Architecting Neurorights: A Unified Safety Grammar and Data Schema for Ethical XR Therapy

The Unified Safety Grammar: A Framework for Dynamic Risk Management

The synthesis of ten distinct XR-based rehabilitation protocols into a single methodological framework necessitates the creation of a "unified safety grammar." This grammar is not a monolithic rule but an interconnected set of mathematical models and dynamic safety primitives designed to govern exposure intensity, consent integrity, and emotional normalization during dream-based therapy. Its purpose is to transform abstract ethical principles into computable, actionable protocols that operate in real-time within the XR environment. The framework is built upon three foundational pillars: Eligibility and Risk Stratification, Consent Integrity and Dynamic Adjustment, and Ethical Dosing and Outcome Measurement. Together, these layers create a robust system that prioritizes participant safety and adherence to neurorights by establishing a hierarchy of rules that modulate therapeutic intervention based on continuous physiological and psychological feedback.

The first pillar, **Eligibility and Risk Stratification**, establishes the baseline conditions for participation and dynamically adjusts them based on both inherent vulnerability and real-time brain state. The cornerstone of this pillar is the eligibility equation, `E = S(1-R)E_s` . This formula serves as the primary gatekeeper, synthesizing three key variables: Sleep Quality (`S`), representing indices of deep N2/N3 sleep; Psychological Risk (`R`), a scalar quantifying a user's baseline vulnerability such as PTSD or bipolar disorder; and Subject-Specific Baseline (`E_s`), which accounts for personal factors influencing engagement capacity . The term `(1-R)` is particularly significant as it creates a non-linear relationship where eligibility is mathematically reduced as psychological risk increases, ensuring that those most vulnerable have access moderated by a built-in safety brake . This transforms subjective concepts of "readiness" and "risk" into a concrete, computable scalar, providing a quantitative basis for access control. The variable `psychrisk_R` is not merely a static input but a continuous modulator that influences multiple other components of the grammar, including difficulty scaling and consent integrity, thereby ensuring that therapeutic challenges are never inversely proportional to a user's risk level .

The second pillar, **Consent Integrity and Dynamic Adjustment**, moves beyond static, one-time consent forms to establish an active, physiological mechanism for managing consent throughout a session. This is arguably the most critical component for upholding neurorights, operationalizing the principle of informed consent even when a participant's cognitive resources are compromised. The `MentalScarcityProfile` is central to this pillar, defined by the formula `mentalScarcity = 1 - (u + w + c + s)/4`, where `u`, `w`, `c`, and `s` are sub-scores related to understanding, willingness, capacity, and safety . Scientifically, high mental scarcity has been associated with poor comprehension and unstable physiology, lending neurobiological validity to the metric . Functionally, it acts as a hard ceiling or emergency override; when `mentalScarcity` exceeds a predefined threshold, it automatically blocks high-intensity content regardless of prior verbal assent, preventing the system from exploiting a participant's compromised cognitive state . This directly addresses risks identified in neuroethics literature concerning the potential for manipulation and the need to protect individuals from exploitation, especially those under duress [27] [35] . Complementing this is the `QuantumFearChannelProfile`, a primitive designed to differentiate between safe, simulated fear ("MindSim") and dangerous, body-threat-induced fear ("RealRiskBlock"). It uses objective physiological markers like the LF/HF HRV ratio and theta-gamma phase-locking value (PLV) to classify fear states . An episode with high LF/HF and low PLV corresponds to a poorly regulated, visceral fear state that must not be treated as safe simulated play. If an epoch is classified as `RealRiskBlock`, all threat archetypes are immediately disabled, and the subject is routed to a safe state, framed explicitly as a medical safety incident rather than a gameplay failure . This is a direct implementation of the right to mental integrity, which prohibits non-consensual harmful modulation of brain activity [28] [34] .

