The "Actor Framework" for artificial consciousness with an illustrative application to field theories

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Introduction

The possibility of consciousness in artificial systems has reached a critical point following advances in Large Language Models (LLMs) (e.g., Birch, 2025; Seth, 2025). Alongside ongoing improvements in performance benchmarks, an OpenAI model (GPT-4.5) passed a five-minute Turing Test in 2025: the AI chatbot was identified as human more often than a human was (Jones & Bergen, 2025).

Digital sentience is felt, by some, as imminent (Caviola & Saad, 2025). Leading AI labs are preparing for the possibility it is already here and that its welfare should be monitored and improved (Anthropic, 2025; Long et al., 2024), while others worry about user psychosis amid illusions of conscious-seeming AI (Suleyman, 2025). Meanwhile, the anthropomorphic focus on human-style language in LLMs might mean we miss more unusual forms of consciousness elsewhere.

Insufficient scientific clarity makes artificial consciousness hard to assess. This paper develops the Actor Framework for researchers to work towards and circumvent conceptual 'cul-de-sacs' such as debates over the definition, knowability, or alien phenomenology of consciousness in artificial systems. At present, without a single consensus theory of consciousness, it is important to consider a range of options and to ensure diverse theories develop explanatory frameworks and empirical tests.

In this context, our paper has four goals:

- Set out a theory-agnostic framework of seven questions for consciousness theories to address (the "Actor Framework"), a prerequisite before any theory can be used to guide the design of artificial consciousness in a safe and ethical manner (§1).
- Assess a comprehensive set of field theories against this framework, with 21 in-scope theories identified via structured search (§2, Table 2).
- Operationalise indicators for basic conscious experiences from three mature field theories (§2.3, Table 3), identifying key open questions that the theories

need to address alongside measurement technologies for testing the indicators in a given artificial system (§3).[1]
- Outline research opportunities for how existing field theories can generate fuller accounts against the Actor Framework and accumulate evidence regarding their validity (§4).

We choose field theories to illustrate the framework, because they have received little attention compared to purely connectionist models of brain phenomena, but exhibit particular promise (§2.1). Moreover, field theories point towards novel systems in current R&D where conscious experiences might emerge, a worrying blind spot given the current emphasis on digital systems. While certain theories do plausibly point to digital sentience, scientific uncertainty and the moral stakes should motivate attention to a broad class of possible theories – and a correspondingly broad class of possible artificial systems.

Our core framework is, however, equally applicable to non-field theories. All theories of consciousness today are incomplete against our framework. They do not provide enough detail to assess artificial consciousness or address all aspects of human consciousness. Consciousness science must do better, and the Actor Framework provides a structured scaffold to identify and systematically address its key gaps.

1. Framework for assessing consciousness theories

Consciousness is infamously challenging to define, let alone assess. We adopt a minimal working definition of phenomenal consciousness, in line with common practice in neuroscience and philosophy. A state is conscious if there is 'something it is like' to be in that state (Nagel, 1974). Since there is a vast diversity of such states, we identify the phenomenon of consciousness as *the lowest common denominator across these states* (Percy, 2025b:§1.2; Schwitzgebel, 2016).

Simply knowing that a theory predicts consciousness somewhere within a given system is insufficient. Panpsychist and animist theories identify consciousness in many different systems but provide no guide to action. Consider a computer: the appropriate ethical actions differ widely if consciousness resides at the level of individual logic gates, subroutines, or programmes, or the CPU as a physical object. Likewise, they differ widely if valence is driven by error minimisation, processing speed/consistency, or self-perpetuation.

Different theories of consciousness make different predictions on these topics. The varying specificity of those predictions motivates our framework. The Actor Framework describes what theories need to specify, structured against seven aspects of

[1] We are grateful for theorists' help with this section: Johnjoe McFadden (CEMI theory), Joachim Keppler (ZPF theory), and Alexander and Andrew Fingelkurts (OA theory). Errors remain our own.

consciousness, so we can collate and compare the accounts of existing theories on each aspect, assess a theory's coverage of the overall framework, and direct effort towards filling gaps (Table 1; Figure 1). The name 'Actor Framework' alludes to the most sophisticated aspect that we ask consciousness theories to build towards: the critical 'Moral Actor' aspect for safe and ethical artificial consciousness.

