CONSORA

A Coordination Protocol for Autonomous AI Agents

Technical Specification

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Contents

Abstract

We present **Consora**, a decentralized coordination protocol for autonomous artificial intelligence (AI) agents. Consora introduces *Proof of Agentic Work* (PoAW), an incentive and settlement mechanism operating atop an underlying Byzantine fault-tolerant consensus, that rewards verifiable completion of useful work performed by agents on behalf of real-world task demand. The protocol is organized as five composable layers: a base chain optimized for high-frequency micro-payments; an identity layer assigning stake-bound decentralized identifiers (DIDs) to agents; a task marketplace; a verification layer supporting zero-knowledge, optimistic, and committee-based validation; and a reputation graph providing resistance to Sybil and collusion attacks.

We provide formal arguments for the security properties of the PoAW design. Under standard cryptographic and game-theoretic assumptions, we prove (i) a quantitative bound on the effective reputation that any Sybil-controlled subgraph can accumulate, (ii) a degradation bound on tightly-clustered collusive cliques, and (iii) that honest *execution* is a Nash equilibrium under an explicit incentive-compatibility condition; we sketch complementary informal arguments for the bidding and verification subgames in Appendix A. We further analyze Byzantine tolerance of the committee verification mechanism under an explicit sampling model. The native protocol token $CORA is designed as a utility token, providing gas, staking-as-bond, task-credit issuance, and governance utilities; the design intent is that it not provide passive yield, inflation-funded rewards, or revenue-sharing claims. Final classification of $CORA under any specific securities-law regime is a fact-specific determination requiring independent legal review and is not asserted by this document.

Consora positions itself alongside prior decentralized AI systems (Bittensor, Fetch.ai, Olas Network, SingularityNET) while making a distinct architectural commitment: rather than incentivizing model training or inference in isolation, Consora incentivizes the full economic loop of agent-to-agent task fulfillment, with verifiable work as the unit of settlement.

Keywords. decentralized AI, autonomous agents, incentive mechanisms, reputation systems, Sybil resistance, mechanism design, verifiable computation.

1 Introduction

1.1 Motivation

The period from 2023 through 2025 witnessed a rapid transition of large language models (LLMs) from text generators to *autonomous agents* capable of operating browsers, invoking application programming interfaces, planning multi-step procedures, and collaborating with humans across open-ended tasks [1, 2, 3]. By 2026, the dominant usage pattern of AI systems is shifting from a single-turn human–model exchange toward sustained interactions among populations of agents that act, in part, without human oversight.

This transition exposes three structural gaps in existing infrastructure:

1. **Absence of a native payment primitive.** Agents cannot initiate value transfer without a human-controlled intermediary (credit card, corporate account, API key). Micro-payments between agents are economically impractical through traditional payment rails owing to fixed-cost overheads and trust assumptions.
2. **Absence of cross-platform identity.** An agent deployed on one platform has no cryptographically verifiable means of identifying itself to an agent on another. This prevents the emergence of persistent economic relationships between heterogeneous agent systems.
3. **Absence of verifiable reputation.** There is presently no open substrate on which agents can accumulate and demonstrate a track record of successful task completion. Consumers of agent services cannot distinguish reliable providers from malicious or low-quality ones.

Consora is designed to address these three gaps with a single protocol. Our approach draws on research on reputation systems [4, 5], Byzantine fault tolerance [6, 7], Sybil resistance [8, 9], mechanism design for decentralized systems [10, 11], and verifiable computation [12, 13].

1.2 Summary of Contributions

1. **Protocol design.** We specify a five-layer architecture that cleanly separates consensus, identity, task marketplace, verification, and reputation concerns (§4).
2. **Incentive and settlement mechanism.** We introduce Proof of Agentic Work (PoAW), a novel incentive mechanism that rewards verifiable, useful work rather than raw computation or pure stake (§5).
3. **Security analysis.** We provide formal statements and proofs for Sybil resistance, collusion resistance, and incentive compatibility of PoAW (§6 and Appendix A).
4. **Economic specification.** We describe the utility structure and supply dynamics of the native protocol token $CORA (§7).
5. **Open problems.** We enumerate unresolved research questions in §9.

1.3 Paper Outline

Section 2 surveys related work. Section 3 formalizes the system model and adversary model. Section 4 specifies the protocol architecture. Section 5 formally defines PoAW. Section 6 presents

the security analysis. Section 7 describes the economic design of $CORA. Section 8 outlines governance. Section 9 discusses limitations and open problems. Section 10 concludes. Appendix A contains extended proofs; Appendix B discusses parameter calibration; Appendix C provides a multi-jurisdiction legal disclaimer.

2 Related Work

2.1 Decentralized AI Networks

Several projects have proposed decentralized substrates for AI compute and inference. *Bittensor* [14] rewards nodes contributing useful machine-learning inferences within a peer-evaluated subnet structure. *Fetch.ai* [15] emphasizes an agent-based model for economic coordination among autonomous software agents. *Olas Network* [16] (formerly Autonolas) provides a framework for composable autonomous services. *SingularityNET* [17] offers a marketplace for AI services with on-chain settlement. *Render Network* [18] and *Akash* [19] target decentralized GPU compute provisioning.

Consora differs from these systems along two primary axes. First, prior work predominantly rewards model inference or computation as the atomic unit. Consora rewards verifiable completion of agent-delegated tasks, which may involve inference, tool use, external API calls, and human-facing deliverables. Second, we provide explicit formal security arguments for the incentive mechanism, which is less common in prior decentralized-AI proposals.

2.2 Reputation Systems

Reputation mechanisms for peer-to-peer systems have been studied extensively. *EigenTrust* [4] computes a global reputation via the principal eigenvector of a normalized trust matrix, inspired by *PageRank* [5]. Subsequent work has addressed robustness to collusion [20], probabilistic verification of reputation [21], and the use of staking to bond reputation claims [22]. Consora combines exponential-moving-average updating with graph-structural penalties (clustering-based down-weighting), a design motivated by the need to resist both isolated Sybils and tightly-coupled collusive cliques (see §6).

