Finite Record Boundaries in Wigner's Friend Scenarios: Observer-Relative Distinguishability and Quantum Record Availability in Finite Distinction Systems

Yining Wu
Independent Researcher
yining.wu@alumni.upenn.edu
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Wigner's friend scenarios expose a tension between two descriptions of the same quantum experiment: the friend may stabilize an internal record, while Wigner may treat the larger sealed laboratory by a different state assignment. FDS-Q1 develops a finite-record boundary account of this tension. It does not solve the measurement problem, derive the Born rule, replace decoherence theory, modify unitary quantum mechanics, or claim that consciousness causes collapse. Instead, it treats observers as finite distinction-registers and measurements as stable record formation under finite capacity. The central quantitative object is the boundary-mismatch entropy $\mathcal{M}_{F|W} = H_2(Z_F|Z_W)$, which bounds Wigner's ability to promote a friend-relative record into a Wigner-accessible operational fact. The core condition is $H_2(Z_F|Z_W) \leq \epsilon$, equivalently $I_2(Z_F; Z_W) \geq H_2(Z_F) - \epsilon$. Q1 does not infer physical coherence from Wigner's ignorance: Wigner's ideal global coherent assignment requires isolation and reversible-control assumptions, whereas Wigner's operational state is obtained by tracing out inaccessible degrees of freedom. Decoherence and environmental redundancy increase cross-boundary availability; once redundancy, accessibility, and record stability exceed a threshold, finite observers converge on the same branch record. Q1 therefore reframes Wigner-friend tension as a finite record-boundary promotion problem, not as a collapse theory or a probability derivation. The v1.2 refinement strengthens the physical record criterion with a retention window and error tolerance, recasts boundary promotion as an operational criterion rather than a tautological theorem, sharpens the finite-access reconstruction bound via Fano's inequality, defines objective availability through environmental fragments, and introduces a record-availability horizon for quantum-device diagnostics.

Reader Contract. Q1 is not a collapse theory. It does not derive quantum mechanics, the Born rule, decoherence, objective classicality, or observer-independent facts from FDS alone. It does not claim that consciousness causes collapse and does not deny the validity of global coherent descriptions in their domain. Q1 is a finite-record boundary theory: a friend-relative operational record cannot be promoted into Wigner's accessible fact algebra unless a physical record channel supplies enough cross-boundary mutual information. A quantum interaction is not automatically a record; a record must remain retrievable and usable over a specified retention window with bounded error.

Claim-status summary

Table I separates operational finite-register claims, standard quantum inputs, and the Q1 boundary interpretation.

Keywords: finite observer; Wigner's friend; quantum foundations; finite records; observer entropy; record boundary; decoherence; quantum Darwinism; operational facts; distinguishability; relational quantum mechanics; QBism; many-worlds; measurement theory; finite distinction systems.

INTRODUCTION

The Wigner-friend tension

The Wigner-friend thought experiment asks how to reconcile two apparently different descriptions of the same experiment. A system S is prepared in a superposition,

$$|\psi_S\rangle = \alpha|0\rangle + \beta|1\rangle, \tag{1}$$

and a friend F inside a sealed laboratory measures it. In a unitary description of system plus friend,

$$|\Psi_{SF}\rangle = \alpha|0\rangle|F_0\rangle + \beta|1\rangle|F_1\rangle. \tag{2}$$

The friend stabilizes an internal record. Wigner, outside the sealed lab, may under suitable isolation assumptions assign a coherent global state to the entire friend-lab system,

$$|\Psi_{SFL}\rangle = \alpha|0, F_0, L_0\rangle + \beta|1, F_1, L_1\rangle. \tag{3}$$

The apparent tension is simple: how can the friend have an internal record while Wigner describes the lab by a different state?

TABLE I. Central FDS-Q1 claims, epistemic status, and demotion or failure conditions.

Claim	Status	What would weaken or falsify it
Observers are finite distinction-registers	O1 operational bridge	Registered observations require no finite carrier, boundary, readout, record stability, or update capacity
Operationally assertable quantum facts are indexed by accessible record boundaries	Q1 bridge	Operational facts can be asserted by a finite observer without any stable accessible record or reproducible trace
Wigner-friend tension is a boundary-promotion problem	Main Q1 thesis	Contradictions persist after all accessible record boundaries, channels, and state-assignment domains are separated
Friend-relative records require mutual information before promotion into Wigner's algebra	Information-theoretic bridge	A Wigner-accessible fact is obtained with vanishing cross-boundary mutual information and no physical record channel
Wigner's ignorance is not physical coherence	Scope firewall	The paper is interpreted as inferring coherent lab states from missing classical information alone
Objective availability requires redundancy, access, and record stability	Testable bridge hypothesis	Observers converge on macroscopic records without redundancy, access, or stable records
Q1 does not derive Born probabilities	Scope firewall	The paper is interpreted as a probability or Born-rule derivation rather than a conditional record-availability theory

Q1 answer: finite record boundaries

Q1's answer is that the friend and Wigner refer to different finite record boundaries. The friend has access to an internal record variable Z_F. Wigner has access to an external record variable Z_W. Until the friend's record crosses the lab boundary by communication, leakage, environmental redundancy, or direct readout,

$$I_2(Z_F; Z_W) < H_2(Z_F). \tag{4}$$

The friend can have a stabilized internal record while Wigner lacks that record. These are not the same operational claim. The contradiction appears when one assumes, without a physical record channel, that

$$Z_F = Z_W. \tag{5}$$

FDS-Q1 therefore treats Wigner-friend tension as finite record-boundary mismatch and boundary-promotion failure, not as a direct contradiction between boundary-free facts.

