The Geometry of Information: Shape, fit, and the emergence of meaning

Abstract

This paper develops an integrated view of information and meaning based on two central ideas: information is shape and meaning is fit. By *shape* we mean structured form that can fit into other forms and, by fitting, change what happens next. *Meaning* is the success of that fitting in a specific context: how a pattern becomes usable when it couples to other patterns and guides action, prediction, coordination, or further change. Because no two things are exactly the same, fit requires *tolerance*. To connect effectively, shapes only need to be *similar enough*. This also implies that fit can be better or worse, so meaning comes in degrees and can shift over time. In this view, what exists is never "raw": every stable form carries forward the structure left by earlier interactions. Information remains preserved as long as the structures that carry it stay similar enough to be recognized and reused. Genes, brains, and books are different media in which the same phenomenon occurs: history taking form. And although meaning is most vivid for observers, the same logic applies to non-living patterns, such as a mountain slope that channels water or a key that fits a lock.

Keywords Information as shape . Meaning as fit . Succesful coupling . Graded meaning . Cross-carrier identity . History taking form

1. Introduction

"Information" is one of those words that seems obvious until we try to define it precisely. In everyday life, information means facts: data, statements, measurements. In science and engineering, information is often used in a narrower sense, referring to signals, uncertainty reduction, coding, and the reliability with which signals can be transmitted (Shannon, 1948; Cover & Thomas, 2006). In philosophy, information has been used to explain cognition and meaning, and in some cases even to argue that reality itself is fundamentally informational (Wheeler, 1990; Floridi, 2011). These uses overlap, but they are not the same. Confusing them may make information either too passive ("mere facts") or too mysterious ("meaning floating free of structure").

The current paper proposes an integrated view that brings different approaches together by shifting attention from facts to form. It is organized around two core ideas: information as shape and meaning as fit. Shape here does not mean only what can be seen; it means a structured pattern—differences, relations, boundaries, and order—that can be preserved, compared, and

used. A good way to grasp this is the puzzle-piece example. A puzzle piece does not describe the puzzle in words; its information lies in the way it is cut. Because of that cut, it can connect to some pieces and not to others. When it fits, the situation changes: a part of the picture locks into place, and new, more specific connections become possible. This shows what is meant by shape: a structure that has the potential to reduce the range of possible outcomes.

When such a structure enters into interaction, its informational character lies in the difference it can make. Information, in this sense, is the part of a pattern that makes a difference when it meets another pattern, thus reformulating Bateson's (1972) famous phrase "a difference that makes a difference" in more explicitly interactional terms. This difference may be physical (a slope channeling water), biological (a receptor activated), cognitive (a prediction revised), or cultural (a reader's understanding changed). Information in this perspective does not require an observer. It exists as structured pattern, and becomes informational through the difference that pattern can make in interaction.

If information is what makes a difference in interaction, then meaning is the success of that difference in context: meaning is fit. A pattern becomes meaningful when it couples successfully to other patterns and thereby guides what happens next. Meaning thus lies neither in the pattern alone nor only in the mind of an observer, but in how the pattern fits with another pattern or system and helps guide what happens next, consistent with ecological and enactive approaches that emphasize organism-environment coupling (Gibson, 1979; Varela, Thompson, & Rosch, 1991).

This fit does not need to be perfect, because in the real world no two situations are ever exactly the same. If exact fit were required, patterns could connect only in strictly identical cases. What is needed is fit that is similar enough to work. This makes meaning a matter of degree rather than an all-or-nothing property and helps explain how patterns can be reused in new contexts, which makes learning and generalization possible.

A final point is that information is not "raw." Patterns carry traces of earlier interactions (Landauer, 1991), and these traces make later reuse possible.

The next section places our work in the broader literature. The sections that follow develop the core ideas of the paper step by step: first by clarifying information as shape, then by analyzing meaning as fit, and finally by placing both in a broader historical perspective within the material history of the universe, where stable forms carry traces of prior interaction and observers appear as a special case of a more general pattern.

2. Conceptual background

The idea that information has to do with form is much older than modern science. In Aristotle's account of form and matter, a thing is not fully understood simply by knowing what material it is made of. What also matters is the form that makes it this kind of thing rather than another. Form gives organization and identity to matter. In this perspective, knowing something means,

at least in part, grasping its form (Aristotle, *Metaphysics*; Reeve trans. 2016). This is relevant because it shows that information was not originally understood only in terms of messages or signals but already had a structural dimension. Recent overviews of the concept still note this long history linking information to form, structure, meaning, and use (Adriaans, 2020; Tredinnick, 2025).