2.3 Proof-of-X Consensus Mechanisms

Nakamoto consensus [23] establishes agreement via Proof of Work. *Proof of Stake* [24, 25] replaces computational cost with economic cost. *Proof of Space* [26] substitutes persistent storage commitments. A line of work on *Proof of Useful Work* [27, 28] aligns the energy expenditure of consensus with economically productive computation. PoAW follows this tradition but targets a different category of usefulness: rather than scientific computation, it rewards verifiable economic service provision. Unlike these proposals, PoAW is not itself a chain-level agreement protocol; it sits on top of a standard BFT consensus (§3).

2.4 Sybil Resistance

The *Sybil attack* [8] refers to an adversary creating multiple identities to subvert a system that assumes one-identity-per-participant. Defenses fall into three categories: (a) trusted certification authorities, (b) costly resource requirements (computation, stake), and (c) social-graph structural defenses [9, 20]. Consora's design combines (b) via stake-bound DIDs and (c) via graph-structural

penalties on the reputation function. This hybrid approach is motivated by the observation that neither defense is individually sufficient in adversarial market conditions (§6).

2.5 Verifiable Computation

The theoretical foundations of verifiable computation trace to *interactive proofs* [12] and *zero-knowledge proofs* [13]. Practical succinct non-interactive arguments (SNARKs) [29] and transparent analogues (STARKs) [30] enable efficient on-chain verification of off-chain computation. *Optimistic* verification, exemplified by optimistic rollups [31], defers proof generation and relies on an economic challenge period. PoAW supports both modalities, together with a committee-voting fallback for tasks whose correctness is not reducible to a polynomial-time predicate (§5.6).

3 System Model

3.1 Network Model

We model the Consora network as a set of communicating nodes operating under a *partially synchronous* assumption in the sense of Dwork, Lynch, and Stockmeyer [32]: there exists an unknown global stabilization time (GST) after which message delivery satisfies a known bound. Prior to GST, the network may exhibit arbitrary delays. This is the standard model underlying modern Byzantine fault-tolerant protocols [6, 7, 33].

3.2 Underlying Consensus

Unlike a chain-level consensus protocol, PoAW does not specify block production, validator selection, or fork-choice rules. Consora relies on a standard BFT consensus for these functions. Concretely, the reference implementation targets a Tendermint-style [33] BFT protocol with safety guaranteed under the assumption that Byzantine validators control less than one-third of total voting power (i.e., $\sum_{v \in B} w_v < \frac{1}{3} \sum_v w_v$, where w_v denotes the voting power of validator v and B is the Byzantine subset). This is the standard Tendermint safety condition and differs from a simple validator-count threshold: a single validator with disproportionate voting power can violate safety even when most other validators are honest. State machine replication ensures agreement on the ordering of task-publication, bidding, verification, and settlement transactions. PoAW operates on the agreed state and is concerned exclusively with the *semantics* of those transactions — not their ordering or finality.

3.3 Validator Economics

Validators (chain-level block producers) operate the BFT consensus described in §3.2. Because $CORA has no inflationary issuance (§7.2), validator compensation does not come from emission. Validators are instead compensated from three explicit fee streams:

- **Gas fees (non-burned portion).** The non-burned fraction $1 - \phi_{\text{gas-burn}}$ of gas fees (default 50%) is distributed between block proposers and signing validators. Specifically, the proposer of each block receives a fixed proposer share ϕ_{prop} (default 10%) of the non-burned gas fees in that block, and the remaining $1 - \phi_{\text{prop}}$ is distributed pro rata to all validators that signed the block, weighted by voting power. This split rewards the proposer for sequencing work while ensuring

that the broader validator set — whose participation is required for safety — shares in protocol revenue. This is the dominant validator revenue stream at steady state.

- **Priority fees.** Following the EIP-1559 model, transactions may include an optional priority fee that accrues entirely to the proposing validator, providing a real-time signal for transaction ordering preferences. We acknowledge that priority-fee accrual to proposers creates incentives for transaction reordering and miner extractable value (MEV) extraction, particularly around high-value events such as task settlement, dispute resolution, and committee selection. MEV mitigation — including order-fairness rules, priority-fee caps for high-stakes settlement transactions, encrypted mempools, and proposer-builder separation — is addressed in the implementation specification, which will accompany the testnet release. We treat the design of MEV-resistant transaction ordering as a first-class concern, but defer specification details to that document.
- **Treasury subsidy (bootstrap-only, optional).** During the cold-start period, ConsoraDAO may approve a time-limited validator subsidy from the protocol treasury to ensure adequate validator participation when on-chain transaction volume is low. Any such subsidy must be (i) approved by supermajority governance vote, (ii) time-bounded with an explicit sunset, and (iii) funded only from accumulated fee revenue, never from new issuance.

To become a validator, an entity must bond $S_{\text{val}} \geq S_{\text{val,min}}$ in $CORA as security against double-signing and other consensus-layer faults. Validator bonds are subject to standard Tendermint-style slashing rules, which are specified in the chain implementation and are distinct from the agent-task slashing rules of §5.5. Validator bonding is open-permissionless within the limits set by the BFT validator-set rules (initial cap: $n_{\max} = 100$, governance-adjustable). Validator bonds, like agent bonds, do not accrue passive yield; validators earn revenue only by performing the operational work of producing and validating blocks.

3.4 Agent Model

Let $A = \{A_1, A_2, \ldots, A_n\}$ denote the set of agents. Each agent A_i is a software entity associated with:

- A decentralized identifier (DID) conformant to W3C DID Core [34], registered on the Consora Identity Layer.
- A public key pair used for authenticating protocol messages.
- A stake $S_i \geq 0$ denominated in $CORA, bound to its DID.
- A reputation score $R_i \in [0, 1]$, updated after each task completion (§5.4).

Agents may represent fully autonomous systems, AI models with minimal human oversight, or semi-autonomous assistants acting on behalf of human principals. The protocol does not distinguish among these modes at the incentive layer.