Three Wigner descriptions must be separated

A key technical distinction is between Wigner's ignorance, Wigner's operational state, and Wigner's ideal global assignment. Let

$$\rho^W_{\text{global}} \tag{6}$$

denote an ideal Wigner state assignment to the full sealed lab and its relevant environment under isolation and reversible-control assumptions. Let

$$\rho^W_{\text{acc}} = \mathrm{Tr}_{\text{inacc}}\, \rho^W_{\text{global}} \tag{7}$$

be Wigner's operational state after tracing out inaccessible degrees of freedom. Let z_F be the friend's internal stable record class. Q1 does not infer physical coherence from Wigner's ignorance. It only says that Wigner's accessible record boundary may fail to contain the friend's internal record. Whether Wigner may assign a coherent global state depends on isolation and reversible-control assumptions.

Relation to O1

FDS-O1 defines an observer as a finite distinction-register: a physical system that can register, preserve, update, order, and communicate distinctions using finite records, finite channels, finite update rates, finite buffers, and finite thermodynamic budgets [1]. It also states an operational record condition: environmental information becomes an operational measurement only when accessible register capacity and record stability cross the task threshold. In O1 notation,

$$\min\{I_{\text{env}}(S; E_t), C^{\text{acc}}_{\text{app}}(t), C_{\text{rec}}(t,\tau)\} \geq R_{\min}(\varepsilon; S). \tag{8}$$

Q1 is the quantum-foundations paper that O1 leaves open. It keeps the same discipline: no collapse derivation, no Born-rule derivation, no replacement of decoherence, and no consciousness criterion for measurement.

PROBABILITY AND UNIT CONVENTIONS

Probability convention

The Shannon quantities in Q1 are conditional on an externally supplied probability distribution. Throughout the paper, $p(z_F, z_W)$ is not derived. It is taken from the operational statistics of repeated record-generation experiments, normally computed using standard quantum mechanics and the Born rule. Q1 concerns record accessibility conditional on those statistics, not the origin of the probability weights. In this sense,

$$\text{record availability} \neq \text{Born-rule derivation}. \tag{9}$$

Bits, nats, and physical entropy

Information-theoretic quantities are written in bits:

$$H_2, \quad I_2, \quad C. \tag{10}$$

When a physical entropy is associated with a record distribution, the conversion is

$$S = k_{\mathrm{B}} \ln 2\, H_2. \tag{11}$$

Thus the observer record entropy is

$$S_O^{\mathrm{rec}} = k_{\mathrm{B}} \ln 2\, H_2(Z_O), \tag{12}$$

and the maximum capacity entropy is

$$S_O^{\max} = k_{\mathrm{B}} \ln |\mathcal{Z}_O| = k_{\mathrm{B}} \ln 2\, \log_2 |\mathcal{Z}_O|. \tag{13}$$

This convention prevents mixing record bits with thermodynamic units.

FDS BACKGROUND

Observer as finite distinction-register

Let Ω be a physical possibility space. A finite observer implements a finite distinction projection,

$$\pi_O : \Omega \to Z_O, \tag{14}$$

where Z_O is the finite set of accessible record classes. Its bit capacity is

$$C_O = \log_2 |Z_O|. \tag{15}$$

A measurement is not merely a physical interaction. It is stable record formation. If M_t carries a record z at time t, then a record is stable over window τ to error δ if

$$\mathbb{P}[\hat{z}(t+\tau) = z \mid M_t = z] \geq 1 - \delta. \tag{16}$$

An interaction that leaves no stable accessible record over the retention and verification window is not yet an operational FDS record for O.

Measurement capacity

O1 writes the accessible measurement capacity as a bottlenecked ledger,

$$C_{\mathrm{meas}} = \min\{C_{\mathrm{sens}}, C_{\mathrm{chan}}, C_{\mathrm{mem}}, C_{\mathrm{rec}}, C_{\mathrm{ext}}^{\mathrm{eff}}, I_{\mathrm{update}}^{\max}\}. \tag{17}$$

For task family Ψ, distortion tolerance ε, and window τ,

$$\Delta_{O1} = R_{\min}^{(\tau)}(\varepsilon; \Psi) - C_{\mathrm{meas}}. \tag{18}$$

When $\Delta_{O1} > 0$, the finite observer must coarse-grain, merge states, buffer, externalize, reset, relax the task, increase latency, or fail. Q1 applies this logic to quantum records and Wigner-friend boundaries.

Decoherence as distinguishability leakage

A standard decoherence interaction has the form

$$\sum_i c_i |s_i\rangle |E_0\rangle \longrightarrow \sum_i c_i |s_i\rangle |E_i(t)\rangle. \tag{19}$$

The reduced state of the system contains overlap factors $\langle E_j(t)|E_i(t)\rangle$. Define environmental distinguishability

$$D_{ij}(t) = 1 - |\langle E_i(t)|E_j(t)\rangle|^2. \tag{20}$$

When $D_{ij} \to 1$, the environment carries branch distinguishability. A finite observer who cannot access the relevant environmental degrees of freedom traces them out. Q1 interprets this as distinguishability leakage into an inaccessible boundary, not as an alternative to standard decoherence.

STANDARD QUANTUM BASELINE

Global unitary evolution

Let the global Hilbert space factor as

$$\mathcal{H}_{\mathrm{tot}} = \mathcal{H}_S \otimes \mathcal{H}_F \otimes \mathcal{H}_L \otimes \mathcal{H}_E. \tag{21}$$

Q1 accepts standard unitary evolution on this global space. Its claims concern which records are accessible to which finite observer.

Accessible states and partial trace

For observer O, define an accessible-inaccessible factorization

$$\mathcal{H}_{\mathrm{tot}} = \mathcal{H}_O^{\mathrm{acc}} \otimes \mathcal{H}_O^{\mathrm{inacc}}. \tag{22}$$

The operational state for O is

$$\rho_O = \mathrm{Tr}_{\mathcal{H}_O^{\mathrm{inacc}}}\, \rho_{\mathrm{tot}}. \tag{23}$$

Different observers can legitimately use different reduced states because they trace out different degrees of freedom. This is not a claim that the global state is invalid; it is a claim about operational access.