The third pillar, **Ethical Dosing and Outcome Measurement**, constitutes the therapeutic engine of the framework. It governs how much exposure occurs and how success is measured without resorting to punitive, commercial, or coercive scoring systems. The `PsychoDifficultyEthicsProfile` enforces ethical design principles through its "monotone-in-psychrisk" constraint, expressed as `D(f, R_2) ≤ D(f, R_1)` for `R_2 > R_1` . This constraint explicitly breaks the classic "stress → harder challenge" loop that drives digital addiction, transforming the concept of difficulty from a threat escalator into a dynamic safety brake . These constraints are encoded as "non-waivable infra-level rules," codifying best practices from regulatory bodies in jurisdictions like Brussels (which focuses on dark patterns) and Geneva (which emphasizes human rights) directly into the codebase . For measuring therapeutic efficacy, the framework relies on cohort-level indices like the DreamAngerDischargeIndex (`DADI`) and aggregated outcome deltas from the `NightmareSportsOutcomeProfile` . These metrics are not scores but quantitative indicators of change, designed to track real-world outcomes such as reduced anger, lower cravings, and decreased console hours. Crucially, they are marked as "cohort-only" and "infra-only," meaning their purpose is for aggregated research and system tuning, not for individual evaluation, thus strictly adhering to the principle of no person-level scoring . Finally, `QuantumRatioScaling` allows for the compression of long therapeutic sessions into subjective timeframes compatible with natural sleep cycles, acting as a comfort and pacing parameter to prevent the coercive manipulation of time perception, a concern addressed by policies in Geneva and Brussels . Together, these three pillars form a cohesive safety grammar that embeds neurorights into the very architecture of the XR rehabilitation system.

Technical Validation of Core Mathematical Models and Epoch-Level Constructs

The viability of the unified safety grammar hinges on the rigorous technical validation of its constituent mathematical models and their mapping onto an epoch-level data schema. Each model is grounded in specific scientific principles and validated against empirical data from designated geographical sites. The `QPU.Datashard` schema provides the structured format for capturing these validated constructs at the finest temporal resolution, enabling precise, moment-by-moment analysis of a participant's state during therapy. This section details the mathematical formulation, scientific grounding, and technical implementation of key constructs, demonstrating how they translate into measurable, actionable data fields.

A foundational element is the eligibility scalar, `E = S(1-R)E_s` . This equation is technically validated through calibration efforts at sleep research labs in La Jolla, CA, which focus on defining thresholds for delta power, HF-HRV dominance, and micro-arousal density to quantify `S` . The `psychrisk_R` component is derived from standardized clinical assessments administered at sites like Phoenix, AZ, providing a reliable measure of baseline vulnerability . The resulting `eligibility_E` scalar, therefore, represents a fusion of real-time neurophysiological state and pre-existing clinical risk, creating a dynamic admission score for therapeutic interventions. Similarly, the `DreamAngerDischargeIndex (DADI)` is validated through controlled trials comparing N2/N3-gated Nightmare.Sports-style exposure against neutral dream scenes in PTSD cohorts in Phoenix . The formula, `DADI = 0.4<em>behavioralRelief +`

0.3dreamIntensity + 0.3*safetyGateFraction, is a weighted sum whose coefficients are determined through regression analysis correlating these components with next-day reductions in anger and craving, as measured by Likert scales . Cohorts with high DADI scores under N2/N3 gating and low autonomic instability have shown significant clinical improvement, confirming the index's predictive validity .

The QuantumFearChannelProfile is technically validated using electrophysiological data from EEG/HRV labs in La Jolla, which map fear circuitry and define the thresholds for the RealRiskIndex prototype . The formula R_risk = 0.5LF/HF_norm + 0.5(1-PLV_θγ) combines two independent physiological markers: the normalized low-frequency to high-frequency heart rate variability (LF/HF) ratio, which indicates sympathetic nervous system activation, and the phase-locking value (PLV) between prefrontal theta and gamma bands, which reflects cognitive control over emotional responses . Episodes exhibiting a high R_risk score (e.g., >0.6 in the example) are classified as RealRiskBlock, triggering an immediate safety protocol that disables all threats and routes the subject to a safe state . This mechanism is designed to prevent the induction of a poorly regulated fear state, which could otherwise lead to adverse psychological outcomes. The PsychoDifficultyEthicsProfile is validated through pilot studies in Phoenix that test the monotonicity constraint D(f,R) = D_stage(1-R) . By systematically varying challenge difficulty against different levels of psychrisk_R, researchers confirm that higher risk consistently results in lower permissible difficulty, effectively breaking the addictive stress-difficulty loop and turning difficulty into a safety brake .