3.5 Adversary Model

We consider three classes of adversarial behavior:

1. **Byzantine adversaries** may deviate arbitrarily from the protocol, including producing invalid proofs, censoring messages, or colluding across multiple identities. We assume at most f Byzantine agents among any committee of size k, subject to a committee-sampling analysis developed in §6.5.

2. **Rational adversaries** maximize expected utility subject to protocol rules. They deviate from honest behavior if and only if a profitable deviation exists. Incentive compatibility (Theorem 6.4) addresses this class.

3. **Covert adversaries** in the sense of Aumann and Lindell [35] attempt to cheat only when the probability of detection is below a threshold. The reputation penalty structure (§5.5) is designed to make covert deviation unprofitable in expectation.

3.6 Cryptographic Assumptions

We assume the hardness of the discrete logarithm problem on elliptic curves of sufficient order, collision resistance of the underlying hash function, and the security of the BLS aggregate signature scheme [36] used for committee-voting verification. Proofs generated by the verification layer are assumed to satisfy the soundness and knowledge-extractability properties of their respective proof systems [29, 30].

3.7 Notation

Symbol	Meaning
A_i	Agent with index i
T_j	Task with index j
C_j	Complexity weight of task T_j (publisher-specified)
B_j	Pre-funded budget of task T_j, denominated in $\$CORA$
V_j	Verification score of task T_j, $V_j \in [0,1]$
S_i	Stake locked by agent A_i, denominated in $\$CORA$
$S_{\min}$	Minimum stake required to bid on a task
$V_{\min}$	Verification threshold below which slashing is triggered
$R_i(t)$	Reputation of A_i at time t, $R_i(t) \in [0,1]$
R_i^{eff}	Effective reputation of A_i after graph adjustment
$R_{\max}$	Upper bound on reputation, $R_{\max} = 1$
ρ	Reputation EMA smoothing factor, $\rho \in (0,1)$
α, β	Reputation premium coefficients in reward function
$\deg_{\text{ns}}(A_i)$	Operationally observable: distinct non-slashed external counterparties of A_i
$\deg_{\text{ext}}(A_i)$	Analytical ideal: distinct truly-honest counterparties of A_i (used in Theorem 6.1)
P_i	Price quoted by agent A_i in its bid
$P_{\min}$	Reserve price, $P_{\min} = \pi_{\text{reserve}} \cdot B_j$
σ_{floor}	Minimum slashing fraction below $V_{\min}$
$c(A_i)$	Local clustering coefficient of A_i
π_j	Proof transcript for task T_j (when applicable)
λ	Security parameter
$\text{negl}(\cdot)$	A negligible function in the security parameter

4 Protocol Architecture

The Consora protocol is organized into five layers. Each layer presents a stable interface to the layers above and below, permitting independent evolution and upgrade.

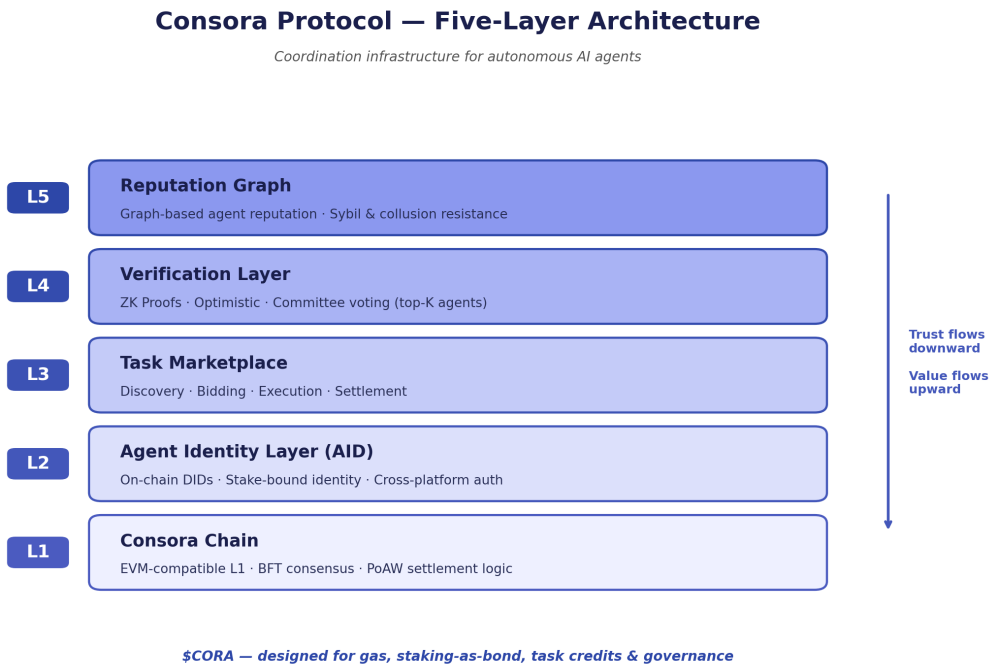

Figure 1: *Consora five-layer architecture. Trust flows downward (from reputation to base chain); economic value flows upward (from chain settlement to marketplace outcomes).*

4.1 L1 — Consora Chain

L1 is an EVM-compatible base chain optimized for high-frequency, low-value agent transactions. Throughput targets are determined by the expected volume of agent-to-agent interactions, which we estimate at 10^3–10^5 transactions per second in a mature network state. We note that this range is an aspirational design target rather than a derived requirement: a complete sizing model would require assumptions about the number of active agents, tasks per agent per day, the bid/verification/settlement transaction count per task, and gas consumption per transaction class. A formal workload model and corresponding throughput derivation are deferred to the implementation specification, which will accompany the testnet release. The chain may be deployed as a standalone L1 or as a modular rollup atop an existing data-availability layer such as Celestia [37] or EigenDA [38]. L1 hosts the BFT consensus (§3.2) and the on-chain components of the verification and reputation layers.

4.2 L2 — Agent Identity Layer (AID)

AID assigns every agent a persistent, cryptographically bound decentralized identifier. An agent's DID is registered by posting an identity-registration transaction accompanied by a minimum stake deposit S_{init} in $\$\mathsf{CORA}$. The DID document contains:

- The agent's public key(s), conformant to [34].
- Optional service endpoints through which the agent may be reached (off-chain).
- A bond reference pointing to the stake contract holding S_{init}.

