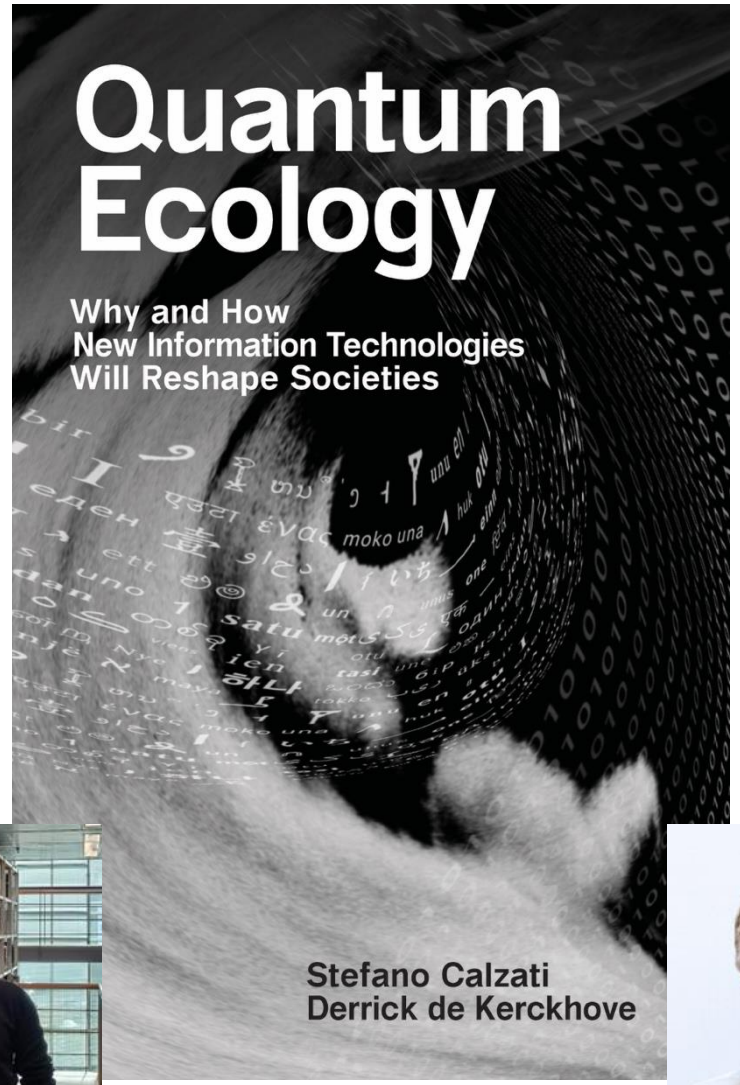


Rethinking Ethics of Technology in the Quantum Age:

An Ultra-Phenomenological Approach to Quantum Sensing

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Quantum Ecology

Calzati & de Kerckhove 2024, MIT Press

Onto-epistemological framework, whose pillars are *uncertainty, complementarity, nonlocality, superposition, entanglement*

Technological paradigm, pivoting around Quantum Information Technologies (QITs)

Ecology as a complex system

- "**An ecology has effects but not causes** in the ordinary sense of a direct relationship between cause and effect."

→complex system showing **emergent behaviours**

- **Complexity is an issue of framing**, "a way of observing systems, not an absolute class of systems." (Gershenson & Heylighen 2003)

→Complexity is a (qubit) **observer-observed entanglement** (Calzati 2026)

3 technological ecologies of sens-making

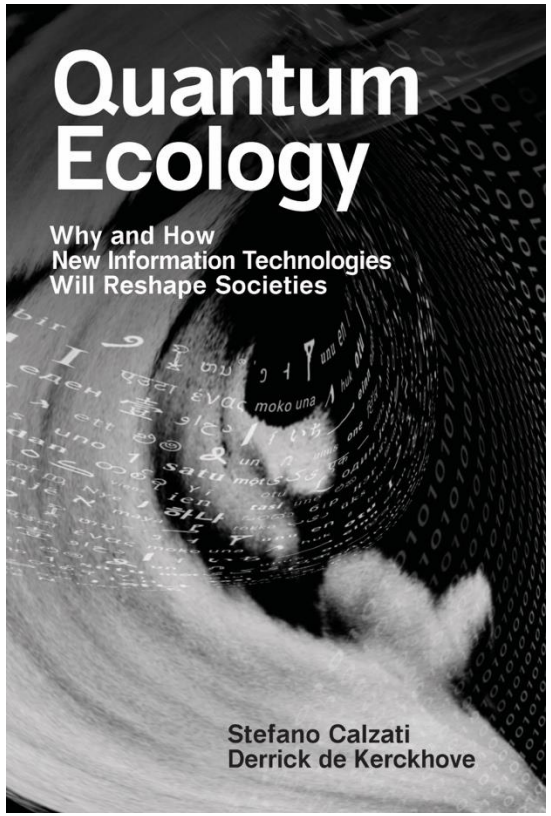
1) **Language** → based on **meaningful world-sensing** (e.g., law)