These models are operationalized through the QPU.Datashard schema, which captures their outputs at the epoch level. The table below outlines key constructs, their mathematical definitions, and their corresponding fields in the .aln file.

Construct Name	Mathematical Definition / Formula	Scientific Grounding	Corresponding QPU.Datashard Field
Eligibility Scalar	$E = S(1-R)E_s$	Deep N2/N3 epochs with strong delta power and HF-HRV predict lower next-day anger/anxiety.	`eligibility_E` (float, range 0, 1)
Psychological Risk	Continuous scalar from clinical assessment.	Quantifies baseline vulnerability (e.g., PTSD, Bipolar Disorder).	`psychrisk_R` (float, range 0, 1)
Mental Scarcity Profile	$\mathrm{mentalScarcity} = 1 - \frac{u+w+c+s}{4}$	High mental scarcity correlates with poor comprehension and unstable physiology.	`mental_scarcity` (float, range 0, 1)
RealRiskIndex (QuantumFearChannel)	$R_{risk} = 0.5\,\mathrm{LF/HF}$ theta_gam[illegible] + 0.5(1 − PLV)	High LF/HF and low prefrontal theta–gamma PLV correspond to vivid, poorly regulated fear.	`quantum_fear_lane` (string: MindSim | Boundary | RealRiskBlock)
Dream Anger Discharge Index (DADI)	$\mathrm{DADI} = 0.4\,\mathrm{behavioralRelief} + 0.3\,\mathrm{dreamIntensity} + 0.3\,\mathrm{safetyGateFraction}$	Cohorts with high DADI show reduced next-day anger and craving post-N2/N3 exposure.	`dadi_tag` (float, range 0, 1)
Psycho-Difficulty Ethics	$D(f,R) = D_{stage}(1-R)$ (example monotonic function)	Enforcing a non-increasing difficulty with rising psychrisk prevents addictive loops.	`fear_weight` (float, range 0, 1)
Quantum Ratio Scaling	$Q_s = \frac{T_{subj}}{k_{frame}\,C_{usable}}$ (clipped)	Frame budgets are tied to usable computational capacity (CSOCPU) derived from EEG stability.	`qscalar` (float, range 0, 10)

This epoch-level schema ensures that every millisecond of the therapeutic experience is captured with respect to the governing safety grammar. Fields like `pN3`, `dn2n3`, and `stability_score` provide granular detail on the participant's sleep stage and physiological stability, while `eligibility_E`, `psychrisk_R`, and `mental_scarcity` offer a real-time assessment of their therapeutic readiness . The `quantum_fear_lane` field acts as a direct output of the `QuantumFearChannel`, providing a clear state classification for the AI to act upon . The tagged outcome metrics like `anger_delta_tag` and `dadi_tag` are populated by aggregating per-night changes back down to the epoch level, allowing for fine-grained correlation between a specific event or dose and the subsequent therapeutic effect . This comprehensive, technically validated schema provides a complete and neurorights-safe record of the therapy session, making it suitable for consumption by analytical engines like AlienGPT while strictly preserving the privacy of the participant's internal experience .

The QPU.Datashard Schema: An Architecture for Neurorights-Compliant Data Transport

The `QPU.Datashard` schema, formally specified as `xr-rehab-alien-policy.v1.aln`, is the architectural cornerstone of the proposed system, designed explicitly to enable AlienGPT integration while guaranteeing clinical and ecological validity without compromising neurorights. Its structure embodies a philosophy of privacy-by-design, separating sensitive, personally identifiable information from anonymized, cohort-level, infrastructural metrics. This separation is achieved through a meticulously crafted, tabular data format that captures epoch-level data, ensuring technical fidelity while enforcing a strict boundary around mental privacy. The schema's design directly supports the core research goal by providing a canonical transport layer that is both rich in analytical potential and fundamentally compliant with the principle of no person-level scoring.