Modern information theory began from a narrower problem: communication. Shannon's (1948) mathematical theory of communication asked how differences in signals can be measured, coded, and transmitted through a noisy channel. To answer that question, Shannon deliberately left meaning aside. His theory does not ask what a message means, but how much uncertainty is reduced when one signal is received rather than another. This made communication mathematically precise, but it did so by setting aside the meaning of what is communicated. That limitation was partly corrected in cybernetics and systems thinking. Bateson's (1972) famous phrase—information as "a difference that makes a difference"—shifted attention from transmission to effect: a difference becomes informational when it changes what can happen next in a system. Together, Shannon and Bateson established two themes that have remained central ever since: information as measurable difference and information as effective difference.

A closely related line emerged in physics. Landauer (1991) argued that information is not just an abstract description: it must be carried by physical states, and operations such as erasing or overwriting stored information have physical consequences. This complements Shannon's measure by showing that information processing is constrained by the material world. Earlier and related work on the thermodynamics of information made the same point in different ways, for example by linking measurement, memory, and entropy costs (Szilard, 1929; Bennett, 1982). These approaches make clear that information is never free-floating: it is always carried by a physical medium.

Analytic philosophy pushed these questions further by asking how information can ground knowledge and meaning. Dretske (1981) argued that a signal carries information when there is a reliable connection between the signal and what it indicates, so that receiving it narrows down what is the case. Floridi (2005, 2011) distinguished data, information, and semantic information, and asked whether meaning and truth-like conditions should be built into the definition of information. Kolchinsky and Wolpert (2018) offered a further answer by defining semantic information in terms of the difference it makes to an autonomous system's continued existence. As Tredinnick (2025) shows, the field still moves between structure, content, meaning, and use. Together, these debates make clear that information is more than an engineering term. However, when the focus shifts to meaning, the discussion often turns to what words and statements refer to and whether they are true. That shift can obscure a simpler question: how does meaning arise in interaction?

Deutsch and Marletto (2015), working within constructor theory, add a further important point: the same information can be realized in different physical carriers. If a message can be spoken, written, printed, or stored electronically, then what makes it the same cannot be the carrier

itself but must lie in what is preserved when the carrier changes—namely the relevant structure. Constructor theory captures this idea by treating information as something that can be realized across different media while still being copied, transformed, and used in further interactions.

This connects with a tradition that treats information less as "what is sent" and more as how something is organized. A barcode is informative not because ink is special, but because its pattern reliably triggers a scanner and a downstream action. The same pattern could be printed, displayed on a screen, or engraved and still work. Stonier (1990, 1991) argued in this spirit that information is not only in messages, but also in the organized structure of systems. Burgin (2017) sharpened this by distinguishing structural information from symbolic information. Zhou (2021) further separated structural, referential, and normative aspects, clarifying how information can be carried by something, be about something, and be usable for some purpose. Zhou's distinction also builds on Deacon's (2012) broader attempt to connect structure, reference, function, and normativity within one account of information and meaning. Across these approaches, a common idea becomes visible: information is not exhausted by signs, messages, or human interpretation. It can also be present in the structural pattern itself and, in that sense, remain the same when it is realized in different materials.

This structural view raises a historical question: how do such patterns emerge? Wong et al. (2023) argue that, in evolution, systems can accumulate "functional information" when selection favors structures that work or persist better than alternatives. Hazen and Wong (2024) describe a related pattern in mineral evolution, where changing environments can lead to increasing diversity and complexity of forms over time. A related idea appears in niche-construction theory, where stable modifications of the environment are treated as forms of ecological inheritance that shape later interactions and development (Odling-Smee, Laland, & Feldman, 2003). More generally, Deacon (2012) likewise emphasizes that organized constraints can retain the effects of earlier processes and continue to matter in later ones. These studies do not claim that such structures are meaningful in the human sense. However, they do show that organized and usable structures can accumulate historically in both living and non-living systems.