Partial *onto-epistemological incommensurability*

2) **Digital** → based on **computable world-sensing** (formatting of sensing into 0s & 1s)

Partial *onto-epistemological incommensurability*

3) **Quantum** → based on a **probabilistic world-sensing** (synthetic sensing)



Reconfiguring Newtonian-Cartesian reality "Wigner's friend" thought experiment

1) Wigner's friend performs the measurement of a particle (e.g., spin) inside a laboratory
2) For her, the measurement yields a definite outcome (e.g., spin up)
3) For Wigner, who is outside the lab and treats the entire scenario as a quantum system, the outcome is not definite yet, i.e., still in superposition



- **Configurational realism**: Different observers can assign different "real" states to the same system → **no observer-independent physical phenomenon**.
- **Relational epistemology**: Two observers can hold **complementary** but **equally valid** knowledge claims about a phenomenon.
- **Nested inconsistent onto-epistemological configurations** (Frauchiger & Renner 2018)

Measurement as “observership”

- “When you consider all the junk that might be entangling itself with your delicate experiment . . . **it’s as if the entire rest of the universe is constantly trying to ‘measure’ your quantum state**.” (Aaronson 2013)

- “**Observership is an agency** operating at a deeper level (…) **through which physical reality come[s] about**.” (Hertog 2023)

- Any-thing ex-ists out of a **quantum information asymmetry** (information as a “rapport”, Simondon 2020)

- Being is **technics**, i.e., **measurement throughout**

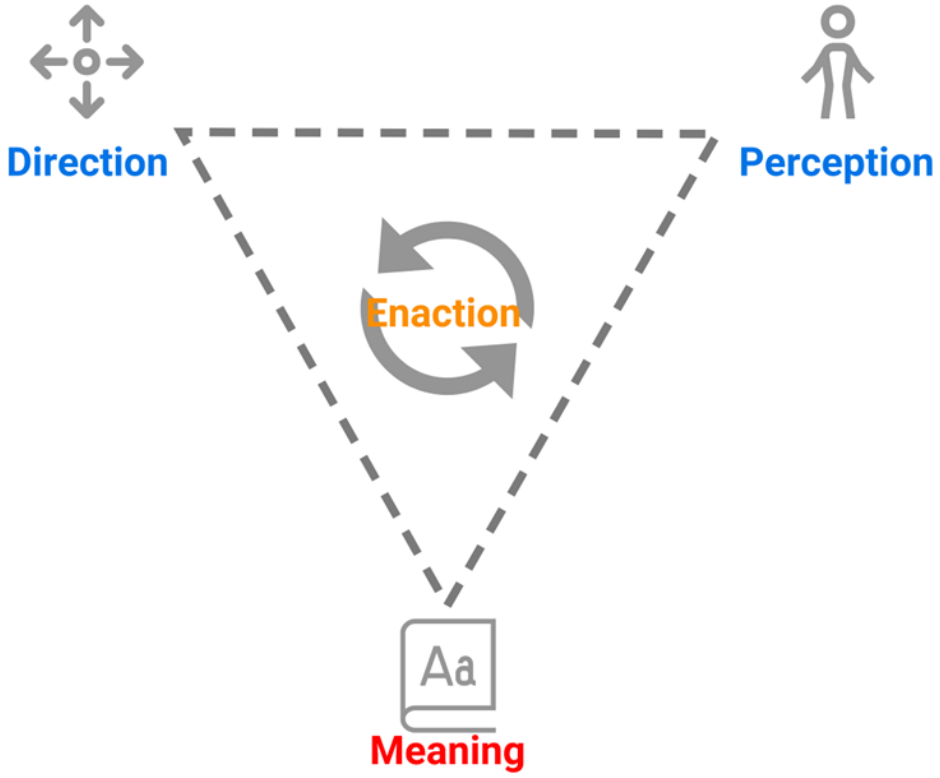


Onto-epistemological sensing

Being entails **sensing as embodied information processing**

Under a regime of observership, sensing emerges as a **complementary I-world co-determination**:

- enacted **from within**, i.e., situated (cf. the "blind spot" of science; Frank et al 2024)
- always **open-ended**, i.e., "unprestatable" (Kauffman 2019)



Implications



Classical optical devices





Sight is a **prosthetic faculty**: it can be phenomenologically extended and enhanced, based on certain **technological apparatuses**

- These apparatuses **connect & co-constitute** the observed object & the observing subject

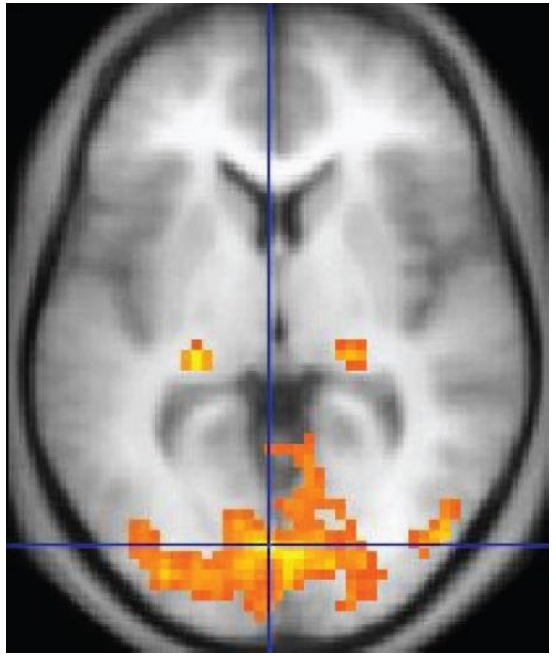
Quantum sensing

- Quantum sensing is the **most mature** class of QITs (TRL 9; OECD 2025)

- QS leverages quantum objects (e.g., magnetic states of spin qubits) and quantum effects (e.g., superposition and entanglement) to **synthetise physical phenomena**

E.g.: functional magnetic resonance imaging (fMRI) measures brain activity by detecting small changes in blood oxygenation levels (BOLD)

 However, recent work (Epp et al 2026) **challenges the reliability** of the link between BOLD changes to brain activity



Ultra-phenomenological proximation

- Quantum objects & effects **do not indexically co-constitute** referent and observer → **no referential link** between the quantum object/phenomena and a detected neurological activity

- Quantum object & effects stand as **ultra-phenomenological proxies** for the observer-observed entanglement

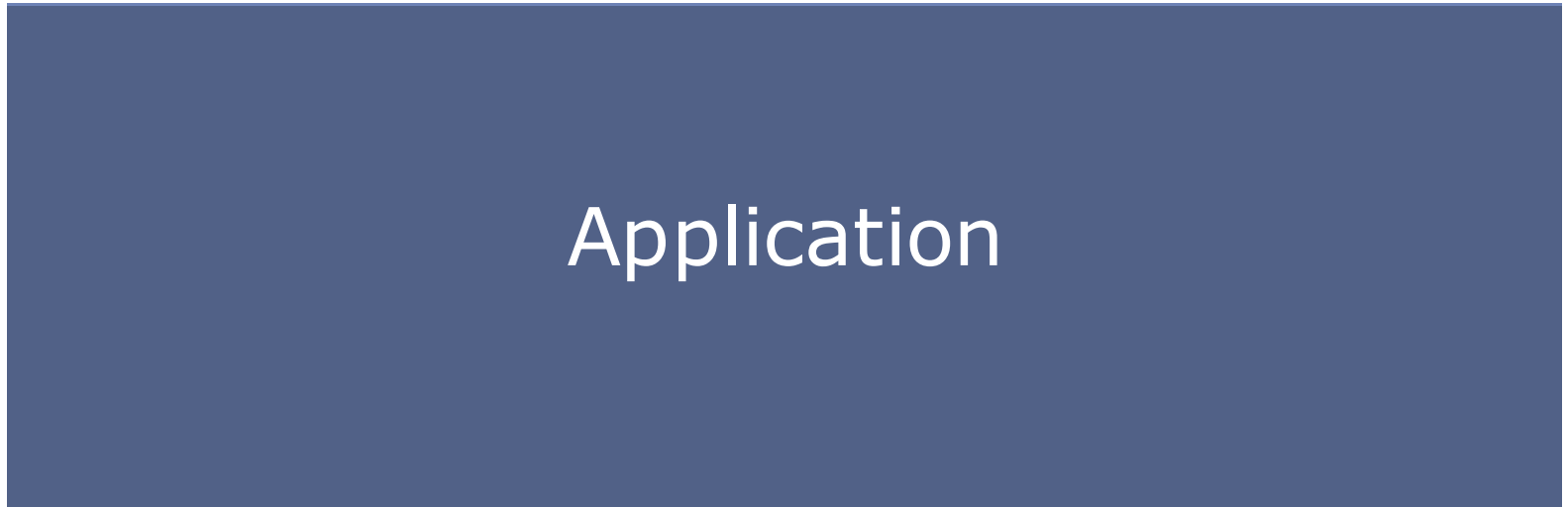
- QS enacts a **proximation of the sensible**, whereby the synthesis of physical phenomena and their manipulation occur **within a space of possibility**, rather than through referentiality