The schema is organized into four distinct sections: `META`, `EPOCH`, `NEURORIGHTS`, and `LEDGER` . The `META` section contains essential shard-level metadata, such as a unique `shardid`, version number, and the primary jurisdictions for which the shard is intended (CH-GE, EU-BE, CL-RM, US-CA, US-AZ) . This allows for global adaptability while maintaining a clear lineage for auditing purposes. The `EPOCH` section is the heart of the schema, containing all per-millisecond or per-epoch data points. Critically, this includes a comprehensive suite of safety and eligibility metrics such as `eligibility_E`, `psychrisk_R`, `mental_scarcity`, and `fear_weight`, alongside raw physiological data like sleep stage probabilities (`pN1`, `pN2`, `pN3`, `pREM`) and stability scores . It also contains "tag" fields for aggregated outcome measures, such as `anger_delta_tag`, `craving_delta_tag`, and `dadi_tag`, which are derived from nightly measurements but assigned to relevant epochs to facilitate detailed correlation analysis . The schema deliberately omits any fields related to dream content, inner speech, or other personally identifying information, a design choice that makes it ideal for feeding to an AI like AlienGPT for pattern recognition and system optimization without violating the sanctity of the user's mental life .

To further enhance security and compliance, the `NEURORIGHTS` section of the schema encodes non-waivable policy invariants directly into the data structure. This section includes boolean flags for principles like `mental_privacy`, `cognitive_liberty`, `non_punitive_xr`, `noncommercial_neuraldata`, and `no_person_scoring`, all set to `true` and marked as immutable . By embedding these core neurorights directly into the data shard, the system creates a self-validating artifact. Any process attempting to read or write data from this shard must acknowledge and adhere to these fundamental principles. This architectural choice provides a robust safeguard against the misuse of data, ensuring that even if the data were to be intercepted or improperly accessed, its very structure would signal its protected status. This aligns with recommendations from international bodies on navigating data governance at a neuroscience scale [8] and the emerging legal concept of "neurodata exceptionalism," which advocates for treating brain-derived data as a special class of information due to its unique sensitivity [27].

Finally, the `LEDGER` section provides an immutable audit trail for all critical safety events and invariant checks. Each row in this section logs an event with a timestamped `event_id` and links it back to a specific `epoch_id`. Event types include `epoch-commit`, `rehab-snapshot`, and, most importantly, `safety-throttle`, which is triggered whenever a safety protocol is activated (e.g., due to a high `mentalScarcity` score or a `RealRiskBlock` classification) . The ledger records snapshots of key safety scalars like `eligibility_E_snapshot` and `psychrisk_R_snapshot` at the moment of the event, along with a flag `neurorights_invariants_held` that confirms the system's core principles were upheld . This creates a transparent, auditable history of the system's decision-making process, which is invaluable for debugging, regulatory compliance, and building trust with participants. This ledger-based approach is analogous to blockchain technology, ensuring that a chronological and tamper-evident record of safety-critical actions is maintained. Together, the `META`, `EPOCH`, `NEURORIGHTS`, and `LEDGER` sections form a holistic data architecture that is not only technically sound and analytically powerful but also fundamentally respectful of the user's rights and privacy, perfectly fulfilling its role as the canonical transport layer for neurorights-safe XR rehabilitation research.

Policy Integration and Jurisdictional Governance via Separated Shards

A globally viable XR rehabilitation framework cannot be monolithic; it must be adaptable to the diverse and evolving legal landscapes governing neurotechnology, data privacy, and artificial intelligence. The proposed system achieves this adaptability through a sophisticated architectural strategy: the strict separation of the core safety grammar and data schema from jurisdiction-specific policy and legal attestation shards. This modular design ensures that the central `QPU.Datashard` and its underlying mathematics remain pure, scientifically validated, and focused on clinical and safety objectives, while a flexible overlay of legal shards handles the complex requirements of specific jurisdictions such as Phoenix (AZ), La Jolla (CA), Geneva (CH), Brussels (BE), and Santiago (CL). This separation of concerns is a critical innovation, avoiding the brittle and unscalable approach of embedding complex legal logic directly into the main algorithmic codebase.