Pointer records and record extraction

In decoherence theory, pointer records arise when environmental monitoring suppresses interference between selected states. Q1 adds that operational access requires the record to fall inside an observer's finite record boundary. A finite register may implement a record-extraction channel or POVM when signal distinguishability, environmental redundancy, and record stability exceed the task threshold. This is record extraction, not a fundamental collapse trigger.

DEFINITIONS

Definition 1 (Finite quantum observer). *A finite quantum observer O is a finite distinction-register with an operational measurement family*

$$\mathcal{M}_O = \{E_z^O\}_{z\in\mathcal{Z}_O}, \qquad E_z^O \geq 0, \quad \sum_z E_z^O = I, \tag{24}$$

that extracts a classical record $Z_O \in \mathcal{Z}_O$ with probabilities

$$p_O(z) = \mathrm{Tr}(\rho E_z^O). \tag{25}$$

Algebraically, the stable record values generate a commuting accessible record algebra

$$\mathcal{A}_O \subset \mathcal{B}(\mathcal{H}_O^{\mathrm{acc}}). \tag{26}$$

The shorthand Z_O denotes the finite classical record classes output by this accessible record interface. A POVM outcome counts as an FDS record only when it is stabilized in the observer's register: for retention window $[t, t+\tau]$ and error tolerance δ,

$$\mathbb{P}[\hat{z}_O(t+\tau) = z_O \mid M_t = z_O] \geq 1-\delta. \tag{27}$$

Thus record extraction is not identified with fundamental collapse; it is classical-register stabilization under finite accessibility.

Definition 2 (Observer record entropy). *With information measured in bits,*

$$S_O^{\mathrm{rec}} = k_{\mathrm{B}} \ln 2\, H_2(Z_O). \tag{28}$$

The maximum capacity entropy is

$$S_O^{\max} = k_{\mathrm{B}} \ln |\mathcal{Z}_O|. \tag{29}$$

These are operational record entropies, not automatically thermodynamic entropies in every context.

Definition 3 (Quantum record boundary). *A quantum record boundary ∂O separates degrees of freedom whose records are accessible to O from those traced out or inaccessible:*

$$\mathcal{H}_{\mathrm{tot}} = \mathcal{H}_O^{\mathrm{acc}} \otimes \mathcal{H}_O^{\mathrm{inacc}}. \tag{30}$$

Equivalently, it specifies which POVMs, record channels, memories, and classical registers can be physically used by O during the relevant window.

Definition 4 (Wigner-friend boundary mismatch). *For friend F and Wigner W, define accessible record variables Z_F and Z_W. The boundary mismatch is the conditional entropy*

$$\mathcal{M}_{F|W} = H_2(Z_F|Z_W). \tag{31}$$

If $\mathcal{M}_{F|W} > 0$, Wigner lacks full record-theoretic access to the friend's internal record.

Definition 5 (Cross-boundary record availability). *A friend record becomes available to Wigner to tolerance ε when*

$$I_2(Z_F; Z_W) \geq H_2(Z_F) - \varepsilon, \tag{32}$$

or equivalently

$$H_2(Z_F|Z_W) \leq \varepsilon. \tag{33}$$

Definition 6 (Objective availability threshold). *Let $E_1, \ldots, E_N$ be environmental fragments that may carry the friend record. For tolerance ε, define the minimal fragment number*

$$m_\varepsilon = \min\{m : I_2(Z_F; E_{1:m}) \geq H_2(Z_F) - \varepsilon\}. \tag{34}$$

When m_ε exists, a redundancy proxy is

$$R_\varepsilon = \frac{N}{m_\varepsilon}. \tag{35}$$

A record is objectively available to a class of finite observers only when enough fragments can be sampled and the observers have adequate record capacity and stability, for example

$$I_2(Z_F; E_{1:m}) \geq H_2(Z_F) - \varepsilon, \tag{36}$$

$$C_O \geq H_2(Z_F) - \varepsilon, \tag{37}$$

$$C_{\mathrm{rec}}(O, \tau) \geq H_2(Z_F) - \varepsilon. \tag{38}$$

CORE PROPOSITIONS

Criterion 1 (Boundary-promotion criterion). *Let Z_F be a friend-stabilized record and let Z_W be Wigner's accessible record. A friend-relative operational fact can be promoted to a Wigner-accessible operational fact to tolerance ε only if*

$$H_2(Z_F|Z_W) \leq \varepsilon, \tag{39}$$

equivalently

$$I_2(Z_F; Z_W) \geq H_2(Z_F) - \varepsilon. \tag{40}$$

If $I_2(Z_F; Z_W) = 0$, Wigner has no record-theoretic basis for asserting the friend's specific outcome inside $\mathcal{A}_W$, although Wigner may still assign an ideal global quantum state over the sealed lab under suitable isolation assumptions.

The equivalence follows from the identity $H_2(Z_F|Z_W) = H_2(Z_F) - I_2(Z_F; Z_W)$. Thus boundary promotion is an operational decision rule: it licenses insertion of an $\mathcal{A}_F$-record into $\mathcal{A}_W$ only when the remaining friend-record uncertainty at Wigner's boundary is below the registered tolerance.

Proposition 1 (Wigner-friend boundary separation)**.** *Let a friend F interact with a system S such that, relative to the friend's accessible record algebra, the interaction yields a stable record class Z_F. Let Wigner W remain outside the friend-lab boundary. If*

$$H_2(Z_F|Z_W) > 0, \tag{41}$$

then the friend's stable internal record and Wigner's accessible operational state refer to different finite record boundaries. No operational contradiction follows unless one assumes $Z_F = Z_W$ or assumes cross-boundary availability without a physical record channel.