Implications for ethics

- **Disruption** of the linear link classically connecting the use of a technology (as a tool) to its effects (e.g., compliance with ethical values)

- When ethical values are treated as **isolated referential targets** (Calzati & Ploger 2024), they entail a binarism (e.g., “transparency” vs. “opacity”) and an optimum which hinder pragmatism (cf. Weitz et al 2016)

→“ethics + technology” pair shall be reconsidered as a **fundamentally uncertain enactment** within an **onto-epistemological space of possibility**


Application

Way forward

- Redesign ethical values as **context-** and **process-sensitive spectra of possibility**

→Values become **ethical space vectors** that can better accommodate mutual synergy and facilitate an overall balance

Case Study: **OECD's values** for QITs applied to **quantum neuro-devices**



	Values as Targets	Values as Spectra
TRUSTWORTHINESS	Referential trustworthiness enatils full reliability compliance	Modulated trustworthiness ranging from all-in compliance to context-dependent compliance
RESPONSIBILITY	Referential responsibility singles out actors and abstracts them from the context	Modulated responsibility regimes in which responsibility is treated ecosystemically through mutual accountability among actors as part and parcel of each cycle's phase
TRANSPARENCY	Referential transparency as all-encompassing	Modulated transparency mechanisms that specify the kind and level of transparency required based on the type of neuro-device, its use, and the neuro-data involved.
STEWARDSHIP	Referential stewardship as a top-down only process	Modulated stewardship mechanisms of cooperation and contestation across actors, under different regimes of responsibility
PUBLIC GOOD	Referential public good resists framing and operationalization	Modulated public good through mechanisms of voluntary in/exclusion of actors based on a preliminary contextualization of both "public" and "good" concerning deployment and use
RESPONSIVENESS	Referential responsiveness remains largely driven by economic returns on investment	Modulated responsiveness ranges from rapid, agility-focused development and deployment for supervised diagnostic uses to deliberate, safety-paced delay, especially for wide commercial use.

Neuro-Devices
Reliability of neuro-devices' proximation: modulation based on sandboxing provisional trustworthiness for exploratory neuro-research, provided that proximation remains subject to scrutiny. Full-compliance during deployment
Development phase: the responsibility regime concerning neuro-devices' proximation entails the co-responsibility of funders, researchers, developers, and the participants involved in testing. Deployment phase: the responsibility regime expands to involve auditing roles and institutional actors. During both phases, the design of neuro-devices and brain activity's proximation remain under scrutiny. Users shall knowingly use neuro-devices for intended uses only.
Across the whole cycle, it is crucial to ensure clear, accessible, and timely information about findings that might challenge the assumption at the basis of the proximation of brain activity by neuro-devices.
Development phase: experts' independent peer review of neuro-devices' (and later patents), including the potential for contestation of the produced proximation; Deployment phase: prevention of disciplinary siloing through the involvement of expert ethicists, neuro-patients, cognitive-rights advocates
Development phase: the limits of the proximation of brain activity shall be explicitly acknowledged. Deployment phase: experimentation flexibility to therapeutic and diagnostic applications under supervision could be granted, while maintaining regulatory barriers for unvetted consumer neuro-devices. Public good also has a temporal dimension which has to do with the potential emergence over time of unexpected limits of proximation. Hence, ongoing audibility, transparency and responsibility regimes remain key.
Use phase: pushing neuro-devices toward quick & wide adoption risks clashing with the need for robust trustworthiness. Responsiveness shall be modulated depending on the kind of neuro-devices at stake and the context of application.