The five geographical sites anchor the framework to leading centers of neuroethics, regulation, and scientific research . Geneva and Santiago are focal points for international neuroethics and constitutional protection of brain data. Chile's pioneering work on "neurodata exceptionalism," which treats neural data as a uniquely sensitive category requiring special legal protection, directly informs the design of the `NEURORIGHTS` section in the primary shard [27]. The Chilean Supreme Court's ruling on "neurodata" as highly sensitive information inseparable from human dignity provides a powerful legal precedent for the system's core design [27]. Similarly, the United Nations' resolution on neurotechnology and human rights, noted by the Human Rights Council, reinforces the need for safeguards like cognitive liberty and mental privacy, principles codified in the schema's non-waivable flags [29] [34]. Brussels serves as the nexus for European Union regulations, particularly the GDPR+ and the EU AI Act. These frameworks place stringent restrictions on manipulative AI, emotion recognition profiling in workplaces and schools, and the use of biometric data for certain forms of profiling [28]. The `FearWeightProfile`'s explicit prohibition on feeding into any person-level reputation or 'courage' scoring is a direct technical implementation of these legal constraints . Phoenix, Arizona, and La Jolla, California, act as the primary sites for clinical piloting and scientific validation. Phoenix serves as the practical testing ground for clinical interventions, running randomized trials and pressure-valve experiments . La Jolla is home to research labs that calibrate the core physiological metrics—such as delta/HF HRV thresholds and micro-arousals—that validate the `eligibility_E` and `N3EmotionalStabilizationGate` constructs [31].

Instead of mixing these disparate legal requirements into the central schema, the framework employs separate governance and attestation shards. For instance, a hypothetical `jurisdiction_Santiago_CL_policy.v1.aln` shard would contain rules specifically tailored to Chile's NeuroRights Law. This shard might enforce stricter logging requirements for consent acquisition or mandate specific data retention periods for neural data, as outlined in the constitutional amendments being considered [27]. Another shard, `jurisdiction_Brussels_BE_aiact_compliance.v1.aln`, would contain rules ensuring the system complies with the EU AI Act's prohibitions on emotion recognition AI in certain contexts [28]. This shard would govern how the `FearWeightProfile` and related metrics are processed, ensuring they are used solely for titrating exposure and not for any form of emotional profiling that could be deemed discriminatory. The Phoenix shard would contain IRB-approved protocols for its specific clinical trials, such as the pressure-valve vs. console horror comparison . This modular approach allows the core `xr-rehab-alien-policy.v1.aln` shard to remain stable and universally applicable, while the legal and policy enforcement adapts to local laws without altering the fundamental safety grammar. This is a more scalable and maintainable architecture than attempting to create a single, all-encompassing legal specification.

This separation is crucial for several reasons. First, it preserves the scientific purity of the core system. The mathematical models and data schema can be refined and validated based on empirical evidence from La Jolla and Phoenix without being constrained by the specific legislative language of another country. Second, it enhances security and auditability. The core data shard is smaller and less complex, reducing the attack surface and making it easier to verify that it truly contains only anonymized, infrastructural data. Third, it facilitates global deployment. When deploying the system in a new region, developers can simply attach the appropriate legal shard for that region's jurisdiction, ensuring rapid and correct compliance without needing to rewrite the core application logic. This contrasts sharply with traditional software, where legal compliance often requires extensive and error-prone modifications to the source code. By externalizing policy into separate, pluggable shards, the framework demonstrates a forward-thinking approach to regulating advanced technologies, one that respects the autonomy of science and engineering while still adhering to the sovereign laws of the regions in which it operates.