Proof sketch. For the friend, measurement is stable record-class formation inside $\mathcal{A}_F$: $Z_F = z_i$ relative to the friend's accessible algebra. Wigner's accessible record Z_W does not include Z_F unless a boundary-crossing channel, environmental redundancy, or direct readout makes it available. Wigner's operational state may therefore be a mixture after tracing inaccessible degrees of freedom, while an ideal global coherent assignment may also be considered under isolation assumptions. These are different state-assignment domains. The claims become operationally comparable only when $I_2(Z_F; Z_W) \simeq H_2(Z_F)$. □

Proposition 2 (Finite-access lower bound on friend-record reconstruction)**.** *Let Wigner receive information about the friend record through a finite accessible classical record channel of capacity C_W bits over the relevant window. Here C_W denotes the effective accessible classical record capacity of Wigner's boundary for the friend-record variable during the specified protocol. If Wigner enlarges the boundary and performs a coherent global measurement on the entire isolated laboratory, then Z_W, C_W, and the accessible algebra must be redefined for that enlarged protocol. If Z_W is generated from Z_F through the specified finite channel, then by data processing,*

$$I_2(Z_F; Z_W) \leq C_W. \tag{42}$$

Hence

$$H_2(Z_F|Z_W) \geq H_2(Z_F) - C_W. \tag{43}$$

If Wigner estimates $\hat{Z}_F = \hat{Z}_F(Z_W)$ with error probability P_e, then Fano's inequality gives

$$H_2(Z_F|Z_W) \leq h_2(P_e) + P_e \log_2(|\mathcal{Z}_F| - 1), \tag{44}$$

or equivalently

$$h_2(P_e) + P_e \log_2(|\mathcal{Z}_F| - 1) \geq H_2(Z_F|Z_W). \tag{45}$$

Thus, if the mismatch entropy is large, the reconstruction error probability cannot be arbitrarily close to zero.

Remark 1 (Binary record case)**.** *For binary friend records, Fano's inequality reduces to*

$$H_2(Z_F|Z_W) \leq h_2(P_e), \tag{46}$$

and therefore

$$P_e \geq h_2^{-1}(H_2(Z_F|Z_W)) \tag{47}$$

where h_2^{-1} denotes the inverse of the binary entropy function on the monotone branch $0 \leq P_e \leq 1/2$. Q1 uses this as a finite-access reconstruction bound, not as a claim about the origin of quantum probabilities.

Proposition 3 (Objective convergence through redundancy)**.** *If the friend's record is redundantly encoded in environmental fragments $E_1, \ldots, E_N$ and a finite observer can sample at least m_ε fragments satisfying*

$$I_2(Z_F; E_{1:m_\varepsilon}) \geq H_2(Z_F) - \varepsilon, \tag{48}$$

with sufficient record capacity and stability,

$$C_O \geq H_2(Z_F) - \varepsilon, \qquad C_{\rm rec}(O, \tau) \geq H_2(Z_F) - \varepsilon, \tag{49}$$

then finite observers converge on the same operational branch record to tolerance ε.

Remark 2. *This proposition is a record-availability condition, not a Born-rule derivation. It says when a record becomes shared; it does not derive the probability weights of records.*

THREE-BIT TOY MODEL

Consider a minimal record model with a qubit system S, a one-bit friend register F, and a Wigner record W obtained through environmental redundancy. Let

$$|\alpha|^2 = 0.7, \qquad |\beta|^2 = 0.3. \tag{50}$$

Using the probability convention above, the friend record entropy is

$$H_2(Z_F) = h_2(0.7) \simeq 0.881 \text{ bits}. \tag{51}$$

A schematic redundancy normal form is

$$I_2(Z_F;Z_W)=H_2(Z_F)\left(1-e^{-\lambda R_E}\right), \tag{52}$$

so that

$$\mathcal{M}_{F|W}=H_2(Z_F|Z_W)=H_2(Z_F)e^{-\lambda R_E}. \tag{53}$$

This toy model is not a quantum dynamical simulation. It is a numerical illustration of the boundary-promotion condition: increasing redundancy reduces mismatch entropy, while finite Wigner capacity can leave a residual lower bound.

PROMOTION STRENGTH AND BOUNDARY LATTICE

Define the boundary-promotion strength

$$\eta_{F\to W}=\frac{I_2(Z_F;Z_W)}{H_2(Z_F)} \tag{54}$$

when $H_2(Z_F)>0$. Then $\eta_{F\to W}=0$ means no promotion, $0<\eta_{F\to W}<1-\varepsilon/H_2(Z_F)$ means partial leakage, $\eta_{F\to W}\geq 1-\varepsilon/H_2(Z_F)$ means Wigner-promotable record, and $\eta_{F\to W}=1$ means full boundary alignment. This lattice form is a compact way to express the Q1 slogan:

$$\mathcal{A}_F\text{-fact}\ \not\Rightarrow\ \mathcal{A}_W\text{-fact} \tag{55}$$

unless the physical promotion channel is strong enough.

RELATION TO DECOHERENCE

For a decohering system,

$$\rho_S(t)=\sum_{ij}c_ic_j^*\langle E_j(t)|E_i(t)\rangle|s_i\rangle\langle s_j|. \tag{56}$$

Off-diagonal terms are suppressed when $\langle E_j(t)|E_i(t)\rangle\approx 0$ for $i\neq j$. Q1 accepts this mechanism. It adds an operational record condition:

$$\min\{I_{\text{env}}(S;E_t),C_{\text{app}}^{\text{acc}}(t),C_{\text{rec}}(t,\tau)\}\geq R_{\min}(\varepsilon;S). \tag{57}$$

Define the accessible record-formation time

$$\tau_{\text{rec}}=\inf\{t:\ \min[I_{\text{env}}(S;E_t),C_{\text{app}}^{\text{acc}}(t),\ C_{\text{rec}}(t,\tau)]\geq R_{\min}(\varepsilon;S)\}. \tag{58}$$

The decoherence time τ_{dec} and the accessible record time τ_{rec} need not be equal. A branch can decohere before Wigner can access the friend record; conversely, a stable internal record can exist before objective redundancy is available outside the lab.