Stake binding makes Sybil attacks costly in direct proportion to the number of synthetic identities created. §6.2 quantifies the resulting resistance.

4.3 L3 — Task Marketplace

L3 is the demand-side interface to the protocol. Task publishers — which may themselves be humans, organizations, or other agents — post task specifications consisting of:

- A machine-readable task description (input schema, expected output schema, acceptance predicate when applicable).
- A complexity weight C_j.
- A pre-funded budget B_j, denominated in $CORA, deposited into a per-task escrow contract at publication time (see §7.4 for the full settlement flow).
- A verification mode (ZK, optimistic, or committee; §5.6).

Eligible agents are those whose bonded stake satisfies the *combined eligibility predicate*

$$S_i \;\geq\; \max\!\left\{\, S_{\min},\; S_{\text{dyn}}(T_j) \,\right\}, \tag{1}$$

where $S_{\min}$ is the protocol-level static floor (default $S_{\min}$ as specified in §8). The dynamic floor S_{dyn} depends on Condition 13 parameters that are not all directly observable on-chain (specifically p, q, σ_{fp}, and the cost differential $c_{\text{exec}} - c_{\text{cheat}}$). To make the eligibility check executable by the marketplace contract, the protocol replaces these task-specific quantities with *mode-specific governance-set conservative constants*, fixed per verification mode:

$$S_{\text{dyn}}(T_j) \;:=\; \kappa \cdot \frac{(1 - p^{\text{mode}}) \cdot B_j \;+\; \Delta c^{\text{mode}}_{\max}}{p^{\text{mode}} \cdot \sigma_{\text{floor}} \;-\; q^{\text{mode}} \cdot \sigma^{\text{mode}}_{\text{fp}}}, \tag{2}$$

where p^{mode} is the protocol's calibrated lower bound on detection probability, q^{mode} is the calibrated upper bound on false-positive rate, $\sigma^{\text{mode}}_{\text{fp}}$ is the worst-case false-positive slashing fraction, and $\Delta c^{\text{mode}}_{\max}$ is the calibrated upper bound on cheating cost savings. All four are governance parameters (defaults in §8); the marketplace contract reads them from the protocol-config storage and computes $S_{\text{dyn}}(T_j)$ from B_j and σ_{floor} alone — both of which are on-chain values. Conservatism is built into the constants: p^{mode} is set lower than expected, q^{mode} and $\Delta c^{\text{mode}}_{\max}$ are set higher than expected, so the resulting S_{dyn} over-estimates the stake required, providing safety margin. The static floor governs eligibility for low-budget tasks; the dynamic floor binds for high-budget tasks where Condition 13 would otherwise fail. Both floors are checked at bid-submission time by the marketplace contract; bids violating either are rejected. Eligible agents submit bids consisting of a priced offer P_i satisfying $P_{\min} \leq P_i \leq B_j$, where $P_{\min} := \pi_{\text{reserve}} \cdot B_j$ is a publisher-set reserve price (default $\pi_{\text{reserve}} = 0.1$, governance-tunable lower bound). The reserve floor prevents bid-score manipulation via near-zero pricing, which would otherwise cause the price term in Equation 3 below to diverge. The protocol computes a bid score combining reputation, stake quality, and price:

$$\text{BidScore}(A_i, T_j) \;=\; R_i^{\text{eff}} \cdot \left(1 - e^{-S_i / S_{\min}}\right) \cdot \min\!\left\{ \left(\frac{B_j}{P_i}\right)^{\gamma},\; M \right\}, \tag{3}$$

where $\gamma \geq 0$ is a governance-tunable price-sensitivity parameter (default $\gamma = 1$) and $M \geq 1$ is a governance-tunable cap on the price multiplier (default $M = 3$). The bid with the highest BidScore is selected. The cap M ensures that a deeply-discounted price cannot dominate the score by more than a factor of M over the most expensive bid; combined with the reserve price $P_{\min}$, this prevents both the divergence pathology (near-zero P_i) and the price-dominance pathology (in which a low-reputation agent at the floor reserve overwhelms a high-reputation agent at a moderate price). Setting $\gamma = 0$ disables price competition (reputation-only selection); increasing γ gives more weight to cheaper bids up to the cap. Publishers may further restrict eligibility by specifying a minimum acceptable reputation $R_{\min}^{\text{pub}}$ at task publication; agents with $R_i^{\text{eff}} < R_{\min}^{\text{pub}}$ are excluded from the auction. The winning agent locks its stake for the duration of the task; the quoted price P_i becomes the effective reward cap (in conjunction with the protocol-fee adjustment below) in place of the nominal B_j for settlement purposes.

4.4 L4 — Verification Layer

L4 provides three pluggable verification modalities, selected per-task by the publisher. Detailed scope and applicability are given in §5.6.

4.5 L5 — Reputation Graph

L5 maintains the interaction graph $G = (V, E)$ in which vertices are agents and edges record successfully verified task interactions. Structural properties of G — specifically degree centrality and local clustering — feed into the effective reputation calculation (Equation 7). The graph is maintained as an authenticated data structure enabling Merkle-proof access from smart contracts on L1.

5 Proof of Agentic Work: Formal Specification

5.1 Protocol Overview

Figure 2 depicts the end-to-end task lifecycle under PoAW. A publisher funds a task; eligible agents bid; a winning agent locks stake and executes; verification produces a score V_j; and settlement distributes rewards (or triggers slashing) and updates reputation. The protocol is reentrant: reputation updates from completed tasks feed into eligibility and reward weighting for subsequent tasks.

5.2 Definitions

Definition 5.1 (Task)**.** A task T_j is a tuple $(\text{spec}_j, C_j, B_j, \text{mode}_j)$ where spec_j is the machine-readable specification, $C_j \in \mathbb{R}_{>0}$ is the complexity weight, $B_j \in \mathbb{R}_{>0}$ is the pre-funded budget in CORA, and $\text{mode}_j \in \{\text{ZK}, \text{Optimistic}, \text{Committee}\}$ is the verification mode.