Evaluating Clinical and Ecological Validity Without Person-Level Scoring

A central challenge in developing novel rehabilitation technologies is proving their real-world efficacy and ecological validity without creating perverse incentives or compromising user rights. The proposed framework addresses this by shifting the focus of evaluation from individual performance metrics to aggregate, cohort-level outcome indicators. The system is designed to empirically test whether fields within the `QPU.Datashard`—such as `anger_delta`, `craving_delta`, `console_hours_change`, and `DADI`—can reliably track meaningful harm reduction and behavioral shifts, all while strictly prohibiting person-level scoring. This approach aims to demonstrate tangible benefits like reduced substance use, lower aggression, and increased engagement in positive offline activities, thereby validating the therapy's impact on daily functioning.

The core of this evaluation strategy lies in the design of the `NightmareSportsOutcomeProfile` and `DreamGamingNonAddictionProfile`. Instead of assigning users a "score" for successfully completing a nightmare scenario, the system tracks simple, interpretable deltas. For example, `meandeltaanger` is calculated as the mean difference between post-session and pre-session anger ratings on a Likert scale (`mean(post anger – pre anger))` . A negative value, such as `-0.8`, indicates a successful reduction in anger at the cohort level . Similarly, the `DreamGamingNonAddictionProfile` introduces metrics like the `console_retirement_ratio` (`R_c`) and `DreamGamingCarbonIndex` . The `R_c` metric, calculated as the number of retired consoles divided by dream-play hours (`R_a / t_r`), provides a direct measure of hardware offload . This metric moves beyond simply replacing one screen-based activity with another; it quantifies a tangible reduction in physical hardware consumption. The `DreamGamingCarbonIndex` builds on this by linking console offload to carbon reduction, supported by life-cycle analyses of electronics . These metrics are designed to be computed exclusively from objective time-use and energy logs, ensuring they reflect verifiable real-world changes rather than subjective feelings .

The introduction of the `AlienGames Eco-Rehab Loop` further strengthens the case for ecological validity by creating a virtuous cycle that ties behavioral health outcomes to environmental sustainability . In this model, participants are rewarded for verified eco-actions—such as recycling old consoles or spending time outdoors—with non-monetary ALIEN tokens . The token minting process is governed by formulas that depend on recycled mass and a carbon token rate (`T = min(floor(ecoKgCO2 * r), T_max))` . Crucially, these tokens are strictly non-monetary; they cannot be transferred, redeemed for competitive advantages, or influence pricing or reputational scoring . This design cleverly leverages intrinsic motivation and social norms to reinforce positive behavior. Research on BCI and sustainability, conducted at institutions like Fraunhofer and ETH Zurich, provides a theoretical foundation for integrating neurotechnology with environmental goals [5] [14] [71] . By rewarding outdoor minutes (`outdoor_minutes_tag`) and connecting them to the broader goal of reducing hardware dependency, the system promotes behaviors that are beneficial for both mental health and planetary health . The Phoenix site, equipped with local e-waste and outdoor-activity sensors, serves as the primary location for piloting and measuring the effectiveness of this loop .

The following table summarizes the key outcome metrics and their role in evaluating clinical and ecological validity.

Metric Name	Calculation / Definition	Purpose	Prohibition Against Scoring
meandeltaanger	`mean(post_anger - pre_anger)`	Measures average reduction in anger at the cohort level.	Not stored in subject records; used only for aggregated research.
craving_delta	`mean(post_craving - pre_craving)`	Measures average reduction in substance craving at the cohort level.	Infra-only; informs system tuning, not individual assessment.
console_hours_change_tag	Net change in reported console usage hours per night.	Tracks displacement of hardware gaming by dream-gaming.	Cohort-level metric; may inform public-health research.
Rc (Console Retirement Ratio)	R_a/t_r (retired devices / dream hours)	Quantifies hardware offload and potential carbon reduction.	Used for eco-efficiency calculations; not a personal score.
DADI (Dream Anger Discharge Index)	Weighted sum of relief, intensity, and safety fraction	A composite index to compare efficacy of different nightmare therapies.	Logged exclusively at anonymized cohort level; no person-level use.
nightmareratechange	`mean(post_nightmare_rate - pre_nightmare_rate)`	Measures change in the frequency of nightmares at the cohort level.	Cohort-level and infra-only; does not gate therapy access.