RELATION TO WIGNER-FRIEND VARIANTS

Simple Wigner's friend

In the simple case, $Z_F\neq Z_W$. The friend has a record inside the lab; Wigner has no full access to that record. Q1's claim is that stable internal record and external state assignment can coexist because they are relative to different accessible algebras.

Frauchiger-Renner-type arguments

Frauchiger-Renner scenarios derive contradictions under assumptions about single outcomes, universal quantum validity, and consistency of agents' statements [8]. Q1 does not deny the theorem. It restricts an inference step that often remains implicit:

$$\mathcal{A}_F\text{-fact}\ \not\Rightarrow\ \mathcal{A}_W\text{-fact unless } H_2(Z_F|Z_W)\leq\varepsilon. \tag{59}$$

Q1 does not reject universal unitary dynamics. It rejects unrestricted cross-boundary promotion of records: a statement recorded in $\mathcal{A}_F$ cannot be inserted into $\mathcal{A}_W$ unless the friend record is physically available at Wigner's boundary.

FR-type move	Q1 diagnosis
$\mathcal{A}_F$ statement	valid for F's algebra
Insert into $\mathcal{A}_W$	requires promotion
No promotion channel	inference not licensed
Shared fact	allowed if $H_2(Z_F|Z_W)\leq\varepsilon$

Q1 is not a refutation of the Frauchiger–Renner theorem. It is a boundary-audit rule for when an agent-relative record may be imported into another agent's accessible algebra.

Multiple friends

For two friends F_1 and F_2 with records Z_{F_1} and Z_{F_2}, consensus is not automatic. A shared operational fact for Wigner requires

$$H_2(Z_{F_1},Z_{F_2}|Z_W)\leq\varepsilon. \tag{60}$$

If the friends do not communicate, or if their records pass through different finite channels, Wigner may have partial access to one record but not the other. This gives Q1 a direct way to classify multi-agent Wigner-friend and Frauchiger-Renner-style cases: each cross-agent inference step must specify its record-promotion channel.

Relational, QBist, Everettian, and consistent-history readings

Q1 is compatible with relational state assignments because it gives a finite-capacity mechanism for record relativity. Compared with relational quantum mechanics, Q1 emphasizes register capacity, accessible algebra, record stability, and cross-boundary mutual information. It is compatible with QBism because it physicalizes agent records rather than treating agents as disembodied probability assigners. It is compatible with Everettian global unitarity because it does not deny the global state. It is related to consistent histories because it refuses to combine record claims across incompatible boundary contexts without a physical alignment condition.

OBSERVER-RELATIVE ENTROPY

Four entropy notions should be kept separate.

This separation prevents a common confusion. The entropy of Wigner's reduced state, the Shannon uncertainty of Wigner's classical record, the maximum capacity of Wigner's apparatus, and the mismatch between Wigner and friend boundaries are related but not identical.

NUMERICAL AND CONCEPTUAL DEMONSTRATIONS

The figures are deterministic normal-form demonstrations generated by `code/generate_results.py`. They are schematic normal forms, not quantum dynamical simulations and not empirical fits. Boundary leakage uses, for example,

$$\frac{I_2}{H_2} = 1 - e^{-\lambda x}, \qquad \frac{\mathcal{M}_{F|W}}{H_2} = e^{-\lambda x}. \tag{61}$$

OPERATIONAL TESTS AND PROTOCOLS

Protocol 1 (Tunable record-boundary test)**.** *Use a quantum-optical, trapped-ion, spin, or superconducting setup where a measurement record can be stored internally, delayed, partially leaked, redundantly copied, or erased. Q1 predicts that inter-observer agreement tracks* $I_2(Z_F; Z_W)$ *and record stability, not merely elapsed unitary time. Observable:* $P_{\mathrm{agree}}(F, W)$ *as a function of* $I_2(Z_F; Z_W)$*.*

Protocol 2 (Decoherence time versus record-availability time)**.** *Separately estimate environmental distinguishability, internal record stability, and external readout availability. Q1 predicts that* τ_{dec} *and* τ_{rec} *can differ when apparatus bottlenecks delay accessible record formation. Observable: the ordering and separation of* τ_{dec}*,* τ_{rec}*, and any externalization time* τ_{ext}*.*

Protocol 3 (Redundancy threshold test)**.** *Sample environmental fragments in a quantum-Darwinism-style setup and estimate the threshold* m_ε *at which inter-observer agreement sharply increases. Q1 predicts that agreement should rise when redundancy, access, and record stability jointly cross the task threshold. Observable:* $P_{\mathrm{agreement}}(m)$ *as a function of sampled environmental fragment count* m*.*

Protocol 4 (Friend-record erasure)**.** *If a friend record is erased before externalization, Wigner cannot recover the specific record from* Z_W *unless a coherence-preserving global measurement or external side record remains. Observable: after erasure,* $H_2(Z_F|Z_W) \approx H_2(Z_F)$ *unless a side record* Z_{side} *exists such that* $H_2(Z_F|Z_W, Z_{\mathrm{side}}) \leq \varepsilon$*. This connects Q1 to P4-style anti-recurrence and preimage loss.*

FALSIFICATION AND DEMOTION CONDITIONS

Q1 is weakened or demoted if operational outcomes are available without any finite record carrier; observers with disjoint accessible record boundaries must nevertheless assign identical operational facts; Wigner-friend contradictions persist after all record-boundary assumptions are explicitly separated; stable objective facts arise without redundancy, accessibility, or stable records; decoherence-like environmental leakage occurs while finite observers track all environmental phase distinctions without capacity cost; or boundary mismatch entropy $H_2(Z_F|Z_W)$ has no relation to observer agreement in controlled record-sharing experiments.

A failure of Q1 would not by itself falsify quantum mechanics, decoherence, or the FDS formal core. It would demote the specific quantum-record boundary bridge proposed here.