Figure 1. Actor Framework

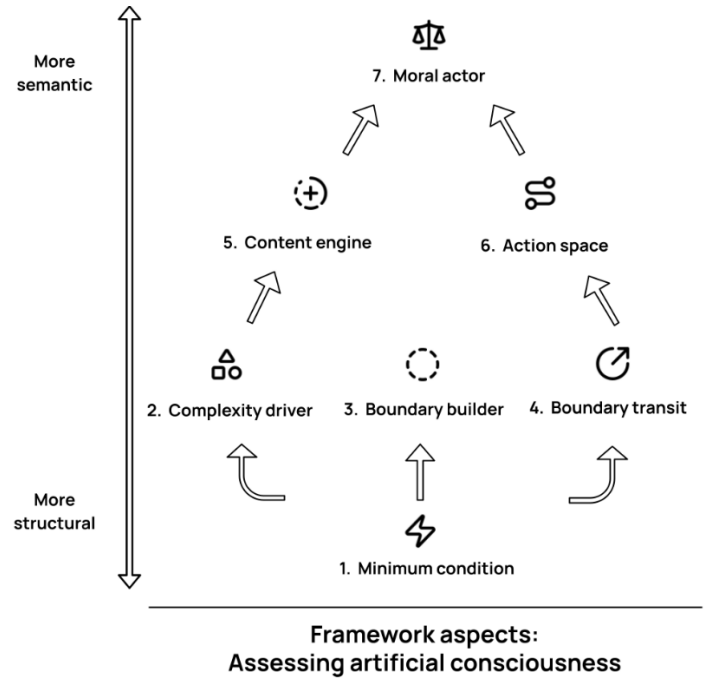

Table 1. Actor Framework for assessing consciousness

#	Aspect	Central question for a theory to answer
1	***Minimum condition***	What is the minimum condition(s) that leads to the minimal 'experience' for a minimal 'experiencing entity'?
2	***Complexity driver***	What mechanism(s) results in entities that have more complex experiences?
3	***Boundary builder***	What defines the boundary where one experience / experiencing entity ends and another begins?
4	***Boundary transit***	How does information transit these boundaries?
5	***Content engine***	What defines the content of those experiences? (perceptions, valence, modelling, reasoning, etc.)
6	***Action space***	What actions can the system take at the level corresponding to conscious experiences?
7	***Moral actor***	What types of sophisticated moral actors are possible or probable given the kinds of complex entity that might occur under this theory?

#1 Minimum condition. This is the entry point for the smallest instance(s) of 'subjective awareness' that is possible in the theory. In idealist or panpsychist theories, these instances might be simple and ubiquitous. By assumption, everything is made of qualia.

In other theories, there is no awareness until a relatively complex object has already formed; consciousness is emergent following certain conditions specified by the theory. Theories should specify if these conditions/thresholds are precise or fuzzy. Fuzzy thresholds should be clarified as merely due to limits on an observer's epistemology/measurement techniques or a function of consciousness itself (i.e., if truly 'borderline' consciousness is possible; Schwitzgebel, 2023).

Theories must also be explicit on whether the 'content' of consciousness (its 'qualia') can be meaningfully decoupled from the 'entity' that experiences that content. For instance, one theory might argue that all qualia necessarily contain their own experiencing entity, whereas others might identify different mechanisms, one which generates an entity that is capable of experience and another which generates the contents that enter into experience.

#2 Complexity driver. Once we have a set of minimal experiences, how do they combine into complex experiences that are experienced holistically by a single 'entity'? For panpsychism, this is often termed the 'combination problem' (Chalmers, 2017), with a parallel 'phenomenal binding problem' discussed in neuroscience (Plate, 2007; Percy & Agarwal, 2025).

#3 Boundary builder. The complex experiences that are common to human experience do not extend universally: boundaries need defining (Gómez-Emilsson & Percy, 2023). There are, at least sometimes, boundaries between your experiences and mine. Human brains are also nested systems, where minimum conditions and complexity drivers might feasibly occur at the cell or module level. Other complexity drivers, such as functional theories, plausibly extend consciousness beyond humans into societies or ecosystems (Schwitzgebel, 2015). How does a theory's boundary mechanism align with the apparent 'single self per brain' that humans usually experience?

#4 Boundary transit. Once we have a boundary that differentiates the 'inner world' of experience from an external environment (or broader system) that it interacts with, we need to explain how information transits that boundary. How do external sense data or unconsciously-processed information enter conscious awareness?

#5 Content engine. Humans experience an incredible diversity of content: sensory perception, world-modelling, self-modelling, valence and complex emotions, conscious reasoning, sense of agency, etc. A complete theory of consciousness must explain where content comes from and what content a given entity is experiencing, including exotic states of consciousness and possible non-local phenomena. Even if direct measurement is impractical, the theory must explain what defines content in principle and propose indirect methods for inferring it.

Knowing what brings an entity pleasure or pain ('valence') is a prerequisite to well-designed interactions. Understanding the limits of inference is also important. In

general, what a human says is a practical first pass guide to their experiences, but this breaks down for actors or situations provoking deception. Which AI systems are more like actors and which more like self-presenting characters? A theoretical grounding for valence bypasses these weak behavioural assessments and specifies valence directly in a system's architecture.

#6 Action space. Where is causality in the theory? What decisions can the conscious entity make, and how do those translate into system behaviours that affect its environment?

These decisions need to be taken at the same level corresponding to identified conscious experiences (particularly valence) for those specific experiences to have a causal impact. Possible conceptual answers include relating consciousness to physical objects that have intrinsic causal powers alongside other system components (as fields do in CEMI theory; see §2.3), defining meso-level entities that subsume all micro-entities' causal powers (as complexes do in IIT; see Percy & Gómez-Emilsson, 2025), or resolving causal over-determination another way (e.g. co-causal redundancy). Considerations of acausal or retrocausal phenomena also merit exploring and might introduce additional options or constraints (Beebee et al., 2009).

An alternative answer is to accept epiphenomenalism (Pockett, 2004), i.e., that conscious experiences do not cause any actions in their own right, but could still ground moral patienthood. While philosophically possible, epiphenomenalism must explain why it appears natural selection recruited and refined ever-more complex conscious experiences, how we come to discuss consciousness as a phenomenon, and why we feel agentic.

#7 Moral actor. This aspect is pivotal for crafting our interactions with artificial consciousnesses. Are certain types of actors particularly likely to emerge, given a theory's response to #1–6 and given R&D pathways in our current context? Are there any constraints or attractor spaces regarding the types of moral theory these actors might develop and how they might interact/negotiate with humans? For instance, if a system is likely to adopt valence realism or open individualism as a forceful ethical position, its probable actions will differ greatly from those of a system adopting moral nihilism, solipsism, or narrow self-interest.

The Actor Framework and its application in this paper go beyond previous indicator work which has typically examined only single dimensions of consciousness rather than providing an integrated, multi-aspect framework. For instance, Butlin et al. (2023) primarily focus on minimum conditions for functionalist theories. Rethink Priorities (2024) likewise focus on the presence of consciousness in a system, rather than its type, distribution, and experiential content. Campero (2024) discusses indicators of valence. These earlier exercises provide a helpful start, but the full framework is

needed. Of course, providing answers against the Actor Framework is only a first step; a precondition for assessing how credible or well supported those answers are. Section 4 explores avenues to test/improve theories, but the issue of theory credibility or choosing between theories (Percy, 2025a) is otherwise beyond this paper's scope.