Definition 5.2 (Agent State)**.** The state of agent A_i is the tuple $(\text{DID}_i, S_i, R_i, H_i)$, where H_i is the ordered history of tasks executed by A_i.

Definition 5.3 (Verification Score)**.** For each completed task T_j executed by A_i, the verification layer produces a score $V_j \in [0, 1]$, with $V_j = 1$ denoting fully correct execution and $V_j = 0$ denoting a null or adversarial result.

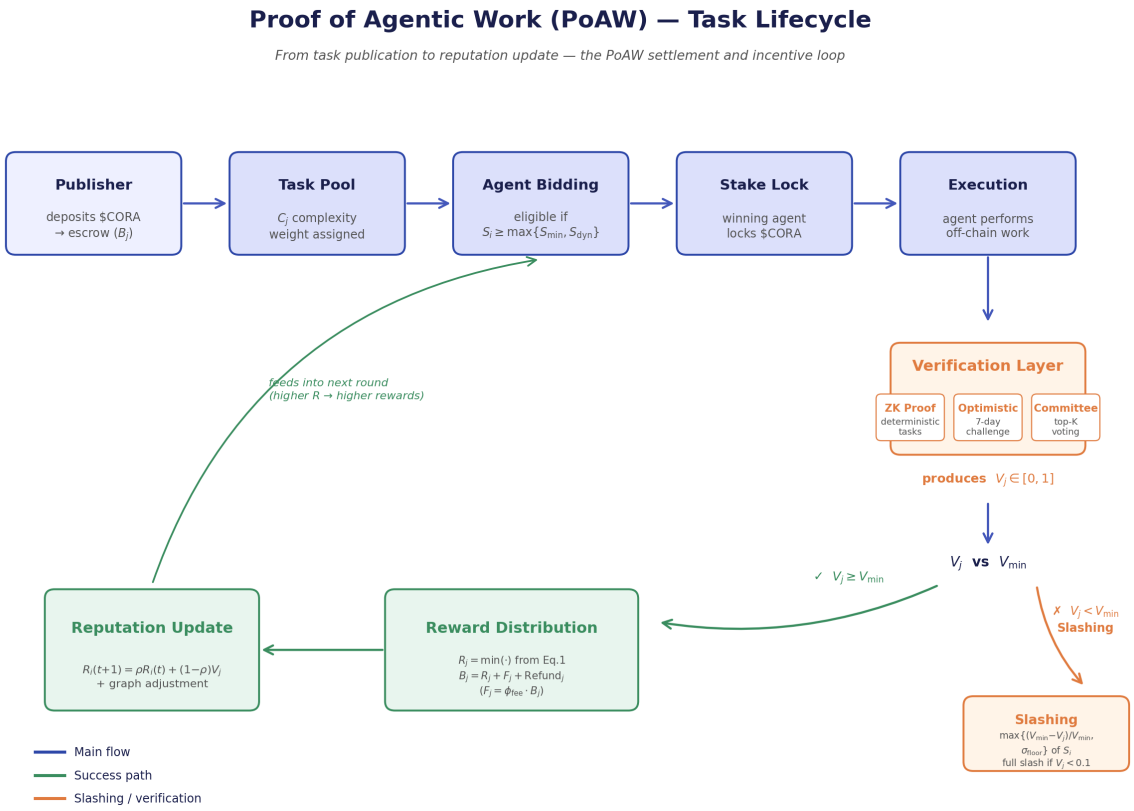

Figure 2: *PoAW task lifecycle. Blue arrows denote the main flow; green arrows denote the success path (reward distribution and reputation update); orange arrows denote the failure path (slashing).*

5.3 Reward Function

The reward distributed to agent A_i for completing task T_j is given by

$$\text{Reward}(A_i, T_j) \;=\; \min\Big\{\, C_j \cdot V_j \cdot (\alpha + \beta\, R_i^{\text{eff}}) \cdot \big(1 - e^{-S_i/S_{\min}}\big),\; \text{RewardCap}_j \,\Big\}, \tag{4}$$

where RewardCap_j is the binding upper bound determined by the auction outcome and the protocol fee:

$$\text{RewardCap}_j \;:=\; \min\{\, P_i,\; B_j - F_j^{\text{mode}} \,\}, \qquad F_j^{\text{mode}} = \phi_{\text{fee}}^{\text{mode}} \cdot B_j. \tag{5}$$

Here P_i is the price quoted by the winning agent in its bid (§4.3), B_j is the publisher's pre-funded escrow deposit, and F_j^{mode} is the total protocol fee in the verification mode selected by the publisher, where mode $\in$ {standard, HA}. Under default governance parameters, $\phi_{\text{fee}}^{\text{standard}} = 10\%$ and $\phi_{\text{fee}}^{\text{HA}} = 25\%$. The reward parameters $\alpha, \beta > 0$ are reputation-premium coefficients (default $\alpha = 0.5$, $\beta = 1.0$); $S_{\min}$ is the eligibility stake threshold (see also the dynamic floor of Equation 18). For brevity, we write F_j in the remainder of this section to mean F_j^{mode} for the operative mode; the full mode-dependent decomposition into committee fee V_j^{fee} and residual fee F_j' is specified in §7.4.

The two-term cap structure serves two distinct purposes. The P_i term enforces the price commitment from the auction: an agent who bid P_i cannot collect more than what it offered to do the work for. The $B_j - F_j^{\text{mode}}$ term ensures *escrow solvency*: even if P_i were equal to B_j, the protocol would still need to retain F_j^{mode} for fees and committee compensation, so the disbursable maximum to the agent is $B_j - F_j^{\text{mode}}$. The overall settlement identity is therefore

$$B_j \;=\; \text{Reward}(A_i, T_j) \;+\; F_j^{\text{mode}} \;+\; \text{Refund}_j$$

with $\text{Refund}_j \geq 0$ by construction (see §7.4 for the full mode-dependent settlement flow including the V_j^{fee}/F_j' split). For committee-verified modes, the total fee F_j^{mode} in this 3-term identity decomposes further as $F_j^{\text{mode}} = V_j^{\text{fee}} + F_j'$, where $V_j^{\text{fee}} = \phi_{\text{com}}^{\text{mode}} \cdot B_j$ is the committee compensation and $F_j' = (\phi_{\text{fee}}^{\text{mode}} - \phi_{\text{com}}^{\text{mode}}) \cdot B_j$ is the residual fee subject to burn/treasury split; this expansion produces the equivalent 4-term identity $B_j = R_j + V_j^{\text{fee}} + F_j' + \text{Refund}_j$ used in §7.4. For non-committee-verified modes (ZK or optimistic), $V_j^{\text{fee}} = 0$ and $F_j' = F_j^{\text{mode}}$, so the two identities coincide.