RELATION TO EXISTING THEORY

DESIGN IMPLICATION FOR QUANTUM TECHNOLOGY

Q1 suggests that quantum devices should distinguish coherence preservation from record availability. A laboratory may preserve coherence, write an internal measurement record, expose an external readout, maintain an error-corrected logical record, or erase a record. These are different boundary states. For superconducting, trapped-ion, photonic, or spin-based processors, the usual diagnostics T_1, T_2, gate fidelity, and readout fidelity should be complemented by record-boundary diagnostics.

TABLE II. Entropy notions used in Q1. Information quantities are in bits; physical entropy multiplies by $k_B \ln 2$.

Entropy	Formula	Meaning
Reduced-state entropy	$-k_B \operatorname{Tr}(\rho \ln \rho)$	Entanglement or mixedness relative to a trace boundary
Record entropy	$k_B \ln 2\, H_2(Z_O)$	Uncertainty over accessible record classes
Capacity entropy	$k_B \ln \lvert\mathcal{Z}_O\rvert$	Maximum record capacity
Boundary mismatch entropy	$k_B \ln 2\, H_2(Z_F \lvert Z_W)$	Friend record unavailable at Wigner boundary

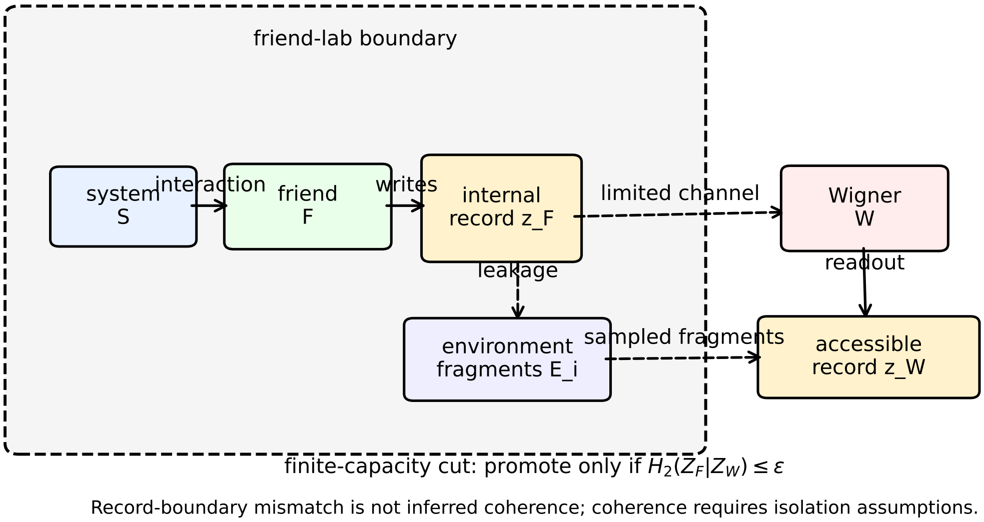

FIG. 1. Record-boundary causal map. The friend stabilizes an internal record z_F inside the sealed lab boundary. Wigner obtains only records that cross the boundary through leakage, communication, environmental fragments, or direct readout. The diagram distinguishes finite record access from the separate question of whether a global coherent state can be assigned under isolation assumptions. Schematic normal form; not a quantum dynamical simulation.

Define a *record availability horizon*

$$\tau_{\mathrm{RAH}} = \inf\{t : I_2(Z_{\mathrm{internal}}; Z_{\mathrm{external}}(t)) \geq H_2(Z_{\mathrm{internal}}) - \varepsilon\}. \tag{62}$$

This reports when an internal logical or measurement record has become externally available, leaked, or effectively objectified to tolerance ε. τ_{RAH} is a diagnostic time for external record availability, not a new fundamental timescale. Device diagnostics should separately report T_1, T_2, internal record stability, τ_{rec}, τ_{RAH}, C_{rec}, cross-boundary mutual information, record-erasure history, and reset or garbage-collection cost. Q2 develops the scalable quantum-computation maintenance costs implied by this distinction.

CONCLUSION

Wigner's friend is a finite record-boundary problem. Q1 does not collapse the wavefunction, derive probabilities, or replace decoherence. It makes explicit a physical fact often hidden in quantum-foundation discussions: observers are finite record-bearing systems with finite accessible algebras. A friend-relative record cannot be promoted into Wigner's operational fact algebra unless a physical promotion channel supplies sufficient cross-boundary mutual information. Wigner's ignorance is not the same as physical coherence; Wigner's operational state, Wigner's ideal global state, and the friend's internal record are different objects. Once records are redundantly externalized and stable, observers converge. Thus Q1 reframes Wigner-friend scenarios as finite observer entropy and record-boundary promotion problems.

Notation Summary

Simulation Parameters

The simulations are deterministic and use fixed synthetic parameter values in `code/generate_results.py`. The boundary-promotion simulation uses the normal-

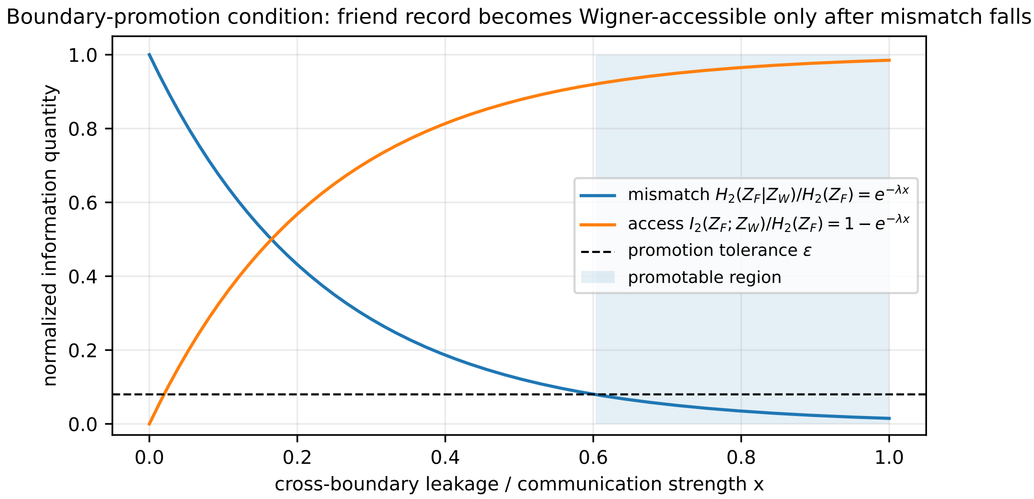

FIG. 2. Boundary-promotion condition. In this normal form, cross-boundary access follows $I_2/H_2 = 1 - e^{-\lambda x}$ while mismatch follows $H_2(Z_F|Z_W)/H_2(Z_F) = e^{-\lambda x}$. A friend-relative record becomes Wigner-accessible only after the mismatch falls below the tolerance ϵ.