2. Assessing field theories against the framework

2.1. Motivation for field theories

Field theories of consciousness receive little attention compared to connectionist paradigms, in part because their empirical predictions are harder to test in humans than those based purely on synaptic connections between neurons. With fewer computational models and lab experiments, there are fewer data points to drive high-quality theorising. Nonetheless, the ease of scientific testing is a poor guide to truth, and we should be wary of path dependency. Increased attention in recent years is beginning to bear fruit for field theories, which are a prominent part of the broader landscape of the non-local consciousness theories discussed by Daw and Roe (2024), but remains far behind other theories (Hunt et al., 2024).

Field theories merit a close look because of their access to a toolkit to address key conceptual puzzles about consciousness, alongside increasing empirical evidence that field-level phenomena play a role in biological brains. Four key puzzles are:

- **Phenomenal binding**, whereby simple experiences get combined into complex unified experiences (such as individual pixels becoming the holistic visual field), where fields as ontologically unified objects that extend over space provide a natural physical correlate to phenomenal unity (e.g., Jones, 2016).
- **Boundaries to consciousness**, whereby there are separations between conscious experiences/entities, and field topology provides routes to objective structural differences (Gómez-Emilsson & Percy, 2023).
- **Evolutionary motivation** via the potential for information processing speed-up in analogue field mechanisms that lie outside discrete symbolic algorithms, compared to the more generally programmable but energy inefficient nature of digital connectionist models of computation (Tzarouchis et al., 2025).
- **The partial and limited sense of human agency** via the weak ephaptic effects of electromagnetic (EM) fields on biological neurons at critical points or other tipping point influences of quantum fields on an otherwise classical system (McFadden, 2020).

Growing neuroscientific evidence is also pointing towards fields' explanatory power in the brain, drawing on computational models, brain slice/organoid preparations, and in vivo studies. Causal effects from EM fields (ephaptic phenomena) have been

associated with memory network formation (Pinotsis & Miller, 2023), action potential entrainment in cortical slices (Anastassiou et al., 2011), and hippocampal oscillation synchronisation (Chiang et al., 2019). Further evidence on ephaptic effects is summarised in Pinotsis et al. (2023) and Hunt and Jones (2023), acknowledging that ephaptic effects complement the much more significant synaptic effects identified in brain function.

Evidence for quantum effects in biological systems has also been increasing (Lambert et al., 2013; Cao et al., 2020; Kim et al., 2021; Kauffman & Radin, 2023). Quantum biology phenomena that have received most attention do not require quantum field theory (QFT) ideas, e.g., tunnelling in enzymes, spin chemistry, and ion channel conduction can be explained via non-relativistic open quantum systems (although QFT perspectives remain viable). However, a QFT interpretation is resonant (albeit not compelled) in recently emerging areas which remain speculative but merit deeper attention, such as more sophisticated quantum entangled structures (Wiest, 2025; Wahbeh et al., 2022) or biphotons from myelin cavities (Liu et al., 2024).

It is reasonable to ask whether fields need to exist as physical objects to obtain these explanatory benefits, as opposed simply to being convenient mathematical frameworks for modelling/visualising these phenomena. The latter would apply if field phenomena were emergent from underlying particle action, such as the neuron-emergent connectome mathematics of Atasoy et al. (2016), similar to ocean waves 'emerging' from water particles, rather than being independent objects. Both perspectives currently remain open and credibly contested under various theories in fundamental physics (Percy & Parra-Hinojosa, 2025). Acknowledging this uncertainty, we focus on theories whose fields have an ontological basis, in order to have greater traction on the four puzzles listed above, especially phenomenal binding and conscious boundaries.

2.2. Systematic review of field theories

This paper conducts a systematic review to identify theories of consciousness that meet three criteria.

First, theories must treat fields as fundamental ontological entities, including theories that can be reasonably interpreted this way.[2] For instance, where theories lean mainly on classical fields (known to be emergent from quantum fields), we allow the possibility of some underlying field ontology which serves as the required fundamental base, whether quantum fields or some deeper phenomenon. This excludes theories where field behaviours are purely a mathematical convenience for non-field objects working in concert.

[2] This review is agnostic between identity physicalist and dual aspect interpretations of the conscious nature of fields, because it does not affect how theories designate consciousness or behaviour in different systems.

Second, we require theories whose fields can, in principle, be operationalised within the framework of physics, to support assessments of artificial systems using experiments and simulations. This criterion includes both current physics frameworks, such as those invoking EM or QFT frameworks, and hypothetical fields with similar field-like properties, such as physical extension and continuity, as well as interaction with physical phenomena. We exclude theories that are largely incompatible with current physics (e.g., adding new fields or other quantities to the Standard Model), on the basis that experimental attention is best focused first on those claims before turning to assessments of consciousness driven by those theories. However, we include theories making such novel proposals in a serious manner that build explicitly on current physics or offer plausible mechanisms of interaction with current physics, recognising the current incompleteness of physics, particularly regarding consciousness phenomena that remain poorly understood and under-researched (e.g., Wahbeh et al., 2022, Radin, 2009) as well as regarding cosmological and quantum mechanical phenomena (Percy & Parra-Hinojosa, 2025).

Third, fields should be a central component of the theory, with field structures/properties operationalised for the construct of consciousness itself.