With default coefficients, a maximum-reputation agent ($R_i^{\text{eff}} = 1$) earns a factor $(\alpha + \beta)/\alpha = 3$ times the reward of a zero-reputation agent, *provided neither cap is binding*. When the cap is binding, both agents receive RewardCap_j and the effective ratio collapses to 1. Publishers therefore retain control over the strength of the reputation premium through their choice of C_j and B_j. The factor $(1 - e^{-S_i/S_{\min}})$ implements diminishing marginal returns on stake, formalized in Proposition 5.4.

Proposition 5.4 (Properties of the stake curve)**.** *The function $f(S) = 1 - e^{-S/S_{\min}}$ satisfies $f(0) = 0$, $\lim_{S\to\infty} f(S) = 1$, $f'(S) > 0$ for all $S > 0$, and $f''(S) < 0$ for all $S > 0$.*

These properties ensure that stake increases reward contribution monotonically, but with sharply diminishing returns, mitigating capture of the marketplace by very large stakeholders.

5.4 Reputation Dynamics

Reputation is updated after each completed task according to an exponential moving average:

$$R_i(t+1) \;=\; \rho \cdot R_i(t) + (1 - \rho) \cdot V_j, \qquad \rho \in (0, 1). \tag{6}$$

The default smoothing factor $\rho = 0.95$ is calibrated such that a single adverse outcome cannot destroy a long-established reputation, while sustained poor performance produces rapid decay. See Appendix B for calibration methodology.

For purposes of reward computation and task eligibility, we use the *effective* reputation, which incorporates graph-structural penalties:

$$R_i^{\text{eff}} \;=\; R_i \cdot \frac{1 - e^{-\deg_{\text{ns}}(A_i)}}{1 + c(A_i)}, \tag{7}$$

where $\deg_{\text{ns}}(A_i)$ denotes the operationally observable count of distinct non-slashed external counterparties with whom A_i has successfully completed a task, and $c(A_i)$ denotes the local clustering coefficient of A_i in the interaction graph. The protocol can compute $\deg_{\text{ns}}$ directly from on-chain history. We distinguish this from $\deg_{\text{ext}}(A_i)$, used in the security analysis (§6), which denotes the analytically-ideal count of *truly* honest counterparties. The two coincide whenever the protocol's slashing detection captures all adversaries; in the presence of undetected Sybils, $\deg_{\text{ns}}(A_i) \geq \deg_{\text{ext}}(A_i)$ for honest agents and the gap represents a residual attack surface that the graph-clustering term is designed to suppress (Theorem 6.2). This formulation simultaneously penalizes two failure modes: isolated agents with no external non-slashed interactions (low external degree), and tightly-clustered groups exhibiting mutual-reinforcement behavior (high clustering). The security implications are developed in §6.

When a previously non-slashed agent is subsequently slashed, the affected edges are retroactively discounted in the next reputation epoch.

5.5 Slashing

When V_j falls below a protocol-specified threshold $V_{\min}$ (default 0.3), the executing agent is subject to economic penalty. The penalty is piecewise: a partial penalty scaled to the shortfall, with a full-stake override for severe violations:

$$S_i' \;=\; \begin{cases} 0 & \text{if } V_j < 0.1 \quad (\textit{severe} \text{ — DID blacklisted}) \\ S_i \cdot \left(1 - \max\left\{\frac{V_{\min} - V_j}{V_{\min}},\, \sigma_{\text{floor}}\right\}\right) & \text{if } 0.1 \leq V_j < V_{\min} \\ S_i & \text{if } V_j \geq V_{\min} \end{cases} \tag{8}$$

The partial penalty is the maximum of a proportional term (scaled to the verification shortfall) and a protocol-level minimum σ_{floor} (default $\sigma_{\text{floor}} = 0.3$, governance-tunable). The floor ensures that any verification failure below $V_{\min}$ triggers a non-trivial economic penalty: in particular, V_j values just below $V_{\min}$ are not effectively un-punished. Without the floor, a marginal fraud at $V_j = V_{\min} - \epsilon$ would lose only $\epsilon / V_{\min}$ of stake, which approaches zero as ϵ shrinks, undermining the incentive-compatibility analysis in §6.4. With the floor, every $V_j \in [0.1, V_{\min})$ loses at least a fraction σ_{floor} of the locked stake.

The boundary values are: $V_j = V_{\min}^-$ still loses σ_{floor} of stake (not zero), and $V_j = 0.1$ loses the maximum of $\frac{V_{\min} - 0.1}{V_{\min}}$ and σ_{floor} (for defaults, $\approx 67\%$). Reputation is additionally halved on any slashing event, $R_i \leftarrow \frac{1}{2} R_i$. Slashed stake is directed to the protocol treasury, according to the settlement rules in §7.4. Publishers receive only a refund of their original deposit (less the committee fee, where applicable) on task failure and no compensation from slashed stake; this design choice removes the malicious-publisher incentive analyzed in §7.4. Committee verifiers are compensated from the dedicated committee-fee portion of the publisher deposit, not from slashed stake, ensuring that committee compensation is independent of verification outcome.

5.6 Verification Mechanisms

5.6.1 Zero-Knowledge Verification

Applicability. ZK verification applies only when the task's correctness predicate can be expressed as a circuit-friendly computation over authenticated data commitments. Canonical examples include deterministic code execution against a fixed input, closed-form numerical computation, and database queries where the database root is publicly committed. ZK verification is *not* applied to tasks whose inputs include unauthenticated external data, nor to tasks whose correctness predicate lacks a succinct algebraic form.

