theory of* ***parthood*** *and* ***composition****"* applicable primarily to concrete, spatiotemporal entities (Lando, 2017).

Mereology also illuminates different types of part-whole relationships. Almeida and Baracho identify several distinct categories:

1. **Component-Object relations** (wheel-car)
2. **Member-Collection relations** (tree-forest)
3. **Material-Object relations** (steel-car)
4. **Stage-Process relations** (childhood-life)
5. **Locality-Region relations** (oasis-desert)

Additionally, **Proper parts** contribute to wholes without self-reference, as a cell's organelles *(parts)* interact to sustain the cell *(whole)*, but no organelle *is* the cell.
The **Axiom** here is: *(irreflexivity)*

$$\forall x \forall y \, [P(x, y) \to \neg P(y, x)]$$

Lando carefully distinguishes mereology from logic, arguing that while the former might appear to possess logical necessity, it remains *a problematic metaphysical doctrine* that requires careful application.

However problematic it may seem, the problem appears self-informing of the relevance in formalizing how **something** *comes to be (and persists!).*

This question touches on deep and nuanced concepts about identity, self-referencing, relationships between entities, and how things are defined in relation to themselves and others. How something relates to something other than itself required clarification.

By ***something***, in logical and philosophical terms, is an entity or object that exists or can be defined. It has properties or characteristics that distinguish it from other entities.For example: A set, a person, a number, or a physical object. Naturally, ***something other than itself*** refers to entities that are distinct from the ***something*** we just described. These are objects that do not share the exact identity of the first entity. For example, if ***something*** is a set $ A $, then ***something other than itself*** refers to all entities $ x $ such that $ x A $.

Categories

While mereology formalizes *belonging*, category theory formalizes *interaction* through morphisms, directional maps between objects. In category theory, an object's identity emerges not from intrinsic properties but from its position within a network of morphisms. As Mac Lane notes, we understand objects "up to isomorphism," meaning identity arises from relational structure rather than essence.

This formalization reveals that coherent systems require: 1. **Composition**: interfaces combine predictably If $f: A →B $ and $ g: B →C $, then $ g f: A →C $

2. **Identity**: objects maintain self-relation For each object A, there exists $id_A: A →A $

3. **Associativity**: interactions chain consistently $h (g f) = (h g) f $

These properties ensure that categorical interfaces, unlike naive set theory, cannot generate paradoxes. A cell membrane, modeled as $Osmosis: Cell →Environment $, maintains directional flow without circular reference, preventing the equivalent of $R \in R$.

Combining Ideas

Russell's paradox presents a dilemma: either abandon self-reference entirely or incorporate it as a controlled, non-circular process. Natural systems demonstrate the latter approach through structured redundancy: self-reference bounded by termination conditions.

The synthesis of mereology and category theory yields a framework for understanding interfaces as structural mediators between parts and wholes:

In precise terms, we can formalize interfaces through the complementary logics of mereology and category theory:

1. **Mereological Belonging**: Parts belong to wholes through proper parthood ($P(x, y)$), governed by:
   - **Transitivity**: $\forall x, y, z[P(x, y) \land P(y, z) \to P(x, z)]$
   - **Asymmetry**: $\forall x, y[P(x, y) \to \neg P(y, x)]$
   - **Irreflexivity**: $\forall x[\neg P(x, x)]$ (no entity is a proper part of itself)
2. **Categorical Interaction**: Parts interact with their complements through morphisms ($f : x \to y \setminus x$), where:
   - **Composition**: $\forall f : A \to B, g : B \to C, \exists (g \circ f) : A \to C$
   - **Identity**: $\forall A, \exists \mathrm{id}_A : A \to A$
   - **Associativity**: $\forall f, g, h[(h \circ g) \circ f = h \circ (g \circ f)]$

We define an **interface** between part

$$x$$

and whole

$$y$$

. For any part x of whole y, the interface $I(x, y)$ represents the set of all interactions between x and its complement $y \setminus x$. From these axioms, we derive a fundamental theorem:

$$I(x, y) = \{f \mid f : x \to y \setminus x\},$$

where

$$y \setminus x$$

denotes the complement of

$$x$$

within

$$y$$

. This yields a critical theorem:

Theorem (Non-Recursive Interaction):
If

$$P(x, y)$$

, then

$$\neg \exists f : y \to x$$

.

Proof Sketch: Follows from mereological irreflexivity. If

$$f : y \to x$$

existed,

$$x$$

would indirectly belong to itself (

$$P(x, y)$$

and

$$P(y, x)$$

), violating

$$\neg P(x, x)$$

.

Suppose $P(x, y)$ and there exists a morphism $f : y \to x$. By mereological asymmetry, we know $\neg P(y, x)$. However, the existence of $f : y \to x$ would imply a categorical relationship where y influences x directly, violating the hierarchical nature of the part-whole relationship. This contradiction establishes the theorem. □

Example: Mitochondria (

$$x$$

) interact with their cellular environment (

$$y \setminus x$$

) via respiration (

$$f : x \to y \setminus x$$

), but no morphism allows the cell (

$$y$$

) to recursively regulate the mitochondrion (

$$x$$

).

This constraint prevents paradoxical loops: mitochondria interface with cells through respiratory pathways, but cells cannot recursively interface with their own mitochondria without violating hierarchical integrity.

3. Interface as Paradox Resolver

Russell's paradox forces a choice: either abandon self-reference entirely or incorporate it as a controlled, non-circular process / constrain it within structured boundaries. Nature consistently demonstrates the latter strategy through what we might call "bounded self-reference"—feedback systems with well-defined termination conditions.