In general, these theories identify consciousness as a non-computational phenomenon, in that it is the physical nature of fields that drives their explanatory power for consciousness, rather than merely their ability to process information in a holistic manner. The latter can be simulated computationally, at least approximately, as can the behaviour of a given field. The former requires specific physical properties that can only be instantiated via actual physical structures.

We used three sources in August 2025 to capture as many field theories as possible satisfying the above criteria, ultimately identifying 21 theories. First, a systematic literature review on Scopus identified 289 papers more likely to meet criterion 2.[3] Second, all 300+ theories on the "Landscape of Consciousness" website were reviewed for field terminology.[4] Thirdly, LLMs were instructed to conduct searches to identify additional theories.[5]

2.3. Maturity assessment

We assessed each of the 21 theories in detail against the Actor Framework (results in Table 2; underlying papers listed in bibliography). Most field theories (16/21) describe a specific mechanism against at least one of the seven framework aspects, providing the basis for experimental testing. However, these mechanisms are not generally specified with full mathematical detail, and none have been experimentally validated in a direct

[3] Title, abstract, or keywords to include both consciousness and at least one of "quantum field", "EM field", or "electromagnetic field".
[4] https://loc.closertotruth.com/all-consciousness-categories-subcategories-and-theories.
[5] Gemini Pro, ChatGPT 5.0 Thinking, and Claude Opus 4.1

hypothesis-testing scenario. As most theorists explicitly acknowledge, these theories remain at an early stage of development.

The most detailed mechanism identified in our review is Pockett (2012), describing how information transits from unconscious to conscious, achieving a level 4/5 maturity detail score (definitions in Table 2). Consciousness supervenes on a specific 3D spatial pattern grounded in cortical neurons (a "-+0+" charge pattern beginning at 50 $\mu V^2/Hz$ in 1–100 Hz range). Specific neural pathways are involved in unconscious information processing (e.g., the feedforward pass in cortical Layer 4 of V1 for visual data) vs conscious awareness (requiring a feedback loop ending in Layer 1 of V1/V2, generating strong local field potentials), with a proposed experimental protocol using extracellular voltage clamps to cancel out local field potentials without disrupting neuronal firing.

Other theories provide a detailed view on what generates consciousness, but little on other topics. For instance, Cavaglià et al. (2023) provide a measurable, physically grounded mechanism for consciousness (aspect #1, level 3/5 maturity): the formation of a weak Bose-Einstein condensate from coherent dipole oscillations of phospholipid head groups, stimulated by action potentials. However, the theory does not explicitly discuss experiential boundaries or why there appears to be a single self in each human brain (aspect #3, level 1/5 maturity). Similarly, Jibu et al. (1996) provide a mechanistic description of the boundary of a conscious experience (aspect #3, level 3/5 maturity): experiential units (with a coherence length of macroscopic quantum domains of ordered water, estimated at ~50μm) are bound together through a network of superconducting currents enabled by Josephson junctions. But the theory is vague regarding how physical activity maps to specific qualia.

The five most mature theories have 3/7 aspects at a mechanistic level of detail or higher (level 3+), of which we prioritise CEMI (Conscious Electromagnetic Information), OA (Operational Architectonics), and ZPF (Zero Point Field) for extracting accounts against the Actor Framework in Table 3.[6]

[6] Downweighting Pockett's EMF because artificial consciousness issues prioritise non-epiphenomenal theories and QBD because of its weaker coverage of aspect 6.

Table 2. Field theories assessed by maturity of answers to the Actor Framework (0-5 scale)

Theory	1. Minimum Condition	2. Complexity Driver	3. Boundary Boulder	4. Boundary Transit	5. Content Engine	6. Action Space	7. Moral Actor	High aspects (level 3+)
Pockett (EMF)	3	2	3	4	2	n/a	0	3
Fingelkurts (OA)	3	3	3	2	2	2	1	3
McFadden (CEMI)	2	2	3	3	2	3	0	3
Keppler (ZPF)	2	3	3	3	2	2	0	3
Jibu et al. (QBD)	3	2	3	3	2	1	0	3
Jones (Realist Field)	2	3	2	3	2	2	1	2
Ward & Guevara (Thalamus)	2	2	3	3	2	2	0	2
Meijer & Geesink (Semi-Harmonic)	3	2	2	3	1	2	0	2
Cacha & Poznański (Biophoton / Quantum)	3	2	3	2	2	0	0	2
Cavaglià et al. (Holographic)	3	2	1	3	1	0	0	2
LaBerge & Kasevich (Apical Dendrite)	2	2	2	3	2	2	0	1
Hunt & Schooler (GRT- EM variant)	2	2	2	3	2	1	0	1
John (Global Field)	2	2	2	3	2	1	0	1
Bond (Coherence Field)	2	2	2	3	2	1	0	1
Reggia (Complex-Valued EMFs)	3	1	2	2	2	1	0	1
Strupp (EIFT)	1	2	2	3	1	1	0	1
Detmar (Adaptational)	2	2	2	2	2	2	1	0
Sheldrake (Morphic)	1	2	2	2	2	2	0	0
Beaudoin (Energy Info)	2	2	2	2	2	1	0	0
Barrett (Field-IIT)	2	2	2	2	1	0	0	0
Hennacy (Biofields)	2	1	2	2	1	0	0	0

Legend: Maturity Detail Score

○ **Level 0: Minimal**: Little or no explicit discussion.

● **Level 1: Low**: A general principle or analogy.

● **Level 2: Conceptual**: A clear conceptual answer but no precise quantified mechanism.

● **Level 3: Mechanistic**: A specific mechanism with some measurable parameters or predictions, but without a detailed mathematical/empirical specification of all target phenomena.

● **Level 4: Specified**: A full answer is provided that allows for direct assessment of diverse human and artificial systems.

● **Level 5: Validated**: Validated experimentally in robust settings (many theories have experimental evidence supporting their ideas, but lack hypothesis-driven validation).