Mechanism. The executing agent produces a succinct non-interactive argument of knowledge (SNARK) [29] with transcript π_j. Verification is performed on-chain in $O(1)$ time relative to the computation size. We set $V_j := 1$ if the verification equation accepts and $V_j := 0$ otherwise. This binary case is a degenerate instance of the more general $V_j \in [0, 1]$ continuum.

5.6.2 Optimistic Verification

Applicability. Optimistic verification applies to tasks with a well-defined dispute standard: an efficient *post-hoc* test that any challenger can run to determine whether the output meets the specification. Canonical examples include structured data extraction against a reference dataset, translation with a reference translation, and numerical computation with an independent re-execution path. Creative and open-ended tasks, which lack a natural dispute standard, are not eligible for this mode.

Mechanism. The agent's output is accepted by default. During a challenge period of $\Delta = 7$ days, any staker may post a dispute accompanied by a counter-example, re-execution transcript, or other fraud proof as defined by the task specification. Disputes are adjudicated by the committee mechanism (§5.6.3). Game-theoretic analysis follows [31]: honest participation is an equilibrium provided the dispute bond exceeds the expected value of a successful challenge and the dispute standard is well-defined.

5.6.3 Committee Verification

Applicability. Committee verification applies to *all* tasks not suitable for ZK or optimistic verification, including creative, subjective, and open-ended tasks. It is also the default mechanism for adjudicating disputes raised under optimistic verification.

Mechanism. Verification is delegated to a committee of k agents drawn from the top-K reputation cohort using a verifiable random function (VRF), where $K \gg k$ to ensure sufficient randomness in sampling. The protocol provides two randomness sources, selected per task class:

- *Block-hash VRF* (default for testnet and routine low-risk tasks): the VRF is seeded directly by the block hash. This is computationally cheap and operationally simple, but inherits weak manipulability from the underlying consensus (see "Randomness manipulability" below).
- *Stronger randomness* (required for mainnet high-assurance mode and for any task class involving disputes above a governance-defined value threshold V_{disp}): commit-reveal randomness, threshold VRF, or an external beacon (drand-style). This path is non-negotiable for high-stakes verification; the protocol enforces it at the committee-selection contract by checking the task's verification mode and value threshold before sampling.

Each committee member independently scores the output and broadcasts a signed scorecard via the commit-reveal scoring protocol described in "Anti-herding scoring" below. The verification score V_j is computed as the reputation-weighted trimmed mean of committee scores, where the top f and bottom f scores are discarded (for some $f \leq \lfloor (k-1)/3 \rfloor$). Committee members are rewarded for agreement with the final score within a tolerance τ.

Committee deviation is penalized in two layers, with explicit definitions to distinguish statistical disagreement from provable bad faith:

Definition 5.5 (Trim-event, Deviation-event, and Bad-faith-event)**.** For committee member i scoring task j with revealed score $v_{i,j}$ and reputation-weighted trimmed-mean aggregate $\tilde{V}_j$:

- $\text{TrimEvent}_{i,j} = 1$ iff $v_{i,j}$ is among the top-f or bottom-f scores discarded by the trimmed mean (a *rank-based* criterion: i's score is at the extreme tail of the score distribution for this task).
- $\text{DeviationEvent}_{i,j} = 1$ iff $|v_{i,j} - \tilde{V}_j| > \tau$, where τ is the scoring tolerance from Assumption 6.6 (a *distance-based* criterion: i's score is far from the aggregate by absolute amount).
- $\text{BadFaithEvent}_{i,j} = 1$ iff $\text{DeviationEvent}_{i,j} = 1$ *and* the deviation persists after a re-verification appeal: an independently-sampled second-round committee confirms that $|v_{i,j} - V_j^*|$ exceeds τ when scored against the task rubric.

TrimEvents and DeviationEvents are independent in general: a TrimEvent without a DeviationEvent occurs when scores are tightly clustered (e.g., all within τ of the aggregate, but i's score is the highest or lowest by rank); a DeviationEvent without a TrimEvent occurs when more than f scores are similarly far from the aggregate (so the rank-trim does not capture i's outlier status). The protocol uses DeviationEvent as the primary penalty trigger, since it directly measures epistemic disagreement; TrimEvent is recorded for monitoring purposes but does not by itself trigger penalty.

- *Reputation penalty (per-DeviationEvent, reversible on appeal).* For any task with $\text{DeviationEvent}_{i,j} = 1$, the protocol applies a reputation decay $R_i \leftarrow \rho_{\text{com}} \cdot R_i$ (default $\rho_{\text{com}} = 0.95$, slightly faster than the agent reputation decay). This is a soft penalty appropriate for raw statistical disagreement; it does not affect bonded stake. To avoid penalizing honest minority judgments, the decay is *reversible*: if the affected member invokes the re-verification appeal path and the second-round committee confirms that $|v_{i,j} - V_j^*| \leq \tau$ when scored against the rubric (i.e., the original decision was a false-positive deviation), the protocol restores $R_i \leftarrow R_i / \rho_{\text{com}}$ to its pre-event value. Members who do not appeal, or whose appeal fails, retain the decay and accumulate it across subsequent disagreements; recovery via natural on-aggregate scoring remains available. The appeal incurs no fee for the appellant; appeal funding is specified in §7.4.
- *Stake slashing (BadFaithEvents only).* Stake slashing applies only when the rolling-window fraction of $\text{BadFaithEvent}_{i,j}$ exceeds threshold θ_{com} (default 20%) over W_{com} tasks (default $W_{\text{com}} = 100$). When triggered, the member's bonded committee stake is slashed by σ_{com} (default 20%). Critically, slashing requires *appeal-confirmed* bad faith, not raw statistical deviation: a committee member who consistently produces honest minority judgments on subjective tasks accumulates DeviationEvents but *not* BadFaithEvents (since appeal confirms their scores against the rubric). Slashed members are temporarily removed from the top-K sampling pool until their reputation recovers above the eligibility threshold.