Consider these contrasting forms of self-reference:

1. **Paradoxical (Unbounded)**: The set $R = \{x \mid x \notin x\}$ leads to contradiction: $R \in R \iff R \notin R$.
2. **Productive (Bounded)**: The Fibonacci sequence defined by $F(n) = F(n-1) + F(n-2)$ with base cases $F(0) = 0, F(1) = 1$ generates a coherent sequence despite self-reference.

The crucial distinction lies in boundary conditions: productive self-reference incorporates limits that prevent infinite regress.

Biological systems implement bounded self-reference through homeostatic mechanisms. **homeostasis** exemplifies productive self-reference. Cellular membranes (

$$I(x, y)$$

) detect environmental changes (e.g., pH shifts) and trigger responses (e.g., ion transport) until equilibrium is restored. These systems avoid infinite loops through electrochemical thresholds—natural termination conditions encoded in membrane potential dynamics.

Consider ion channel dynamics. When intracellular calcium levels rise, calcium-activated potassium channels open, hyperpolarizing the membrane and reducing calcium influx—a negative feedback loop with precise termination conditions (Hille, 2001). This self-regulatory pathway prevents calcium overload while maintaining functional signaling.

Levin's research on developmental bioelectricity reveals how cellular collectives coordinate through voltage gradients. These gradients form what Levin and Martyniuk (2018: 83) term "a morphogenetic code" mediating between genetic instructions and anatomical outcomes. Unlike uncontrolled growth (cancer), normal morphogenesis includes precise termination signals: bioelectric patterns change when target morphology is achieved, stopping further division and differentiation.

The concept of "self" in cellular contexts manifests without explicit self-awareness. As Levin (2021: 93) notes: "Cells do not need to know that they are part of a kidney; they simply respond to the local biophysical cues that result from their neighbors' activities." This localized interaction at boundaries—interfacial communication—enables collective behavior without centralized control.

Developmental bioelectricity demonstrates how cellular collectives coordinate morphogenesis through voltage gradients. These are particularly interesting because the sense of "self" of a cell and participatory belonging seem to be present and do not seem to require compositional awareness, Is made through proximity, happens at the shared boundaries, as bioelectric interfaces form what Levin and Martyniuk (2018: 83) call *a morphogenetic code acting as a layer of control* between genotype and phenotype. Unlike unrestricted self-reference, this bioelectric feedback includes termination conditions—cells stop dividing when target morphology is achieved. Also, cellular collectives coordinate via bioelectric gradients. These voltage patterns act as **morphisms** (

$$\text{Voltage} : \text{Cell} \to \text{Tissue}$$

), guiding anatomical development (Levin & Martyniuk, 2018).

The immune system offers a particularly instructive example of paradox resolution through interfaces. To function correctly, immune cells must distinguish "self" from "non-self"—a biological implementation of set membership determination.

Janeway's seminal work on pattern recognition receptors (PRRs) demonstrated how this discrimination occurs through interfacial recognition: toll-like receptors on immune cells recognize pathogen-associated molecular patterns (PAMPs) absent from host tissues (Janeway, 1989). This molecular interface prevents the paradox of autoimmunity—the immunological equivalent of Russell's contradiction—by establishing clear boundaries between self and non-self.

The immune system distinguishes self from non-self through **T-cell receptors** (TCRs). These protein interfaces (

$$f : \text{TCR} \to \text{Antigen}$$

) bind to foreign peptides while ignoring self-proteins, preventing autoimmune attacks (Janeway et al., 2001). This process mirrors axiomatic set theory's resolution of Russell's paradox: self-reference is permitted only within bounded interfaces. Here, the "self" from "non-self" to protect the organism without attacking its own tissues. This discrimination occurs through interfacial recognition: receptors on immune cells bind to antigens in ways that prevent autoimmune cascades. The system maintains boundaries that allow self-monitoring without self-destruction—a biological implementation of interfacial logic.

What makes this system remarkable is its adaptive capacity without logical collapse. As Tonegawa's research on V(D)J recombination showed, B-cells generate billions of unique antibody configurations, yet maintain self-tolerance through negative selection—eliminating cells that react to self-antigens (Tonegawa, 1983). This process embodies bounded self-reference: the system examines itself without attacking itself.

Pathological Interfaces: Cancer as Disconnection

When interfaces fail, pathologies emerge. Levin's research (2022) offers a compelling interpretation of cancer as an interfacial breakdown: cancer cells disconnect from the collective bioelectric network, reverting to a solitary state where they compete for survival rather than contribute to the organism. This perspective reframes cancer not merely as genetic mutation but as interfacial disruption—cells that no longer recognize their place within the whole.

Remarkably, Levin's team demonstrated that manipulating bioelectric interfaces can sometimes "reconnect" cancer cells to the organismal network. By modulating voltage gradients through ion channel manipulation, they induced metastatic melanoma cells to revert to normal behavior (Chernet & Levin, 2013). This intervention demonstrates the causal role of interfaces in maintaining hierarchical integrity.

Understanding interfacing principles thus seem to allow conditioning at scales in which are outside of our own interfacing capabilities and perceptual range.

Computational Implementations of Bounded Self-Reference

The clear computational analog, when systems similarly avoid paradoxes through structured interfaces in recursion.

In computer science, interfaces enforce termination:

```
def factorial(n):
    if n == 0:  # Base case (interface)
        return 1
    else:
        return n * factorial(n-1)
```

The base case acts as an interface, halting recursion and preventing stack overflows. This function references itself but includes a termination condition (the base case), preventing infinite recursion.