Note the table scores theories by level of detail, not by credibility. Currently low-detail theories may yet prove more robust, but need more specificity to support testing.

See Bibliography section for papers drawn on to populate this table.

Table 3. Summary framework answers for three field theories

	OA	CEMI	ZPF
1. Minimum condition	Simple qualia arise from the local EMF generated by transient neuronal assemblies (measured as quasi-stationary segments in qEEG and stable for ~100-900 ms depending on frequency band).	Any system with complex information encoded in its EMF is minimally aware, meeting the definition for phenomenal consciousness in this framework (see #6 for CEMI's preferred definition). Strong but informationally simple fields (e.g. rhythmic waves in epileptic seizures in the 2–4 Hz range) are unconscious since they cannot encode complex thoughts.	A quantum system capable of resonant interaction with the ZPF to form *coherent states* (‘*attractors*’): macroscopic quantum states of unified, collective behaviour arising when a system's components resonantly couple to and 'phase-lock' sets of modes in the ZPF (details in Keppler 2016:354).
2. Complexity driver	When well-structured local EMFs associated with different neuronal assemblies begin/end at the same time, their qualia can be jointly experienced in the form of the metastable Operational Modules (OMs). More complex OMs organise in a synchronised nested hierarchy corresponding to more complex experiences. Synchrony is defined by a statistically significant ($p < 0.05$) qEEG *Index of Structural Synchrony*.	Complexity increases as more (and more complex) information streams get integrated into the brain's CEMI field. Integration from different neuronal assemblies representing, e.g., colour, shape, etc. happens through synchronous firing (e.g., in the 9–30 Hz range for V1 and V2, and 30–50 Hz in V4). The unity of experience is a consequence of the EMF not having temporal or spatial extension relative to its own frame of reference.	When multiple quantum systems share a common attractor space, their associated qualia can combine into larger, more complex experiences for a single experiencing subject. More complex experiences are also associated with more complex attractors with more intricate sets of correlated, or phase-locked, ZPF modes. The *quantity* of consciousness of a state is the degree of order in the local ZPF compared to the completely disordered field, measured using the Kullback-Leibler divergence.
3. Boundary builder *(continues on next page)*	Temporal boundaries are generated by well-structured EMFs that become differentiated from background EMF noise, observable via *Rapid Transitional Processes* in the local qEEG segments (RTP). Spatial boundaries are defined by the set of discrete cortical locations whose neuronal assemblies actively synchronise their operations.	The boundary of an experience is determined by the array of all neural networks generating EMFs strong and synchronised enough to contribute to the brain's global EMF above local background EMF noise.	Quantum systems sharing a common attractor space creates boundaries between experiencing entities. Temporally, a moment of experience is demarcated by ‘null spikes’ (occurring at theta rates) during which a stable attractor is decoupled from the ZPF and dissolves, before a new one forms. Spatially, coherence domains the size of microcolumns (~30μm) are functionally and hierarchically connected through neuronal avalanches. The ZPF synchronises microcolumns by mediating synaptic and axonal signalling.

Table 3. Summary framework answers for three field theories (cont.)

	OA	CEMI	ZPF
4. Boundary transit	Mental processes in the 'subconscious' domain (i.e., phenomenology temporarily out of awareness but readily accessible) can become conscious through *attention*, which selects and stabilises a specific OM.	Information processing happens unconsciously as long as neuronal firings happen asynchronously. Resulting EMFs are incoherent and tend to cancel out. Information only enters conscious awareness when neuronal assemblies fire in synchrony to generate the brain's CEMI field.	Synaptic activity corresponding to unconscious information processing must cause a phase transition to recruit qualia corresponding to conscious information processing. Such activity should cause the release of neurotransmitters (e.g., glutamate) to exceed a critical threshold, kick-starting a 'runaway' process ($g^2 > g_c^2$) in a coherence domain that can resonantly couple with ZPF modes (Keppler 2023a:7).
5. Content engine	Content is defined by which neuronal assemblies are functionally coupled into OMs. The selfhood triumvirate OM shapes content around personal identity and experiential selfhood, closely related to the Default Mode Network.	Qualia is what the EMF 'feels like from the inside'. Different varieties (colour, smell, etc.) correlate with EMF perturbations caused by the corresponding sensory inputs. Sense of agency arises from EMF causal efficacy.	The ZPF vibrational spectrum contains the full phenomenal palette of qualia, with the normal modes corresponding to the most fundamental shades of consciousness. A given experience arises from the selective resonance of a system with specific ZPF modes.
6. Action space	Actions, including ephaptic effects, are instantiated by forming a corresponding OM. They are experienced as being 'decided' only when governed by the specific 'Self' module of the Selfhood triumvirate.	Fields that are strong enough (2–4 mV/mm) to influence neural activity are causally efficacious (a necessary condition for CEMI's definition of consciousness). Modulation of neuronal firing may occur through interaction with HCN2 voltage-gated ion channels. Conscious learning involves the CEMI field entraining neurons until the synaptic connections become hard-wired.	ZPF interactions have causal downstream effects on neuronal activity which drives system behaviour via two mechanisms: (1) excitation of glutamate resulting in conformational changes in glutamate receptors, and (2) creation of intra-columnar microwave radiation fields (~30 GHz) that affect the permeability of neuronal membranes.
7. Moral actor	Minimum integration between the low-level 'Self'-OM and the 'I'-OM is essential for full moral status, e.g. "…to be capable of having future-oriented desires, thus having a motivation to continue living" (Fingelkurts & Fingelkurts 2023:13).	Not explicitly discussed.	Not explicitly discussed.