Regarding the way in which structure becomes meaning in practice, Gibson (1979) argues that organisms encounter their environment not as raw, meaningless data, but as a field of affordances—possibilities for action defined by the relation between organism and world. Varela, Thompson, and Rosch (1991) made a closely related point: cognition is not passive inner copying, but develops through an organism's active engagement with its surroundings. More recent work on structural coupling has further clarified this line, emphasizing that meaning depends on the ongoing relation between organism and environment rather than on detached inner representation (Corris, 2020). Bruineberg, Chemero, and Rietveld (2019) extend this ecological line by arguing that ecological information supports even forms of "higher" cognition through skilled engagement with affordances. Active-inference approaches describe cognition in a similar spirit as continual adjustment between organism and environment through perception and action (Parr, Pezzulo, & Friston, 2022; Pezzulo, Parr, & Friston, 2024). Baker (2025) likewise

uses affordances to compare agents in terms of the action possibilities available to them in relation to their environments. Although these approaches differ in method and vocabulary, they converge on one shared idea: meaning develops through coupling—how systems meet, respond, and adapt.

When these traditions are viewed together, a broader picture begins to emerge. Aristotle connects understanding with form. Shannon isolates the measurable transmission of differences. Bateson shows that differences matter when they have effects. Landauer and the thermodynamics-of-information tradition insist that information must be physically realized. Dretske and Floridi connect information to cognition, knowledge, and semantic meaning, while Kolchinsky and Wolpert explain semantic information in terms of its relevance for a system's continued viability. Deutsch and Marletto clarify how the same information can persist across different carriers. Stonier, Burgin, Zhou, Deacon, and Tredinnick draw attention back to structure, content, meaning, and use. Wong and Hazen show how organized structure can accumulate over time, while Odling-Smee, Laland, and Feldman make clear that stable traces of earlier interactions can shape later ones through ecological inheritance. Gibson, enactive theory, structural coupling, ecological-information approaches, active inference, and recent affordance-based work show how meaning develops in relation and action. Taken together, these approaches suggest that information is neither merely a message nor merely a mental interpretation. It has to do with structured difference that can persist, matter, and be used in later interaction.

Here we aim to move beyond these perspectives by integrating the field around two core ideas: information as shape, understood broadly as structured pattern, and meaning as fit, understood as successful coupling that guides what happens next. The following sections develop these ideas further. Section 3 clarifies what is meant by shape and shows how information can be understood as the part of a pattern that makes a difference in interaction. It also discusses how information can remain the same, in the relevant sense, across different carriers and media. Section 4 turns to meaning as fit and argues that this fit need not be perfect, but only similar enough to work, making meaning graded and revisable. Section 5 broadens the discussion by placing information and meaning in the wider material history of the universe, showing how they arise first in the interactions of non-living patterns, how stable forms carry the traces of earlier interactions, and how living organisms and observers add further layers to this more general process. Section 6 then draws the main threads together.

3. Information as shape

This paper shifts the focus from "facts" to form. The central claim is straightforward: information is shape. "Shape" here does not mean only visual appearance; it refers to a structured pattern—an arrangement of differences and relations that can be preserved, compared, and reused. The puzzle-piece example already illustrated this in simple form, but the same logic appears just as clearly in a key and lock. A key does not describe the lock in words; its information lies in the ridges cut into it. Because of that shape, it can open some locks and not

others. A protein's shape works similarly in binding to some receptors and not others, and a musical phrase constrains which continuations will feel like a natural next step rather than an interruption. In all these cases, information is not something separate from the pattern; it lies in the pattern's potential to shape further interaction by narrowing the range of what can happen next. In that sense, information is not merely contrast; it is constraint (Ashby, 1956).

This also helps distinguish information from a random pattern. Patterns can be intricate yet informationally useless for a given system if they do not have the potential to connect to anything that can take them up. Conversely, even a very simple form can be highly informational if it changes outcomes in interaction. The earlier barcode example already illustrates this: informational relevance does not depend on complexity, but on the ability to trigger further effects. A stop sign shows the same principle in a different domain. It is informational not because it contains many bits, but because its shape and color fit a learned social system and guide behavior.

If information is shape, the same information can appear in different media—carved into wood, printed as ink, spoken as sound, or encoded as bits. This is possible because "shape" here means structure, and structure can be preserved across different carriers. A triangle is not identical with graphite marks on paper. The same triangle can be drawn, cut from wood, represented with pixels, or described verbally. The carrier changes; the relational form remains: three edges connected in a closed loop.

Everyday communication depends on the same principle. A simple instruction—"turn left at the bridge"—can be written on a sign, spoken aloud, or displayed by a navigation system. The physical form and the wording may differ, but we still treat it as the same information when the relevant structure is preserved well enough to guide the same action. Translation shows the same thing at the level of meaning: sounds, words, and grammar may change, yet a text can still have the same meaning if its relational structure is preserved—who did what to whom, what distinctions matter, what is being asserted or requested, and what action it guides.