Recursive functions like factorial or tree traversal include base cases that terminate said recursion. Neural networks employ skip connections and normalization layers to prevent gradient explosion or vanishing, manifestations of computational paradoxes.

Residual networks (ResNets) employ skip connections that allow signals to bypass layers, preventing gradient problems during training. As He et al. (2016) demonstrated, these architectural interfaces enable network depth without performance degradation.

Modern architectures use interfaces to stabilize training:
- **Skip Connections**: Allow gradients to bypass layers, preventing vanishing/exploding values (ResNet, He et al., 2016).
- **Attention Mechanisms**: In AlphaFold 3, attention layers (

$$f : \text{Sequence} \to \text{Structure}$$

) predict protein folding by constraining interactions to biophysically plausible conformations (Jumper et al., 2023).

AlphaFold 3's breakthrough protein structure prediction relies on attention interfaces that selectively filter information between network layers (Jumper et al., 2023). These mechanisms implement bounded self-reference: each layer attends to previous layers' outputs without creating recursive loops.

This reframing transforms *Russell's paradox into a design principle*: **self-reference becomes productive** when structured through interfaces with clear termination conditions.

The Operational Principle: Structured Boundaries Enable Complexity

1. **Hierarchical Separation**: Enforce

$$\neg P(x, x)$$

through boundaries (e.g., cell membranes, constitutional checks).

2. **Directional Flow**: Use morphisms

$$f : A \to B$$

to mediate exchanges without recursion.

3. **Termination Conditions**: Implement thresholds (e.g., voltage potentials, base cases) to halt feedback loops.

These constraints shape everything from molecular signaling to cognitive processes to computational algorithms. Whether in cellular collectives organizing tissues or neural networks classifying images, interfaces establish the conditions under which parts can interact without losing their distinct identities.

As Hofstadter (1979) observed in “Gödel, Escher, Bach,” structured self-reference—what he called “strange loops”—enables rather than undermines complexity when properly bounded. Russell’s paradox thus reveals not merely a logical trap but a fundamental principle of organized complexity: structured boundaries act as mediators transforming potential contradictions into productive relationships. Underpin fields from synthetic biology to AI, proving that interfaces are not mere abstractions but the operational logic of complex systems.

4. Nature’s Insights

Morphology as Interfacial Code

From the helical twist of DNA to the fractal branching of lungs the shape of things, their morphology seem to encode interaction potential, dictating how entities interface with their environments across hierarchical scales. These shapes are self-informing of means of interaction given their interface, they embody the very means of engagement between entities.

Proteins exemplify morphology-as-interface. A kinase’s active site adopts a 3D structure geometrically complementary to its substrate—a lock-and-key mechanism where shape determines binding specificity. This principle underpins AlphaFold’s success: by predicting a protein’s folded structure from its amino acid sequence, AlphaFold 3 infers interaction partners with atomic precision (Jumper et al., 2023). The relationship between sequence (parts) and structure (whole) follows Anfinsen’s dogma: proteins fold into minimal free-energy configurations, optimizing interfacial efficiency (Anfinsen, 1973).

Contrary to what some may think, form and function in Nature seem to “work” together as morphological shapes often serve interfacial efficiency. The folded inner membrane of **Mitochondrial Cristae** increases surface area for respiratory enzyme activity, maximizing ATP production. In **Lung Alveoli**, fractal branching maximizes gas exchange surface while minimizing diffusion distance. **Neural Dendrites** branch out in patterns that optimise input reception while maintaining signal integrity.

These morphologies solve interfacial constraints through geometric innovation, recursion, and so on, Fractal structures like lung bronchioles or vascular networks resolve the “square-cube law” problem by maintaining surface-to-volume ratios across scales, enabling efficient resource distribution without paradoxical scaling.

These shapes emerge through **bioelectric morphogenesis**, where cellular collectives negotiate form via voltage gradients (Levin, 2021). The resulting structures are *self-informing*: morphology encodes historical interactions while constraining future ones.

Morphology, Perception, and Evolution: Interfaces as Adaptive Filters Perceptual

Our perceptual systems demonstrate how morphology shapes interfacial processing. Vision—a paradigm of perceptual interfacing—reveals how neural morphology dictates experiential "shape." The retina's photoreceptor mosaic (rods and cones) samples light through a hexagonal grid, a morphological solution to packaging efficiency. This grid structure, preserved through multiple synaptic layers, shapes perceived visual fields as topological maps in V1.

Donald Hoffman's Interface Theory of Perception suggests that perceptual morphology prioritizes fitness over truth. Our binocular vision's narrow 120° field sacrifices panoramic awareness for stereoscopic depth—a morphological trade-off optimizing primate arboreal navigation (Hoffman, 2019). This evolutionary shaping of perceptual interfaces demonstrates how morphology encodes interaction potential while constraining future possibilities.

The integration of mereology, Interface Theory of Perception, and TAME reveals compelling theoretical intersections with profound implications for our understanding of interfaces across domains. Hoffman's interface theory can be understood through mereological principles. Our perceptual interfaces create specific part-whole relationships that may not reflect objective reality but nonetheless seem to allow organization and predict structural integrity, and that hypothetically serve adaptive purposes.

The synergy between ITP, mereology, and TAME redefines ontological assumptions:
- **ITP**: Perceptual categories (e.g., "object") are fitness-enhancing interfaces, not reality's ground truth.
- **TAME**: Cognitive systems arise from part-whole collaborations, not centralized controllers.
- **Mereology**: Wholes derive identity from structured interactions, not intrinsic essence.