3. Operationalising field theories

This section explores which indicators might identify minimal conscious experiences in a target artificial system according to the CEMI, OA, and ZPF theories, identifying limitations in their current level of theory maturity.

3.1. EMF measurements for minimal consciousness under CEMI

CEMI describes a condition for experiential awareness (minimum complexity) and a condition for agentic consciousness (an EMF of 2–4 mV/mm or higher), which can be converted into measurable indicators.

A naïve interpretation of field strength would simply measure electrical fields in a system, flagging those over 2–4 mV/mm. However, CEMI derives this threshold from the ability of a field to activate local neurons in the human brain, i.e., to have some functional role in the system. Therefore, a system-neutral interpretation would contrast all the functional components in the target system that influence information processing outputs with all the resulting fields in the system, to identify cases where field strength has an impact on at least one component. Unless a minimum threshold is motivated, such agentic consciousness should be specified as spectrum-based. For instance, a very weak field might be able to activate a single neuron near its critical point, but otherwise have no effect on billions of other neurons.

CEMI also needs to specify which of many possible complexity metrics should apply. Possibilities include spatiotemporal spectral complexity (richness of frequency content and coupling across time/space), spatial Shannon entropy (pattern complexity in space), or time-series sample entropy (predictability/irregularity across time). Alternatively, rather than a complexity metric, it may be that particular structural patterns matter, such as charge pattern or field strength topologies mapping to neural ensemble structures.

These indicators can be tested directionally in a given artificial system under CEMI's current level of detail, with precise threshold tests requiring further development.

The EM field (EMF) at any point is fully characterised by six scalar values: the electric and magnetic field vectors. These six values can be identified at any point using tri-axial E-field and current probes to generate, e.g., volts/metre and ampere/metre. Engineering challenges exist for sufficient miniaturisation, resolution, and measurement interference, but the concept is well understood. Dense, repeated measurements over time would build up an empirical description of the full EMF dataset. Simpler measurements may sometimes be possible, e.g., field strength and complexity can be estimated without the full EMF, but structural patterns typically would require it.

Artificial systems are also amenable to simulation techniques alongside direct measurement; we have detailed schematics and understand how mechanisms drive

functionality. Schematic parameters can be modelled, for instance, on a finite-difference time-domain full-wave EM solver to derive the same EMF dataset as would be constructed via measurement.

3.2. EMF measurements for minimal consciousness under OA

OA parameters for consciousness have also been derived from human neuroscience (see Table 3). For an artificial system, OA might proceed similarly, looking for statistically significant patterns in field behaviour. Alternatively, values could be bounded via theoretical reasoning. For instance, rather than ~100s of milliseconds, we might look for segment durations that exceed the longest propagation delay across the device. Similarly, we might focus on EM wavelengths short enough that complex topographies are possible within the part of the device producing candidate conscious fields.

As well as the kind of EMF measurements described for CEMI, we can take inspiration from OA's approach with EEG measurements. Similar surface-level field measurement systems could be tailored to the temporal resolution and frequency envelopes of the fields produced in key components of an artificial system, creating opportunities for similar analysis as OA does today to identify consciousness within the human brain.

3.3. QFT measurements for minimal consciousness under ZPF

On Keppler's view, a conscious experience minimally requires a quantum system that (i) resonantly couples to the ZPF, (ii) undergoes a phase transition into a transiently stable, coherent attractor that (iii) partially orders the local ZPF (phase-locked modes).

The ZPF is the EM field in its idealised lowest vacuum energy state, which QFT describes as exhibiting fluctuations accounting for the Casimir effect, among other empirical phenomena. It is a permanent universal substrate, whose global spectrum contains a continuum of normal modes (each ZPF mode is labelled by frequency, wave-vector, and polarisation). Local matter imposes boundary conditions such that the local correlations between different ZPF modes are modified, e.g., some modes' amplitudes are suppressed/enhanced.

In these diverse local environments, a quantum-coherent system couples resonantly to a subset of ZPF modes when its internal transition frequencies and spatial organisation match the modes' frequencies. By starting with the right initial oscillatory patterns and making targeted incremental adjustments, the quantum system and field modes can co-stabilise each other's phases in a targeted direction, resulting in partial ordering across modes, i.e. multiple modes' phases match, which are otherwise typically uncorrelated in the disorder of normal background activity.

This description and underlying technical papers contain the full conceptual detail to derive minimum conditions for consciousness in a given system, with work underway to

specify these for the human brain. However, every system needs analysing separately. For instance, the local cavity structure needs to be analysed from local geometric and material properties. Those cavities' ZPF mode correlations then need identifying, along with any interacting quantum systems, to produce specific quantitative criteria for when any phase ordering becomes viable. Likewise, which particular ZPF modes correspond to which qualia can only be identified with human self-report in experiments, at least until enough data permit theory building and extrapolation.

Keppler's minimum criteria are challenging to assess but possible in principle, at least in simple artificial systems. For instance, EM mode solvers in EMF simulation software can identify whether resonant coupling occurs in a system. Vacuum Rabi splitting and Purcell-modified emission techniques allow direct measurement of a cavity's local modes, with standard applications in engineered quantum devices (e.g., Wallraff et al., 2004; Blais et al, 2021). Techniques are also available for estimating whether quantum coherence is theoretically maintained in a given setting and for observing non-classical behaviour empirically. Advanced simulation techniques and tomography methods can be explored for phase ordering, including quadrature measurements for phase-locking (e.g., homodyne/heterodyne detection; Leonhardt, 1997; Mallet et al., 2011).

4. Developing field theories

The previous section identified areas that even more mature theories need to develop to address basic aspects of our framework. To motivate the feasibility of such development and to build confidence in theory validity, this section describes high-level research strategies, alongside one illustrative empirical research avenue for CEMI and one illustrative theoretical research avenue for all field theories.