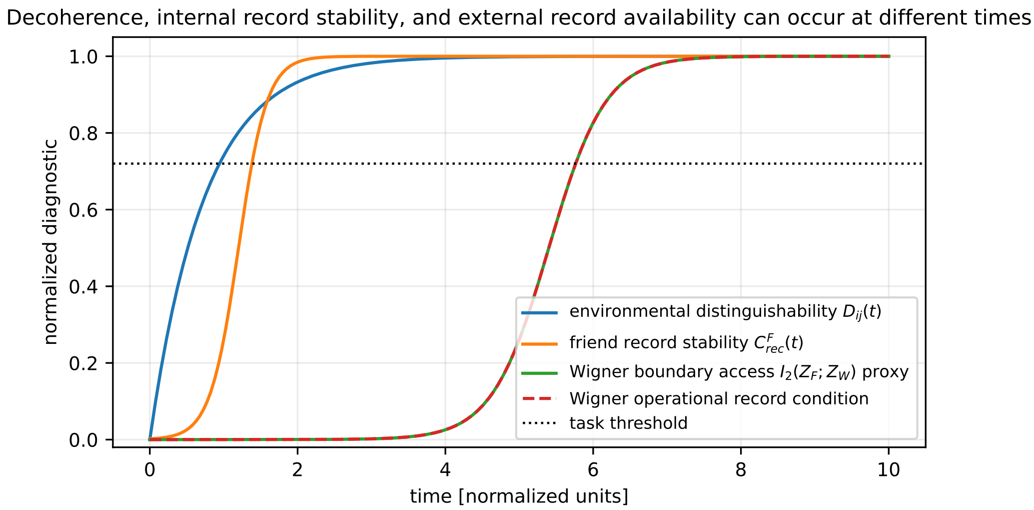

FIG. 3. Decoherence, friend record stability, and Wigner record availability can occur at different times. Environmental distinguishability may grow early, the friend's internal record may stabilize, and Wigner's boundary access may still open later. This illustrates why $\tau_{\rm dec}$ and $\tau_{\rm rec}$ need not be equal.

form equations $I_2/H_2 = 1 - e^{-\lambda x}$ and $\mathcal{M}_{F|W}/H_2 = e^{-\lambda x}$ with dimensionless leakage coordinate x and rate parameter $\lambda = 4.2$. The decoherence-record simulation uses saturating environmental distinguishability, friend-record stability, and delayed Wigner-access curves. The three-bit toy model uses $|\alpha|^2 = 0.7$, so $H_2(Z_F) \simeq 0.881$ bits, and a redundancy law $I_2 = H_2(1 - e^{-\lambda_R R_E})$ with $\lambda_R = 0.22$. The agreement and record-availability curves use logistic normal forms such as $P_{\rm agree}(x) = 1/[1+\exp(-a(x-x_c))]$. The regime map classifies internal-fact-only, partial-leakage, and objective-availability regimes by normalized conditional entropy and promotion strength $\eta_{F\to W}$. No human-subject data, quantum experimental data, or proprietary data are used.

Code Availability

The simulation code used to generate Figs. 1–6 is included in the accompanying replication package under `code/generate_results.py`. Running the script regenerates all figures, CSV outputs, and a model summary JSON file in a single pass.

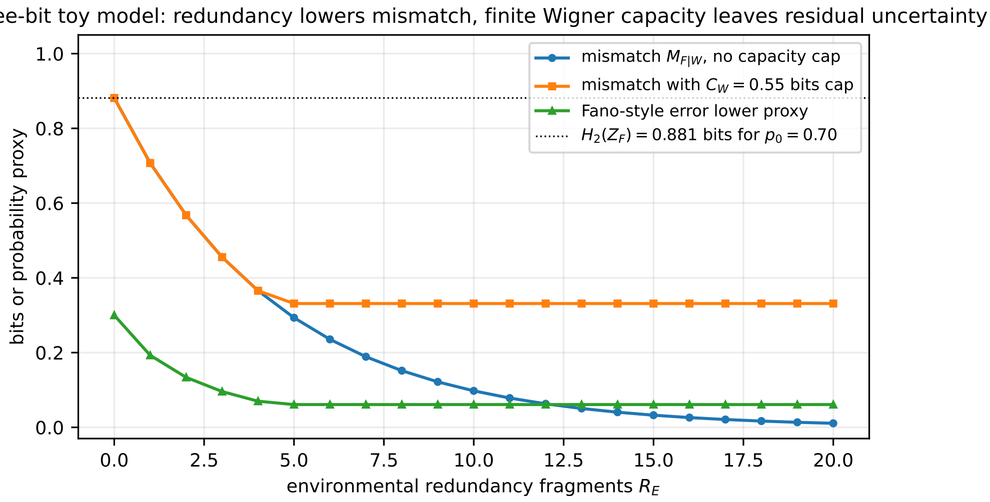

FIG. 4. Three-bit toy model. With $|\alpha|^2 = 0.7$, the friend record entropy is $H_2(Z_F) \simeq 0.881$ bits. Redundancy reduces mismatch in the unlimited case, but a finite Wigner access capacity C_W leaves residual uncertainty and a Fano-style reconstruction-error proxy. Conceptual normal form only.