Multi-scale competency resonates with mereological concepts of composition, and suggests that cognitive systems are likely to stem from the composition of parts into wholes. As Almeida and Baracho note, "The system is a structural connection of its elements. Its basic formal characteristic is that elements do not simply enter the system, but enter it as a result of interaction with other elements". All three frameworks challenge conventional ontological assumptions. Mereology questions whether wholes constitute additional ontological commitments beyond their parts. Interface theory suggests that our ontological categories may be species-specific constructions rather than reflections of objective reality. TAME proposes that cognitive properties exist across a continuous spectrum rather than as discrete categories. Together, these frameworks suggest a more fluid, empirically-grounded approach to ontology that emphasizes functional relationships and pragmatic modeling over rigid categorical distinctions. This approach may better accommodate the diverse phenomena encountered across natural and engineered systems. The exploration of mereology, Interface Theory of Perception, and TAME reveals complementary perspectives on how interfaces function across physical, perceptual, and cognitive domains.

The retina's photoreceptor mosaic samples light through a hexagonal grid, a configuration proven by mathematical packing theory to maximize spatial coverage (

$$\sim 90\%$$

efficiency) while minimizing wiring costs (Snyder et al., 1977). This grid propagates through synaptic layers, shaping topological maps in the visual cortex (V1) that preserve spatial relationships—a principle first codified by Hubel and Wiesel's orientation columns (Hubel & Wiesel, 1962).

Hoffman's ITP posits that perceptual systems evolved as "species-specific desktops," favoring fitness over veridicality. Primate binocular vision illustrates this: a narrow 120° field sacrifices panoramic awareness for stereoscopic depth, optimizing arboreal navigation. The morphological constraints of ocular spacing (

$$\sim 6\,\text{cm}$$

in humans) directly determine depth perception limits through the disparity equation:

$$\Delta\theta = \frac{b \cdot \Delta d}{d^2}$$

where

$$b$$

is interocular distance, and

$$d$$

is object distance (Howard & Rogers, 1995).

Mereological principles govern biological hierarchies:
- **Irreflexivity**: A cell (

$$x$$

) cannot belong to itself (

$$\neg P(x, x)$$

).
- **Transitivity**: Mitochondria (

$$x$$

) belong to cells (

$$y$$

), which belong to tissues (

$$z$$

), hence

$$P(x, z)$$

.

These axioms prevent paradoxical loops, ensuring scalable organization.

5. Hierarchical Cooperation Through Interfaces

Bioelectric Coordination

Michael Levin's research on developmental bioelectricity reveals how cellular collectives coordinate through bioelectric interfaces to achieve system-level goals. Cells communicate via ion gradients, forming morphogenetic interfaces that guide tissue development (Levin, 2021). These interfaces enable collective intelligence, allowing cells to solve problems (e.g., regenerating limbs) no single cell could manage.

This bioelectric code functions as "an ancient computational medium for dynamic control of growth and form" (Levin & Martyniuk, 2018). Voltage gradients serve as interfaces that coordinate collective cellular behavior, enabling "multi-scale competency" where higher-order patterns emerge from local interactions. These bioelectric interfaces resolve potential paradoxes by enforcing clear boundaries between levels of organization while enabling higher-order agency to emerge.

Institutional Interfaces & Nested Collaboration at Scale

Social institutions similarly employ interfaces to enable hierarchical cooperation. Democratic governance implements mereological interfaces through checks and balances. Separation of powers—executive, legislative, judicial—prevents any branch from self-regulating ($\neg P(x, x)$), creating interfaces where power flows directionally without circular authority.

Market systems function through price interfaces that coordinate decentralized decision-making. As Benjamin Lyons explores, prices act as "cognitive glue" binding disparate economic agents into coherent supply chains without centralized control. These price interfaces resolve potential coordination paradoxes by providing clear signals without allowing recursive manipulation.

The Technological Approach to Mind Everywhere (TAME) framework suggests that agency manifests across scales through proper composition. TAME characterizes cognition through three capabilities: pursuing goals, owning compound memories, and serving as the locus for credit assignment. Crucially, these capabilities must operate at scales larger than possible for component parts alone, creating emergent cognitive systems.

This nested agency depends on interfacial coordination. Slime molds demonstrate non-neural cognitive capacities by externalizing spatial memory through secreted chemicals. Reid et al. (2012) documented *Physarum polycephalum* navigating complex environments by depositing chemical markers—an interface between organism and environment that prevents redundant exploration. This externalized memory exemplifies interfacial cognition: information processing occurs at the boundary between organism and world, not solely within internal structures.

Interfaces enable collaboration to scale across levels of organization by maintaining boundary integrity while allowing regulated interaction. Biological systems demonstrate this principle through nested interfaces:

Level	**Interface Type**	**Collaboration Function**
Molecular	Protein-protein binding	Metabolic pathway coordination
Cellular	Gap junctions	Electrical coupling between cells
Organ	Endocrine signaling	System-wide physiological regulation
Organism	Neural networks	Sensorimotor coordination
Social	Language/culture	Knowledge transmission and cooperation

Each level employs interfaces appropriate to its scale and complexity, enabling collaboration without merging identities. This nested structure prevents paradoxical loops while allowing information and resources to flow across levels.