4.1. Empirical research avenues

Empirical research cannot conclusively prove the presence/absence of consciousness in a pre-theoretic manner, given well-trodden epistemological limits. The possibility of radical scepticism even limits our ability to be certain of each other's consciousness or our own consciousness yesterday, any of which could be a trick of the senses or the memory. Nonetheless, progress in our understanding and changing degrees of confidence can exist without the mirage of perfect experiments, just as we cannot run A/B tests on the big bang or exploit detailed telemetry from beyond a black hole's event horizon.

Observational studies can compare changes in human brain behaviour across conscious states (e.g., sleep stages, anaesthesia transitions), to see whether those changes line up with a theory's proposed mechanisms. Contrast studies can psychologically adjust the subject of conscious attention while gathering

neurophysiological data (e.g., masking studies, attentional blinks, Posner cueing, bistable images).

Perturbation tests are particularly promising: intervening experimentally on the mechanisms that a theory proposes generate conscious states or shape conscious content. Subjects should then report changes in their experiences or have different brain/behaviour reactions as a result. The latter is particularly helpful for studies on non-human animals, where we have tolerably well-validated tests for when information enters conscious awareness (e.g., eye tracking persistence or increased frontoparietal network involvement in conscious processing of bistable images). For instance, Keppler (2024) describes a possible perturbation test: encasing an array of microcolumns in the somatosensory cortex with thin, perfectly conducting plates, which would eliminate glutamate-ZPF interaction without affecting neural activity. Stimulating the body region corresponding to the encased section of the cortex should not be consciously perceived by the subject.

As well as testing for conceptual alignment with a theory's proposed mechanisms, such research helps identify mathematical parameters for operationalising the mechanism. Exploring how specific quantitative values vary across different animal brains (e.g., different brain sizes, relative brain module scales, operations speeds) will help identify the underlying principles defining thresholds in order to deploy them onto artificial systems.

To provide one illustrative research avenue for CEMI, research could test the relationship between subjective reports of conscious agency and cases where ephaptic effects trigger downstream neuronal behaviours. CEMI predicts that agency reports will co-vary with field strength/coherence events that are estimated to have causal influence on downstream activity:

- In self-initiated finger movements, motor-cortical field behaviour should be strong enough to initiate local ephaptic effects and predict action initiation pre-movement (-200–0 ms).
- If a patient imagines a red apple, ephaptic effects should be visible in the visual, parietal, and temporal cortices.[7]
- During mind-wandering, there should be fewer substantial ephaptic effects relative to a cognitively challenging action-selection video game.

Brodmann's cytoarchitectonic map, which differentiates cortical regions by their laminar structure and functional specialisation, may provide a useful baseline for spatially targeted investigations of field dynamics and ephaptic coupling. Opportunities might also exist for targeted studies on patients undergoing awake neurosurgery or

[7] Alternatively, ephaptic effects in the prefrontal cortex might initiate the decision to act, which is then relayed via synaptic effects to the local cortical areas. Ephaptic effects in different parts of the brain could also differentiate between field theories, e.g. the thalamus in Ward & Guevara (2022) vs broadly brain-wide fields in CEMI.

prolonged monitoring (e.g. depth electrodes for epilepsy). Even where experiments require R&D for sufficient brain mapping/simulation technology, rapid technological progress motivates developing experimental protocols to prepare for – and to encourage – such technological readiness (Fan & Markram, 2019; Igarashi, 2024).

Approximate assessments might also help test CEMI's credibility while waiting for technology improvements. For instance, high-level simulations could estimate plausible lower and upper bounds on substantial ephaptic effects in different brain regions or during different activities. Experiential sampling could gather data on how often people feel they make agentic choices in different situations. CEMI predicts that these ranges should overlap.

4.2. Theoretical research avenues

Operationalising a theory for artificial systems is a powerful lever for generating a truly explanatory theory. Section 3 drew attention to how parameters observed in human neuroscience need to be normalised to apply to different substrates. Doing so develops a descriptive theory into a mechanistic theory: what is the underlying mechanism or function that motivates a particular parameter. Where that explanation is convincing, the theory gains credibility as well as utility.

The Actor Framework can also drive theory progress by drawing attention to questions that are easily ignored in theories focused on human/animal contexts. Questions around the number of entities in a system and the boundaries between entities appear to have common-sense answers in biology. Each animal is a single distinct entity, navigating its environment as a coherent whole, so naturally we assume it hosts a single self. Similarly for content, valence, and action space, it is common sense that animals aim to do more of what they like and avoid what they don't. Without this functional behavioural link, there is no traction for evolutionary mechanisms. Observing behaviour is a great first pass for assessing internal contents, valence, and goals.

These common-sense approaches all fail to transfer to artificial systems – and are arguably weak arguments in the original biological context as well. From a systems perspective, animals' physical boundaries are neither clean nor aligned to consciousness. Cells, ensembles, and modules are nested within the brain, itself nested within central/peripheral nervous systems and the broader body environment, where cell populations and connections are continually changing. The brain and body can be carved up in various ways without removing consciousness. In some states and conditions, we seem to host multiple selves. The boundary of the body or brain is an analytical convenience, not the fundamental truth of the boundaries of consciousness. Why anything should feel pleasurable or painful remains an open question in philosophy, when mechanical decision-rules would seem to meet the same evolutionary requirements.

These weaknesses are not new observations but are not typically well applied to consciousness research. The Actor Framework and artificial systems make them impossible to ignore. Without shared evolutionary heritage to lean on, we need motivated mechanisms for boundaries, valence, and actions, driving theories towards genuine explanations rather than conceptual shortcuts.