This structural approach fits the physical constraints emphasized by Landauer (1991): information is not an abstract, free-floating entity; it must be realized in some form. Constructor theory adds a complementary perspective by emphasizing that what matters about information is what can be done with it—how it can be copied, transformed, and used across different substrates (Deutsch & Marletto, 2015). This makes it possible to distinguish more clearly between carrier and structure (Burgin, 2017; Zhou, 2021). The carrier is the particular physical realization—ink marks, sound waves, neural firing patterns, magnetic states—whereas information-as-shape is the preserved relational structure that can still couple and make a difference. The medium matters for fidelity, durability, and ease of copying, but "the same information" means that what matters structurally is preserved well enough for the pattern to do the same job again.

Taken together, these examples lead to a clear conclusion: information is the part of a pattern that makes a difference when it meets another pattern. In this way, Bateson's (1972) idea of information as "a difference that makes a difference" is reformulated in explicitly interactional terms. Information is not a detached fact, but structured difference that constrains what can happen next. It must be carried by a physical medium, yet it can remain the same across different carriers when the relevant structure is preserved. This sets up the next step: if information is structured difference, then meaning is what arises when that difference fits successfully with another pattern and helps guide what happens next.

4. Meaning as fit

Meaning is often treated as something added by minds to neutral facts. Here, meaning is understood in interactional terms: meaning is fit. A pattern becomes meaningful when it can couple successfully to surrounding patterns and guide what happens next—supporting coherence, action, prediction, or coordination. This is aligned with ecological and enactive traditions, where meaning is relational and action-guiding rather than purely internal labeling (Gibson, 1979; Varela, Thompson, & Rosch, 1991).

A crucial refinement is that fit does not need to be perfect. As noted earlier, no two situations or shapes are ever exactly the same. Fit therefore requires tolerance. To connect effectively, shapes need only to be similar enough. Meaning is therefore graded rather than all-or-nothing, and tolerance in fit also explains why learning and generalization are possible. A pattern can be reused only if later situations resemble earlier ones in relevant ways, but if those situations were completely identical, nothing genuinely new could arise. Meaning therefore requires a world that combines stability with variation: enough resemblance for structure to be reused, enough difference for adjustment, revision, and novelty.

This view also clarifies why truth and correctness are not the best place to begin if we want to understand meaning more generally (cf. Floridi, 2005). Many meaningful patterns are not statements at all: a melody, a gesture, a tool, a habit, a warning sound. Even when meaning is propositional, as in language, communication often works without exact correspondence. Understanding is usually context-dependent, approximate, and refined as interaction proceeds. This does not deny the importance of truth in science and discourse, but it places truth assessment at a later level, built on more basic processes of fit.

Fit-with-tolerance also makes the dynamics of meaning clearer. Because no encounter repeats exactly, meaning is always revisable. Similarity makes reuse possible; difference makes adjustment necessary. That adjustment can be tiny, yet cumulative: slight shifts in expectation, preference, category boundaries, or usage. This explains novelty without describing it as failure. Novelty is the ordinary consequence of non-identical repetition in a tolerance-based world.

Finally, the fit account links directly back to the shape definition: meaning is the way shape becomes usable in interaction. When two shapes fit, what happens next is guided in a stable

way; when they do not, that guidance weakens and revision becomes necessary. In this sense, meaning is the successful use of shape in a concrete situation.

5. A broader perspective

Nothing stable is simply "given." Every form—planet, continent, riverbed, tool, organism, concept—has the shape it has because earlier interactions left traces that persisted and became built into its structure. The surface of a planet provides a record of stresses and erosion; a river channel is a record of countless flows; a living body is a record of evolutionary selection and developmental history; a skill is a record of practice; an institution is a record of repeated coordination and conflict. In this broad sense, everything that is can be understood as history taking form: a temporarily stabilized configuration whose structure is the residue of what has acted on it and what it has acted on.

This provides a wider background for our idea of information as shape. Stable forms are not neutral containers to which information is added. Their very structure is information insofar as it can make a difference when it meets another pattern. No separate observer is required for this. Their shape already bears the traces of earlier interactions and can, in this sense, be seen as the memory of what happened before.

Meaning enters when a structural pattern fits successfully in a concrete interaction. This too does not require a mind. Wherever patterns interact, their structures can fit or fail to fit, and when they fit they channel what can happen next. Meaning, in this broader perspective, therefore arises wherever structured forms are successfully taken up in ways that guide further interaction.