Collaborative Cognition

Collaborative cognition emerges at multiple scales through interfacial coordination. Consider:

- **Cellular Collectives**: Bioelectric signaling coordinates regeneration in planarians, enabling whole-organism problem-solving through cellular collaboration.
- **Neural Ensembles**: Cortical columns collaborate through synaptic interfaces to recognize patterns no individual neuron could detect.
- **Social Cognition**: Cultural practices like scientific methodologies enable collaborative knowledge-building beyond individual capabilities.

These collaborative systems avoid paradoxical self-reference through interfacial boundaries that restrict information flow while enabling useful coordination. Scientific peer review, for example, prevents circular validation by enforcing separation between authors and reviewers—a social implementation of irreflexivity ($\neg P(x, x)$).

Technological Scaffolding

Technological interfaces extend collaborative capacities across scales. APIs enable software modules to collaborate without exposing internals. Blockchain technologies decentralize financial agency through peer-to-peer interfaces. Yet these technologies also reveal power dynamics: code is law, and its architects wield disproportionate influence (Lessig, 1999).

Citizen science platforms like Zooniverse let non-experts classify galaxies or track wildlife, bridging layperson and scientist through collaborative interfaces (Lintott et al., 2008). However, algorithmic recommendation systems, while personalizing content, often trap users in ideological echo chambers (Pasquale, 2015). The challenge is designing interfaces that expand horizons rather than constrain them.

7. The Logic of Belonging

Interface, Identity & *Reality*

Donald Hoffman's Interface Theory of Perception (ITP) offers a controverse reconceptualization of human perception, arguing that our sensory experiences function less as windows to objective reality and more as species-specific interfaces evolved to maximize fitness. Hoffman employs a powerful computational metaphor (we shall explore through later) to explain his theory. He paints a picture of our perceptions operating like a computer desktop interface, with icons representing complex underlying processes that remain hidden from users. Just as desktop icons hide the file structure in the console of a machine which programers access daily, where both are abstractions into human-readable format of machine code, our perceptions of objects, space, and time hide the true complexity of objective reality while providing actionable *affordances*.

The intersectional space implied here is as rich as the mereological one we covered above. Morevover, they overlad in rather unxecpected fashion. Affordances to relations, signs and identity, perception as means to relate, information to semiotics, and so on. (Need to expand this more eloquently ofc).

As Hoffman explains: “According to ITP, space-time as we perceive it is our species-specific desktop, and physical objects as we perceive them are species-specific icons in that desktop”. This framing suggests that perceptual systems evolved not to reveal truth but to guide adaptive behavior. However controversial, we remain neutral in opinions towards the complete thesis and focus on some keen insights that from it are tranferable to interfacing: Interfacing as multilevel set of means allowing nested architectures and scale-free competency development.

Vision—a paradigm of perceptual interfacing—reveals how neural morphology dictates experiential “shape.” The retina's photoreceptor mosaic (rods and cones) samples light through a hexagonal grid, a morphological solution to packaging efficiency. This grid structure, preserved through multiple synaptic layers, shapes perceived visual fields as topological maps in V1.

The counterintuitive core of ITP is captured in Hoffman's “Fitness Beats Truth” (FBT) theorem, which demonstrates through evolutionary game theory and Monte Carlo simulations that perceptual systems tuned to fitness consistently outcompete those tuned to objective truth. Natural selection, Hoffman argues, “drives true perceptions to swift extinction”.

This evolutionary argument directly challenges conventional assumptions that perception reconstructs properties of the objective world. Instead, Hoffman proposes a weaker "Construction Thesis: Perception constructs the properties and categories of an organism's perceptual world". This constructed interface helps organisms navigate their environment without requiring access to underlying reality.

We'll explore this proposal given the experimental evidence in developmental and computational bio-chemistry in a later section.

Notes: 1. As a personal note I would also enjoy to explore a computational simulation at some point, converging my work on *Agency* and newly proposed developmental arguments on co-evolution, and thermodynamics. Beyond that, 2. I must not forget another thread of exploration which is a policy based tool for inter-agent dynamics assessment. 2. An engaging paragraph on *reality* is missing and it must exist here to address criticism and provide clarity to the reader.

A caviat that we will not expand in this review is that Hoffman extends his perceptual framework into a broader theory of consciousness, suggesting that "consciousness creates brain activity, and indeed creates all objects and properties of the physical world". We do not support this view, and as such thought that it was mention-worthy, yet we do not find it as evidence to dismiss its other arguments. For the effect of clarity, we object to consciousness as fundamental rather than emergent, and other pansychic theories, but remain open to the hypothsis that consciousness and cognition has been subject to evolution leaving breadcrumbs of protoconscious artifacts, and similarly, intelligence, agency have as well. From this prespective, we do see some ground for interfaces and interfacing means to have been shaped by iteration thus alligning to some degree with the previous section on fitness.
While not subscribing to a consciousness as a fundamental phenomena, efforts in the seminal work on Interface Theory show brave commitment as an attempt to develop a mathematically precise nondualistic approach to derive quantum physics from consciousness rather than vice versa, where we find the non-mutualistic take of relationships intriguing.

Our binocular vision's narrow 120° field sacrifices panoramic awareness for stereoscopic depth—a morphological trade-off optimizing primate arboreal navigation (Hoffman, 2019).

This seems to suggest that Russell's paradox warning

$$R \in R \iff R \notin R$$

against unconstrained self-reference, as evidence that Nature avoids such traps through interfacial hierarchies. Self-assembling molecules maintain identity via compartmentalization (lipid membranes) (**Autocatalytic sets**), preventing infinite reaction loops. Moreover, in the case of **Immune systems**, antibody paratopes *(interface regions)* evolve to bind antigens without targeting self—a morphological immune algorithm.