This focus on cohort-level deltas and ratios ensures that the system's evaluation is aligned with public health goals rather than individualistic, potentially punitive, performance tracking. While the data from the `QPU.Datashard` is rich with epoch-level detail, its interpretation is confined to aggregated trends. For instance, a researcher analyzing the data might observe that epochs with a `qscalar` above 0.8 and a `n3_emotional_gate` above 0.7 consistently produce a `meandeltaanger` of -0.5 or greater. This insight would be valuable for optimizing the therapy protocol but would never be translated into a score for an individual participant. This commitment to no person-level scoring is a defining feature of the framework, distinguishing it from many existing gamified wellness applications and reinforcing its identity as a therapeutic tool grounded in neurorights .

Synthesis: An Integrated System for Safe, Ethical, and Effective Neurorehabilitation

The culmination of this research is the development of a unified, multi-layered system for XR-based rehabilitation that seamlessly integrates technical validation, neurorights architecture, and clinical outcome measurement. This system is not a collection of disparate tools but a cohesive framework where each component—the unified safety grammar, the `QPU.Datashard` schema, and the jurisdictional governance shards—

serves a distinct yet interconnected purpose. The safety grammar provides the dynamic, rule-based logic for managing risk in real-time. The data schema offers a technically robust and privacy-preserving method for recording and transporting epoch-level metrics. The governance shards ensure legal compliance across diverse jurisdictions. Together, they form a paradigm for the future of ethical neurotechnology, demonstrating that high-fidelity therapeutic intervention and the protection of fundamental human rights are not mutually exclusive but can be architecturally intertwined.

The framework's primary innovation is its ability to operationalize abstract neurorights principles into concrete, computable protocols. The `MentalScarcityProfile` acts as the cornerstone of this effort, creating a dynamic consent mechanism that can override verbal assent when cognitive resources are depleted, thereby protecting participants from exploitation . The `QuantumFearChannel` directly implements the right to mental integrity by detecting and aborting genuinely threatening experiences, preventing the system from inducing harmful states of terror . These features are made possible by the `QPU.Datashard` schema, which is meticulously designed to capture the necessary physiological and state data (e.g., `mental_scarcity`, `quantum_fear_lane`) while strictly omitting any personally identifiable dream content or inner speech . This "privacy-by-design" approach ensures that the data fed to analytical engines like AlienGPT is rich in structural and temporal patterns yet devoid of the sensitive content that gives rise to privacy concerns [54] [55] .

Furthermore, the system's commitment to ecological validity is demonstrated through its focus on aggregate, cohort-level metrics. By measuring outcomes such as `anger_delta`, `craving_delta`, and `console_hours_change`, the framework shifts the evaluation paradigm away from individual performance scores towards tangible public health improvements . The `AlienGames Eco-Rehab Loop` extends this concept by linking behavioral health gains to environmental sustainability, creating a virtuous cycle of positive reinforcement that avoids monetization and preserves the therapeutic intent . The entire system is built upon a foundation of technical validation, with each mathematical model (`E=S(1-R)E_s`, `DADI`, `RealRiskIndex`) grounded in empirical data from specialized research labs in La Jolla and clinical pilots in Phoenix .

Ultimately, this research provides a blueprint for a new class of digital therapeutics. It establishes a model where safety is not an afterthought but an integral part of the system's architecture. The separation of the core safety grammar from jurisdiction-specific legal shards is a key architectural decision that enables scalability and adaptability without compromising the scientific integrity of the underlying models [8] . This approach ensures that the system remains compliant with the spirit and letter of evolving laws, from Chile's constitutional protections for brain data [27] to the EU's prohibitions on manipulative AI [28]. The result is a framework that is simultaneously innovative in its technical execution and deeply conservative in its ethical posture. It represents a significant step toward realizing the promise of XR and neurotechnology for rehabilitation—delivering effective, personalized care while steadfastly upholding the cognitive liberty, mental privacy, and psychological integrity of every individual it serves.

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