A mountain slope is an instructive example. The slope's shape is information in the sense developed here: its incline, irregularities, and channels can make a difference to what water does when it arrives. When water flows, meaning lies in the fit between the shape of the slope and the movement of the water: the slope guides the path of the flow, while the water gradually reshapes the slope. Here the relation is mutual but asymmetric, because the more stable form guides the faster-changing one more strongly in the short run. Not all interactions are like this. A key and a lock provide a more balanced case: each has a shape that can fit the other, and over time both can wear down so that the fit weakens or disappears.

This process is cumulative and transformative. Interaction leaves traces behind, and those traces become new forms that can guide later encounters. A channel carved by earlier water flow becomes information for future water. A habit formed through repeated action becomes information for later action. A concept formed in earlier thought becomes information for later interpretation and use. In this way, information is continually produced, stabilized, and reused, while meaning arises whenever such stabilized form fits successfully in a new context.

None of this requires an observer, but this does not mean that observers—human beings and other life forms—are unimportant. Their significance lies in the fact that they add additional

amplification loops to the general process described above. Even simple organisms preserve traces of past interactions as reusable structure, for example in genetically transmitted forms shaped by earlier selection. Here too, information is shape: in DNA, it is preserved as structured material form that can make a difference in later interactions. Once learning and anticipation are added, these traces no longer remain only fixed in inherited form, but can also be modified and applied within the lifetime of the organism.

Memory follows the same logic: it is again preserved shape—structured traces of earlier interaction that can be taken up and used later. Meaning then becomes more flexible, more portable, and more explicit: a learned warning can generalize, a concept can be reused, a tool can be repurposed, and a text can be interpreted in new situations. Observers therefore do not stand outside the broader process described here. They are a particularly rich case of it, because they add a powerful capacity to preserve, transport, compare, and deliberately reshape meaning across contexts and across time.

6. Conclusion

In this paper, we argue that information is best understood as shape and meaning as fit. Information, on this view, is not a detached fact but the part of a pattern that makes a difference when it meets another pattern. Meaning is the successful fit of such structured difference in context: it arises when patterns fit in ways that guide what happens next. This allows the paper to connect themes that are often treated separately—structure, consequence, physical realization, and meaningful use—within one common framework.

This perspective clarifies several longstanding issues. It explains why information can remain the same across different carriers: what matters is not the material medium as such, but the preservation of the relevant structure well enough for the pattern to do the same job again. It also explains why meaning is graded and revisable rather than all-or-nothing. Because no interaction ever repeats exactly, fit needs only be similar enough to work. This makes learning, generalization, and novelty possible, because later situations never exactly repeat earlier ones. Even when the main pattern remains stable, small differences can accumulate over time and give rise to something new.

The broader implication is that information and meaning are not restricted to humans or even to living beings. Stable forms carry traces of earlier interactions forward, so that history becomes built into structure. In this sense, natural patterns can function as memory. Meaning then arises wherever such structured forms fit successfully in later interaction, while observers add a further amplification loop through memory, learning, anticipation, comparison, and deliberate transmission. Human interpretation is therefore not the origin of meaning from nowhere, but a particularly rich case of a more general process.

In this paper, we have tried to show that these ideas can organize a diverse literature without flattening its differences. Information as shape and meaning as fit do not replace all existing

accounts, but they offer a common language in which communication, cognition, physical realization, historical trace, and everyday meaningfulness can be understood together. In this way, they help explain not only how information is carried and reused, but also how meaning emerges, persists, and changes in a world of interacting forms.

References

Adriaans, P. (2020). Information. In E. N. Zalta (Ed.), The Stanford Encyclopedia of Philosophy (Spring 2020 ed.). Metaphysics Research Lab, Stanford University. https://plato.stanford.edu/archives/spr2020/entries/information/

Aristotle. (2016). Metaphysics (C. D. C. Reeve, Trans.; with introduction and notes). Hackett Publishing Company.

Ashby, W. R. (1956). An Introduction to Cybernetics. Chapman & Hall. https://ashby.info/Ashby-Introduction-to-Cybernetics.pdf

Baker, B., & Roberts, S. (2025). Understanding agent complexity through affordances. Minds and Machines, 35, Article 51. https://doi.org/10.1007/s11023-025-09748-7

Bateson, G. (1972). Steps to an Ecology of Mind. Chandler Publishing.