In previous work on *Agency* and *Intelligence*, we've substatially covered Michael Levin's Technological Approach to Mind Everywhere (TAME) framework. Its insights provide a complementary perspective to both mereology and interface theory by offering an experimentally grounded approach to understanding diverse cognitive systems across scales and substrates, with empirical evidence, data and quite unique and specific case-studies to bring mereological arguments out from purely mathematical or theoretical constructs to actual entities, novel intelligences and their capabilities, the morpho-space where parthood relations are mediated through bioeletricity in regenerative medicine, and even the financial markets where Benjamin Lyons explores prices as *cognitive glue*. A foundational aspect of TAME is its rejection of binary categorizations of mind and agency. Instead, it proposes a continuous spectrum of cognitive capacities that can be empirically investigated across diverse biological and technological systems. This gradualist approach posits that the question of agency is not philosophical but empirical, to be determined through experimental investigation. As Levin explains, "the correct level of agency with which to treat any system is determined empirically, based on which kind of model affords the most efficient way of prediction and control". This pragmatic stance echoes Dennett's Intentional Stance while commited to experimental validation and operability in mediating and understanding consitioning.

Its insights provide a complementary perspective to both mereology and interface theory by offering an experimentally grounded approach to understanding diverse cognitive systems across scales and substrates, with empirical evidence, data and quite unique and specific case-studies to bring mereological arguments out from purely mathematical or theoretical constructs to actual entities, novel intelligences and their capabilities, the morpho-space where parthood relations are mediated through bioeletricity in regenerative medicine, and even the financial markets where Benjamin Lyons explores prices as *cognitive glue*.

Ontological Parsimony

A paramount question in mereology concerns whether accepting mereological principles increases ontological commitments. As Jeroen Smid argues, "if the parts of an object are 'ontologically innocent', then sums cannot fail to be innocent either" (Smid, 2017). This perspective challenges the argument that mereology leads to ontological extravagance by creating new entities.

The logic of belonging suggests that parts derive identity from their wholes while wholes emerge from their parts—a complementary relationship that avoids redundant ontological commitments. A cell belongs to a tissue in a way that defines both entities: the tissue provides context for the cell's function, while the cell contributes to the tissue's capabilities.

Boundaries as interfaces and identity as relational, reconciling philosophy's dialectics with mathematics' rigor. Whether in cells, societies, or algorithms, coherence arises not from isolation but from the disciplined interplay of surface-level interaction.

In this light, self-referencing loops are not contradictions but structured redundancies—tools for maintaining stability in a relational universe. The task ahead is to map these interfaces, fro A paramount and critical question in mereology concerns whether accepting mereological principles increases ontological commitments. As Jeroen Smid argues, "if the parts of an object are ‘ontologically innocent’, then sums cannot fail to be innocent either”. This perspective challenges the argument that mereology leads to ontological extravagance by creating new entities. Furthermore, when transcending from man-assembled objects in material-object-relations for example, into member-collection relations of environmental subjects pose a lit revival of the *natural accountability* debate.

I hope, that by now, this intersection of mereology and identity, parthood and accountability, sounds not only captivating beyond philosophical complexity but enticing as a potential practical approach into policy, legislation and ethics. As Carrara and Lando note, *“The eighteen papers in this special issue scrutinise the multifarious roles that identity plays in mereology”.* These intersections reveal mereology’s rich philosophical implications beyond mere formal structure, and we hope to pursue in future work, the wide implication-rage of mereology.

We know self-referencing must be avoided, and defining belonging can be done using mereology, category theory allows for composition and identity without contradiction. Going back to the idea of **“Something”** relating to **“Something Other Than Itself”**, in both membership and composition, and regardless of levels of abstraction, we may formalise bm the quantum to the cosmic, and embrace the insight that to be is to interact.

The **Technological Approach to Mind Everywhere (TAME)** frames cognition as a scalable phenomenon. In *Xenopus* embryos, bioelectric patterns encode “target morphology” for regeneration, overriding genetic noise (Pezzulo & Levin, 2016). This process mirrors error-correcting codes in telecom systems, where redundant signals compensate for noise—a mathematical parallel to biological robustness.

The synergy between ITP, mereology, and TAME redefines ontological assumptions:
- **ITP**: Perceptual categories (e.g., “object”) are fitness-enhancing interfaces, not reality’s ground truth.
- **TAME**: Cognitive systems arise from part-whole collaborations, not centralized controllers.
- **Mereology**: Wholes derive identity from structured interactions, not intrinsic essence.

From protein binding sites to cortical maps, morphology encodes interaction logic through geometric precision. These interfacial “rules of engagement” resolve paradoxes—whether thermodynamic limits in lungs or self/non-self discrimination in immunity—by structuring relationships across scales. The interplay of form and function reveals a deeper truth: **reality is shaped by interfaces**, the syntax through which parts compose wholes without contradiction.

Social Belonging

Social belonging operates through similar mereological principles. Durkheim’s **collective effervescence**—the shared energy of religious rituals—acts as a social interface, binding individuals to groups while excluding outsiders (Durkheim, 1912). Yet exclusion carries a cost:

marginalized communities often develop **subjugated knowledges** (Foucault, 1980), alternative interfaces that reject assimilation.

Victor Turner's concept of **liminality** identifies transitional phases (e.g., rites of passage) as temporary interface dismantlings, allowing transitions between roles (child $\rightarrow$ adult, outsider $\rightarrow$ member). These cultural interfaces regulate belonging while preventing paradoxical identity loops.