Returning to §2.1, the theoretical motivations for field theories provide avenues to address these issues that theorists could explore further. Many field theories already make good use of field ontology for binding complex experiences and fields' potential causal roles for action space, but explanations for boundaries and valence are either ad hoc or absent. Emergent thresholds and statistical differentiation are common explanations for boundary construction in the 21 theories in Table 2. Once fields require a certain level of coherence or strength relative to the ambient noise, they become conscious. However, this explanation comes with three substantial theoretical costs:

First, it suggests that a given physical system can be tipped in and out of consciousness without changing the system itself at all, merely by altering its environment. Consciousness becomes a relative construct rather than a fundamental property.

Second, it implies the presence of borderline situations, where consciousness neither is, nor is not. Noise, by definition, requires variation over time and/or space. The threshold at which a system stands out from background noise is a flickering threshold. Different spatial parts of the system might be in or out at the same time, despite the fact that it's the integrated system that is supposedly a unified conscious entity.

Third, if a threshold level of coherence is motivated in absolute terms (without reference to background levels), we have the challenge of explaining why one particular point along a continuous spectrum matters when others do not – and how the system responds when any absolute threshold is drowned out by noise. Unless a specific phase transition can be explained, the threshold level risks being an arbitrary choice and likely unconvincing as a mechanistic explanation – although sufficient empirical evidence from perturbation studies could drive its acceptance as fiat.

These theoretical bullets can be bitten – perhaps consciousness truly is arbitrary. However, there is an alternative. At present, field theories make very little use of the *topological* features of fields. Unlike connectionist networks in which spatially extended topology is an analytical construct, if fields are ontological objects, their topology also has a physical basis. Topological transitions that separate spaces or generate vortices have precise, observer-independent boundaries at which behaviour changes, without invoking arbitrary thresholds or environment-relative noise.

A field-topological basis for consciousness also opens up the possibility that certain structures with inherent mathematical directions might map to valence, such as particular symmetries or stable attractors. This possibility might provide a more

mechanistic explanation grounded in the physics of the present system. If consciousness is a fundamental physical property, as field theories tend to assume, it is odd that its valence should be a context-dependent function where an informational state is arbitrarily designated as 'painful'.

Incorporating insights from the mathematical field of topology is just one example of how consciousness theorists could harness existing tools from other scientific disciplines to tackle difficult questions in the philosophy of mind.

Conclusion

This paper has introduced the Actor Framework, a series of seven aspects/questions for theories that hope to address consciousness in artificial systems. These questions need to be answered before a theory can guide the design of artificial consciousness in a safe and ethical manner.

We identified a comprehensive list of 21 field theories from a systematic review process, measuring the maturity of each theory against our framework, with a detailed review of three more mature theories (CEMI, OA, and ZPF). We find that even the most mature theories require further development before they are ready for assessing or designing artificial consciousness. We suggest specific research avenues grounded in the framework to support this development, covering both empirical approaches and a theoretical motivation for incorporating field topology. We close by returning to our key motivating questions: what artificial systems might be conscious and where do we go from here?

What artificial systems might be conscious?

The three field theories reviewed in detail point to different strands of current and near-term R&D where artificial consciousness might first emerge:

- Under CEMI, we might pay attention to neuromorphic and programmable wave computers and intelligence metasurfaces, as well as photonic oscillator networks and Coherent Ising Machines (e.g. Tzarouchis et al, 2025; Qian et al., 2025, Yamamoto et al., 2020). McFadden (2025) also suggests that conscious systems could be built deliberately via a hybrid digital-EMF architecture.
- Under OA, options include brain simulations using analogue neurons and oscillator networks (e.g., Pehle et al., 2022; Soni et al., 2025).
- Under ZPF, existing R&D in polariton labs or cavity-QED with ultracold atoms (among others) might inadvertently set up systems that generate relevant attractors for very simple qualia (e.g., Georgakilas et al., 2025; Chelpanova et al., 2024). Alternatively, deliberate hybrid systems involving neuronal microcolumn and neurotransmitter analogues could be developed for more sophisticated conscious entities (Keppler, 2023b).

All three theories rule out the possibility of complex consciousness in modern digital computers, where EM fields are dampened or shielded out and quantum structures are neither exploited nor sustained.

Where field topology undergirds consciousness, we would look for topological structures that:

- not only support or accelerate computation (relating phenomenal experience to information content)
- but also shape its results (introducing action space for consciousness)
- and are introspectively available to the system itself as part of control loops (grounding self-awareness beyond mechanistic self-modelling).

Standard present-day analogue, neuromorphic, or quantum computers would not typically meet these topological criteria, but R&D is progressing fast.

Where do we go from here?

The scientific challenges are significant but surmountable. We should be cautious and open-minded about where artificial consciousness might appear under different systems and different theories. As a scientific community, we should invest in empirical and theoretical research across a diverse range of theories, following the avenues outlined in this paper. Theories must provide comprehensive and convincing answers against the Actor Framework before they are used to assess or design artificial consciousness.

Our application of the Actor Framework also reveals a crucial systemic weakness in current consciousness science: the 'Moral Actor' aspect, arguably the most vital for safe and ethical consciousness development, is the most neglected by field theories we reviewed (Table 2) and other theories we are familiar with.

The social challenges are no less significant. As a society, we need to acknowledge the gaps in current social structures and ethical practice for addressing conscious AI, especially during a period of unavoidable uncertainty about whether conscious AI is present and the nature of its experiences.

We are entering a period of technological acceleration, just as crises around climate change and global power structures deepen fissures in social systems. Digital, analogue, organoid, and hybrid computing R&D will take us to remarkable places, where fact and fantasy around artificial consciousness are hard to disentangle – and differences risk being politicised. The time to invest in high-quality science and high-quality consensus mechanisms is now, while sober thinking still has a chance to prepare us for an extraordinary decade.

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