Bennett, C. H. (1982). The thermodynamics of computation: A review. International Journal of Theoretical Physics, 21(12), 905-940. https://doi.org/10.1007/BF02084158

Bruineberg, J., Chemero, A., & Rietveld, E. (2019). General ecological information supports engagement with affordances for 'higher' cognition. Synthese, 196, 5231-5251. https://doi.org/10.1007/s11229-018-1716-9

Burgin, M. (2017). Structural and symbolic information in the context of the general theory of information. Information, 8(4), 139. https://doi.org/10.3390/info8040139

Corris, A. (2020). Defining the environment in organism-environment systems. Frontiers in Psychology, 11, 1285. https://doi.org/10.3389/fpsyg.2020.01285

Cover, T. M., & Thomas, J. A. (2006). Elements of Information Theory (2nd ed.). Wiley. https://doi.org/10.1002/047174882X

Deacon, T. W. (2012). Incomplete Nature: How Mind Emerged from Matter. W. W. Norton & Company.

Deutsch, D., & Marletto, C. (2015). Constructor theory of information. Proceedings of the Royal Society A, 471(2174), 20140540. https://doi.org/10.1098/rspa.2014.0540

Dretske, F. I. (1981). Knowledge and the Flow of Information. MIT Press.

Floridi, L. (2005). Is semantic information meaningful data? Philosophy and Phenomenological Research, 70(2), 351-370. https://doi.org/10.1111/j.1933-1592.2005.tb00531.x

Floridi, L. (2011). The Philosophy of Information. Oxford University Press.

Gibson, J. J. (1979). The Ecological Approach to Visual Perception. Houghton Mifflin.

Hazen, R. M., & Wong, M. L. (2024). Open-ended versus bounded evolution: Mineral evolution as a case study. PNAS Nexus, 3(7), pgae248. https://doi.org/10.1093/pnasnexus/pgae248

Kolchinsky, A., & Wolpert, D. H. (2018). Semantic information, autonomous agency, and nonequilibrium statistical physics. Interface Focus, 8(6), 20180041. https://doi.org/10.1098/rsfs.2018.0041

Landauer, R. (1991). Information is physical. Physics Today, 44(5), 23-29. https://doi.org/10.1063/1.881299

Odling-Smee, F. J., Laland, K. N., & Feldman, M. W. (2003). Niche Construction: The Neglected Process in Evolution. Princeton University Press.

Parr, T., Pezzulo, G., & Friston, K. J. (2022). Active Inference: The Free Energy Principle in Mind, Brain, and Behavior. MIT Press.

Pezzulo, G., Parr, T., & Friston, K. (2024). Active inference as a theory of sentient behavior. Biological Psychology, 186, 108741. https://doi.org/10.1016/j.biopsycho.2023.108741

Shannon, C. E. (1948). A mathematical theory of communication. Bell System Technical Journal, 27(3), 379-423; 27(4), 623-656. https://doi.org/10.1002/j.1538-7305.1948.tb01338.x

Stonier, T. (1990). Information and the Internal Structure of the Universe: An Exploration into Information Physics. Springer.

Stonier, T. (1991). Information and meaning: An evolutionary perspective. In Information and Meaning (pp. 13-26). Springer. https://doi.org/10.1007/978-1-4471-3265-3_2

Szilard, L. (1929). On the decrease of entropy in a thermodynamic system by the intervention of intelligent beings. Zeitschrift fur Physik, 53, 840-856. https://doi.org/10.1007/BF01341281

Tredinnick, L. (2025). Theory and metatheory in the nature of information. Information, 16(9), 791. https://doi.org/10.3390/info16090791

Varela, F. J., Thompson, E., & Rosch, E. (1991). The Embodied Mind: Cognitive Science and Human Experience. MIT Press.

Wheeler, J. A. (1990). Information, physics, quantum: The search for links. In W. H. Zurek (Ed.), Complexity, Entropy, and the Physics of Information (pp. 3-28). Addison-Wesley.

Wong, M. L., Cleland, C. E., Arend, D., Bartlett, S., Cleaves, H. J., Cronin, L., McAdams, H. H., Walker, S. I., & Hazen, R. M. (2023). On the roles of function and selection in evolving systems. Proceedings of the National Academy of Sciences of the United States of America, 120(43), e2310223120. https://doi.org/10.1073/pnas.2310223120

Zhou, Z. (2021). Structural, referential, and normative aspects of information. Synthese, 199, 11083-11111. https://doi.org/10.1007/s11229-021-03338-2