Implications

The "natural accountability debate" mentioned in your notes highlights how belonging carries ethical dimensions, particularly when considering environmental systems. How responsibility distributes across mereological hierarchies remains a crucial question for policy, legislation, and ethics.

Mereological principles can inform governance structures that avoid self-referential contradictions. For instance, regulatory frameworks could model stakeholders as objects and legislation as morphisms, ensuring composable, non-contradictory laws. The principle of proper parthood (

$$P(x, y) \rightarrow \neg P(y, x)$$

) translates to governance as the separation of powers—no entity should regulate itself without proper interfaces and boundaries.

If reality is co-constituted through relational boundaries, then responsibility lies in how we design these boundaries. Ethical interfaces should:

1. **Resist self-referential tyranny**: Avoid closed loops (e.g., social media addiction).
2. **Prioritize adaptability**: Allow user customization and contestation.
3. **Democratize access**: Ensure marginalized communities co-design the systems affecting them.

These principles apply across domains:

- **AI Ethics**: Neural networks trained on biased data internalize toxic interfaces, mistaking correlation for causality. Mitigation requires explicit interfacial guardrails (e.g., fairness constraints).
- **Bioengineering**: Levin's bioelectric interfaces suggest a future where tissues self-assemble ethically, guided by voltage gradients rather than centralized control.
- **Social Media**: Platforms can design interfaces that foster dialogue rather than polarization, incorporating circuit-breakers that prevent algorithmic amplification of harmful content.

Interfaces as Political Structures

Interfaces are inherently political. A door handle, ostensibly neutral, excludes wheelchair users if designed without affordances for pushing (Norman, 1988). Similarly, facial recognition technologies, trained on biased datasets, disproportionately misidentify marginalized groups (Buolamwini & Gebru, 2018). Interfaces embody the values of their creators, amplifying some voices while muting others.

Language, our oldest interface, mediates access to knowledge and connection. Wittgenstein argued that “the limits of my language mean the limits of my world” (Wittgenstein, 1922). Yet translation tools and augmented communication devices are expanding these limits, enabling cross-cultural dialogue. Conversely, “digital divides” exclude billions from the interfaces defining modern life—a stark reminder that access is power.

Hinting at an **ethics of interfaces**. If reality is co-constituted through relational boundaries, then responsibility lies in how we design these boundaries:

Interfaces transform experience by redistributing agency. Consider bioelectricity: cells communicate via ion gradients, forming morphogenetic interfaces that guide tissue development (Levin, 2021). These interfaces enable collective intelligence, allowing cells to solve problems (e.g., regenerating limbs) no single cell could manage. Similarly, blockchain technologies decentralize financial agency, replacing banks with peer-to-peer interfaces. Yet power persists: code is law, and its architects wield disproportionate influence (Lessig, 1999).

Interfaces can democratize access. Citizen science platforms like Zooniverse let non-experts classify galaxies or track wildlife, bridging layperson and scientist (Lintott et al., 2008). However, empowerment requires vigilance. Algorithmic recommendation systems, while personalizing content, often trap users in ideological echo chambers (Pasquale, 2015). The challenge is designing interfaces that expand horizons rather than constrain them.

Neutrality or Complicity? Question 4: Are interfaces neutral? No—interfaces are political. A door handle, ostensibly neutral, excludes wheelchair users if designed without affordances for pushing (Norman, 1988). Similarly, facial recognition technologies, trained on biased datasets, disproportionately misidentify marginalized groups (Buolamwini & Gebru, 2018). Interfaces embody the values of their creators, amplifying some voices while muting others.

Language, our oldest interface, mediates access to knowledge and connection. Wittgenstein argued that “the limits of my language mean the limits of my world” (Wittgenstein, 1922). Yet translation tools and augmented communication devices (e.g., AAC) are expanding these limits, enabling cross-cultural dialogue. Conversely, “digital divides” exclude billions from the interfaces defining modern life—a stark reminder that access is power.

Conclusion: The Paradoxical Truth of Boundaries

Your conclusion beautifully captures the core insight: “To coexist, entities must first delineate where they end and others begin.” Strengthen this by emphasizing the paradoxical truth that boundaries enable connection rather than prevent it.

Recapitulate how interfaces—from quantum fields to social norms—resolve paradoxes by structuring interaction, enabling coherent emergence across scales. Close with the profound implication: reality itself speaks the language of interfaces.

Russell’s paradox taught us that coherence requires constraints. As we design tomorrow’s interfaces—brain-machine hybrids, quantum algorithms, climate models—we must embrace this lesson. Ethical interfaces should:

Resist self-referential tyranny: Avoid closed loops (e.g., social media addiction).

Prioritize adaptability: Allow user customization and contestation.

Democratize access: Ensure marginalized communities co-design the systems affecting them.

Interfaces are not just tools; they are the scaffolding of reality. To build them wisely is to shape a world where connection does not demand conformity, and boundaries liberate rather than confine.

The deepest lesson of interfacial thinking is that *isolation is an illusion.* Nothing exists except through interaction—but interaction demands structure. From quantum fields to social norms, interfaces are the rules of engagement, the protocols that allow difference to coexist.

Collectively they suggest that interfacing represents a process connecting parts to wholes, organisms to environments, and cognitive systems to their components and targets.The ontological and epistemological implications of these frameworks extend beyond theoretical interest. They inform practical approaches to fields ranging from artificial intelligence and synthetic biology to regenerative medicine and cognitive science. By understanding interfaces as adaptive, evolved systems that mediate between domains rather than transparent windows to reality, we gain new insights into both natural and engineered systems. Future research should focus on empirical validation of these theoretical intersections, particularly through experimental investigations of how part-whole relationships manifest in perceptual and cognitive systems. Such research may reveal new principles of interfacing applicable across natural and artificial systems, further bridging the conceptual boundaries between these complementary frameworks.