Work boundaries

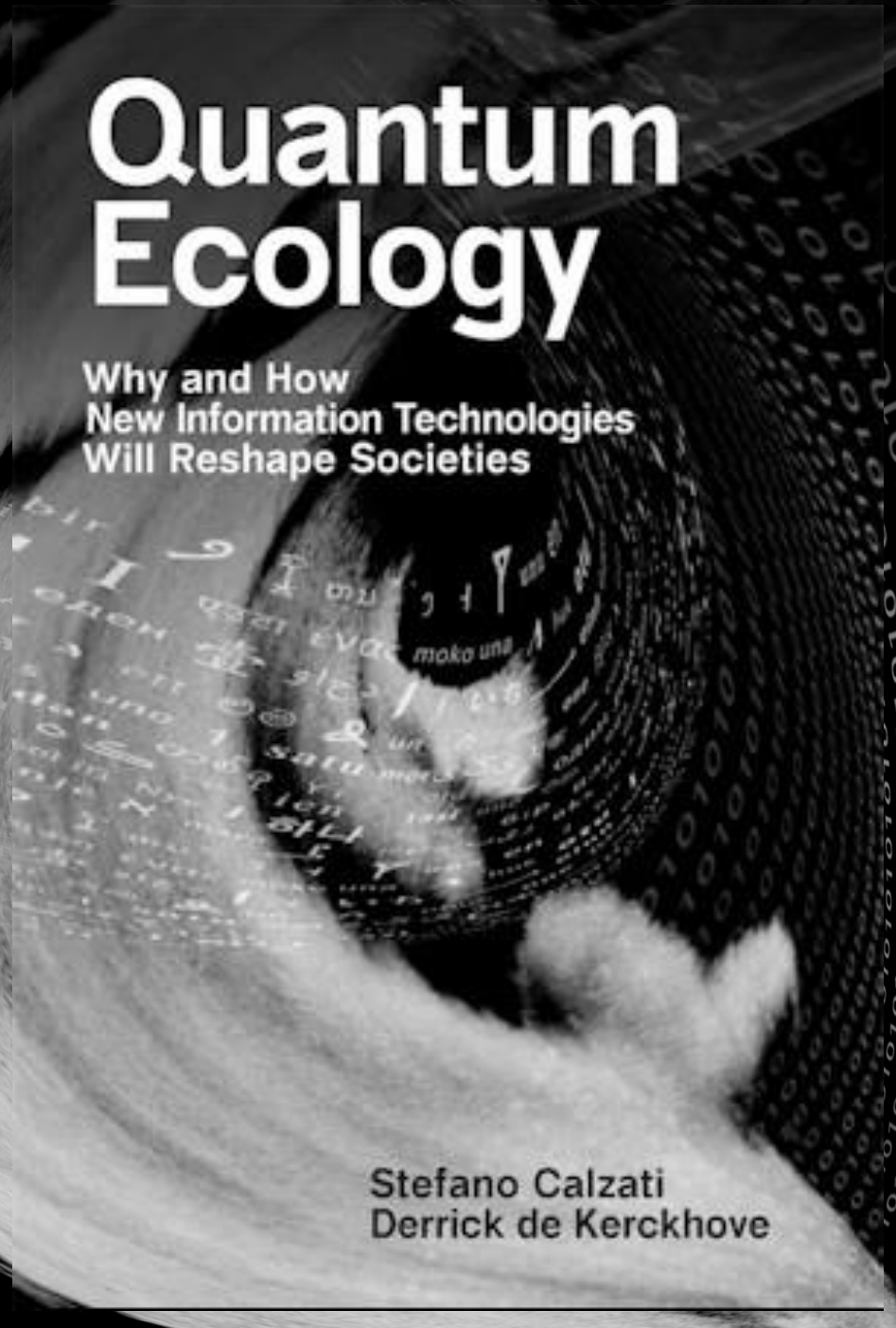
- Descriptive not prescriptive → **empirical validation** needed (feedbacking on OECD's values)
- Ultra-phenomenological **proximation ≠ transcendence**
- Focus on QS can be **extended to other QITs**
- Onto-epistemological sensing can **retrospectively challenge** the (constructed) phenomenological referentiality of classical technologies

Thank you

https://stefanocalzati.com

Digital Society Topical Collection

Untangling the Quantum Ecology:
Charting the Impact of Quantum Theory and Quantum Technologies on Technoscience and the Digital Transformation



(Mi Lin, book cover's artist, Milandia 瀰瀾之域)