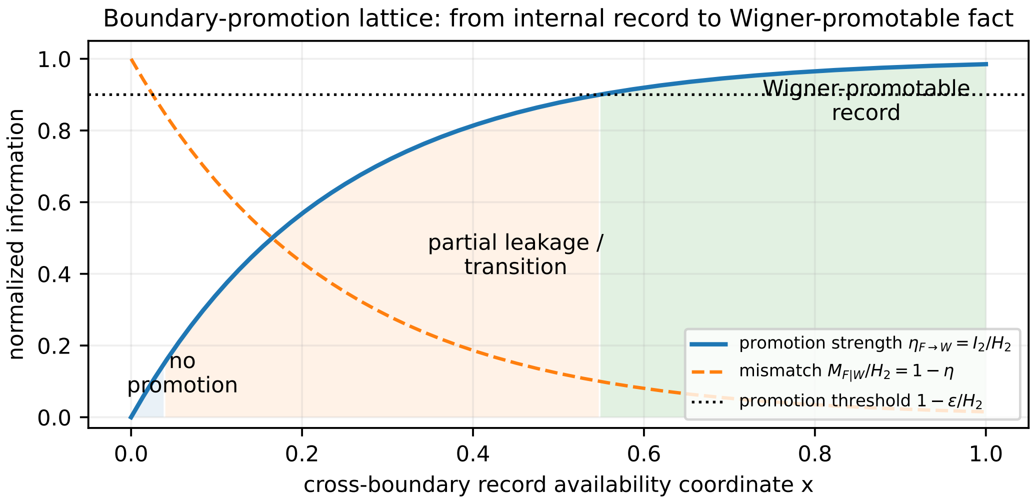

FIG. 5. Boundary-alignment regimes. The transition from friend-internal record to Wigner-promoted record is not instantaneous: partial leakage creates an intermediate regime in which cross-boundary access is noisy or incomplete.

AI Assistance Disclosure

AI-assisted tools were used for language polishing, structural feedback, LaTeX drafting support, and code-debugging assistance. The author reviewed and edited all content and remains responsible for all claims, references, simulations, and conclusions. No AI system is listed as an author.

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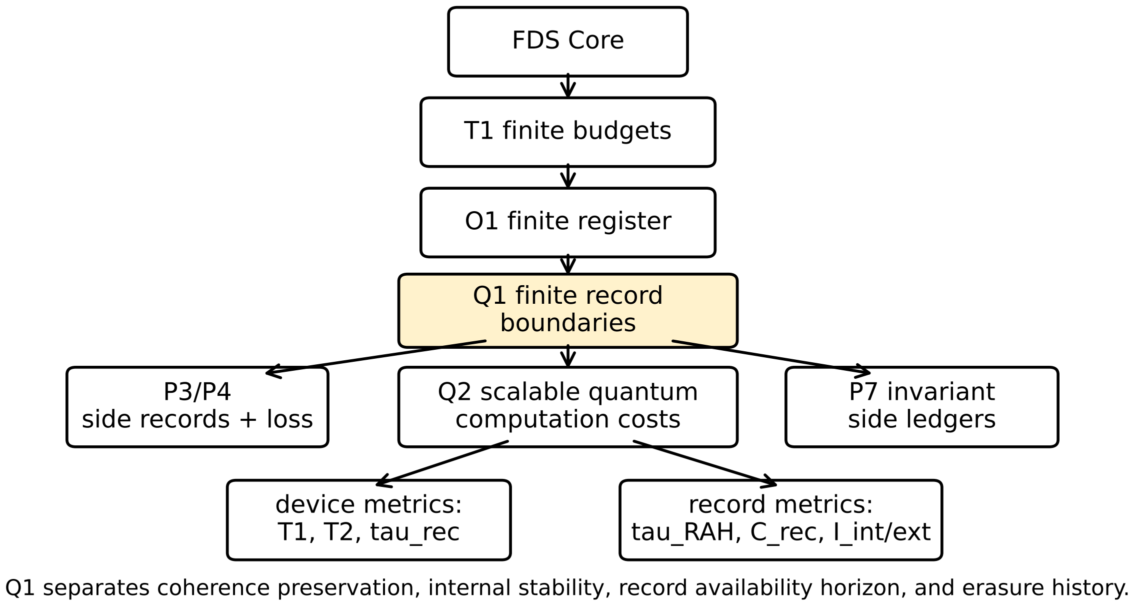

FIG. 6. Relation map and quantum-technology diagnostic split. Q1 connects finite budgets, finite registers, quantum record boundaries, side-record loss, and scalable quantum-computation maintenance costs. Device diagnostics should separate coherence preservation from record availability and erasure history.

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TABLE IV. FDS-Q1 notation summary.

Symbol	**Meaning**
S	quantum system
F	friend or internal observer
W	Wigner or external observer
$\mathcal{M}_O = \{E_z^O\}$	POVM or accessible measurement family for observer O
Z_F	friend's accessible classical record classes
Z_W	Wigner's accessible classical record classes
$\mathcal{A}_O$	accessible commuting record algebra of observer O
H_2, I_2, C	information quantities in bits
S_O^{rec}	observer record entropy $k_{\mathrm{B}} \ln 2\, H_2(Z_O)$
$S_O^{\max}$	maximum capacity entropy $k_{\mathrm{B}} \ln \lvert\mathcal{Z}_O\rvert$
$\mathcal{M}_{F\lvert W}$	boundary mismatch entropy $H_2(Z_F\lvert Z_W)$
$I_2(Z_F; Z_W)$	cross-boundary mutual information
R_E	environmental redundancy
R_c	capacity-dependent objective availability threshold
τ_{dec}	decoherence time
τ_{rec}	finite accessible record-formation time
Δ_{WF}	Wigner-friend access deficit
$\eta_{F\to W}$	promotion strength $I_2(Z_F; Z_W)/H_2(Z_F)$
τ_{RAH}	record availability horizon for externalized access