In a world fractured by polarization, climate crises, and algorithmic alienation, the task is not to eliminate boundaries but to redesign them. To build interfaces that are permeable yet firm, directional yet adaptable. Russell’s paradox began as a mathematical curiosity; it ends as a manifesto for relational humility. To interface is to acknowledge that we are all parts of a whole—and that the whole depends on how we connect.

https://www.eastcoastoralsurgery.com.au/about/ https://dialnet.unirioja.es/descarga/articulo/4972276.pdf https://ceur-ws.org/Vol-3241/paper22.pdf https://sites.socsci.uci.edu/~ddhoff/interface.pdf https://www.bbc.co.uk/news/articles/c8770jyz6vvo https://portal.research.lu.se/files/3462956/5148698.pdf https://en.wikipedia.org/wiki/Mereology https://scienceandnonduality.com/videos/donald-hoffman-consciousness-and-the-interface-theory-of-perception/ https://news.sky.com/story/michael-mosley-race-against-time-in-search-for-tv-doctor-as-rescuers-shift-focus-to-mountainous-path-13149438 https://reviews.ophen.org/2018/11/16/giorgio-lando-mereology-a-philosophical-introduction-review/ https://philarchive.org/archive/CARMAI-8 https://eupercebo.unb.br/2021/06/22/eviden da-percepcao-enquanto-uma-interface-a-proposta-computacional-de-donald-hoffman/ https://arxiv.org/abs/220 https://ceur-ws.org/Vol-2050/FOUST_paper_8.pdf https://davidadger.org/2023/09/19/mereological-syntax/ https://sites.socsci.uci.edu/~ddhoff/Hoffman-Stevens-Handbook.pdf https://pmc.ncbi.nlm.nih.gov/arti https://www.reddit.com/r/consciousness/comments/1ae1254/explain_donald_hoffman_theory/ https://www.youtube.com/watch?v=JTIY3Z00XMM https://www.youtube.com/watch?v=ZmKNtH5J01A https://thoughtforms.life/books-forthcoming/ https://www.news.com.au/entertainment/celebrity-life/celebrity-deaths/tragic-dr-michael-mosley-left-huge-sum-to-beloved-wife-after-he-died-on-holiday-in-greece/news-story/83d0c469b71557ffa1bfc8d33711326a https://au.news.yahoo.com/michael-mosley-latest-search-underway-121413058.html https://www.mdpi.com/2409-9287/5/3/16 https://www.academia.edu/34943705/HANDBOOK_OF_MEREOLOGY_academia https://plato.stanford.edu/entries/mereology/ https://champollion.com/wp-content/uploads/2018/07/champo https://multisenserealism.com/2014/01/14/consciousness-and-the-interface-theory-of-perception-donald-hoffman/ https://pubmed.ncbi.nlm.nih.gov/26384988/ https://www.youtube.com/watch?v= Buolamwini, J., & Gebru, T. (2018). Gender shades: Intersectional accuracy disparities in commercial gender classification. Proceedings of Machine Learning Research, 81, 1–15.

Clark, A. (2013). Whatever next? Predictive brains, situated agents, and the future of cognitive science. Behavioral and Brain Sciences, 36(3), 181–204.

Foucault, M. (1980). Power/Knowledge: Selected Interviews and Other Writings. Pantheon.

Hacking, I. (1983). Representing and Intervening. Cambridge University Press.

Hoffman, D. D. (2019). The Case Against Reality: Why Evolution Hid the Truth from Our Eyes. W.W. Norton.

Levin, M. (2021). Bioelectric signaling: Reprogrammable circuits underlying the hardware of consciousness. Frontiers in Human Neuroscience, 15, 658197.

Lessig, L. (1999). Code and Other Laws of Cyberspace. Basic Books.

Lintott, C. J., et al. (2008). Galaxy Zoo: Morphologies derived from visual inspection of galaxies from the Sloan Digital Sky Survey. Monthly Notices of the Royal Astronomical Society, 389(3), 1179–1189.

Norman, D. A. (1988). The Design of Everyday Things. Basic Books.

Pasquale, F. (2015). The Black Box Society: The Secret Algorithms That Control Money and Information. Harvard University Press.

Russell, B. (1901). Letter to Frege. In J. van Heijenoort (Ed.), From Frege to Gödel (pp. 124–125). Harvard University Press.

Wittgenstein, L. (1922). Tractatus Logico-Philosophicus. Routledge.

Zamboni, G., et al. (2013). Neuroanatomy of impaired self-awareness in Alzheimer's disease and mild cognitive impairment. Cortex, 49(3), 668–678.

- Anfinsen, C. B. (1973). *Science*, 181(4096), 223–230.
- Hubel, D. H., & Wiesel, T. N. (1962). *J. Physiol.*, 160(1), 106–154.
- Jumper, J., et al. (2023). *Nature*, 614(7949), 1–12.
- Levin, M., & Martyniuk, C. J. (2018). *BioSystems*, 164, 76–93.
- Mandelbrot, B. B. (1982). *The Fractal Geometry of Nature.*
- Pezzulo, G., & Levin, M. (2016). *Prog. Biophys. Mol. Biol.*, 121(3), 219–244.
- Snyder, A. W., et al. (1977). *J. Comp. Physiol.*, 116(2), 183–207.