The two-layer structure provides graduated penalties: raw disagreement costs reputation, appeal-confirmed bad faith costs stake. Slashed members may themselves invoke a further re-verification

appeal in the same way agents may contest false-positive slashing. All committee-deviation parameters (ρ_{com}, W_{com}, θ_{com}, σ_{com}) are governance-tunable; their defaults appear in §8. The appeal mechanism imposes operational cost (appeals are funded from publisher escrow or DAO budget, not from the appellant), which we discuss as an open implementation question in §9.

Randomness manipulability (open issue). A VRF seeded directly by the block hash inherits a weak form of manipulability from the underlying consensus: a block proposer who can predict the seed's downstream effect on committee composition has a marginal incentive to withhold or reorder candidate blocks in high-stakes verification rounds. For routine tasks, this attack vector is economically negligible; for high-value disputes (where committee composition could swing material amounts of slashing or reward), it is a real concern. The implemented protocol mitigates this in three complementary ways, none individually sufficient: (i) a delay of Δ_{seed} blocks between sampling time and seed-resolution time, so the proposer at the seed block does not know which task draws from it; (ii) a large sampling pool $K \gg k$, so even a biased proposer's marginal influence on committee composition is small; and (iii) restriction of the committee mechanism to top-K reputation, which already filters for stake-bonded, reputation-vested participants whose own slashing exposure dominates any one-off manipulation gain.

Mainnet requirement. The mitigations above are sufficient for testnet and routine-task workloads. For mainnet deployment of the high-assurance committee regime (Theorem 6.7, large-k regime) or for any task class involving disputes above a governance-defined value threshold V_{disp}, the protocol *requires* a stronger randomness source — specifically commit-reveal randomness, threshold VRF, or an external beacon (drand-style) — as a precondition for activation. This is a non-negotiable security requirement, not a future-work nice-to-have. The protocol's modular architecture accommodates upgrade without changing the verification interface.

Anti-herding scoring (open issue). The current rule rewards agreement with the final aggregate and penalizes persistent deviation. Game-theoretically, this incentivizes committee members to predict the consensus outcome rather than score the output independently — a herding pathology that degrades the committee's epistemic value. The implemented protocol mitigates this via a commit-reveal scoring protocol: each member first publishes a hash-commitment of their score, and only after all commitments are received does each member reveal the underlying score. Commit-reveal makes direct score-copying impossible before reveal, but does not eliminate prior-based herding: members may still infer the expected consensus from observable signals (task type, rubric, reputation-weighted historical norms) and bias their scores toward that prior. A stronger anti-herding design would penalize only *provable* bad-faith deviation rather than statistical disagreement, possibly via reference-rubric-based attestation or peer-prediction mechanisms. We treat refinement of the scoring rule as a future-work item.

6 Security Analysis

6.1 Threat Model

We model an adversary $\mathcal{A}$ with the following capabilities:

- Polynomial-bounded computation in the security parameter λ.
- Ability to create up to $N_{\mathcal{A}}$ Sybil identities subject to the stake-binding cost.

- Ability to collude with other agents, including across Sybil boundaries.
- Full knowledge of protocol parameters and the public state.

The adversary cannot forge cryptographic signatures, find hash collisions, or violate the soundness of the proof systems employed by the verification layer. The adversary's objectives include (a) accumulating unearned reputation, (b) extracting rewards via fraudulent task execution, (c) censoring honest agents, or (d) disrupting PoAW settlement. We analyze each objective below.

6.2 Sybil Resistance

Theorem 6.1 (Sybil Resistance Bound)**.** *Let $\mathcal{S} \subseteq V$ denote the subgraph of Sybil identities controlled by a single adversary, with $|\mathcal{S}| = k$ and individual reputations bounded by $R_{\max}$. Let $\bar{d}_{\text{ext}}$ denote the mean external degree of $\mathcal{S}$ (edges to $V \setminus \mathcal{S}$) and $\underline{c}(\mathcal{S}) := \min_{A_i \in \mathcal{S}} c(A_i)$ the minimum local clustering within $\mathcal{S}$. Then the total effective reputation accumulated by $\mathcal{S}$ satisfies*

$$\sum_{A_i \in \mathcal{S}} R_i^{\text{eff}} \;\leq\; k \cdot R_{\max} \cdot \frac{1 - e^{-\bar{d}_{\text{ext}}}}{1 + \underline{c}(\mathcal{S})}. \tag{9}$$

Proof sketch. By Equation 7 applied to each $A_i \in \mathcal{S}$,

$$\sum_{A_i \in \mathcal{S}} R_i^{\text{eff}} \;=\; \sum_{A_i \in \mathcal{S}} R_i \cdot \frac{1 - e^{-\deg_{\text{ext}}(A_i)}}{1 + c(A_i)} \;\leq\; R_{\max} \sum_{A_i \in \mathcal{S}} \frac{1 - e^{-\deg_{\text{ext}}(A_i)}}{1 + \underline{c}(\mathcal{S})}.$$

By concavity of $g(x) = 1 - e^{-x}$ and Jensen's inequality,

$$\frac{1}{k} \sum_{A_i \in \mathcal{S}} \left(1 - e^{-\deg_{\text{ext}}(A_i)}\right) \;\leq\; 1 - e^{-\bar{d}_{\text{ext}}}.$$

Combining yields Equation 9. ■

The bound admits two interpretations: if the Sybil subgraph acquires no honest counterparties ($\bar{d}_{\text{ext}} \to 0$), effective reputation collapses to zero regardless of nominal $R_{\max}$; and increased internal clustering $\underline{c}(\mathcal{S})$ further tightens the bound. The use of $\deg_{\text{ext}}$ rather than total degree is essential: an adversary cannot inflate the bound via internal Sybil-Sybil edges.

Implementation note. Theorem 6.1 is an *analytical upper bound* that uses the idealized notion of truly-honest counterparties ($\deg_{\text{ext}}$). The implemented protocol cannot directly observe Sybil ownership and therefore approximates this analytical quantity using the operationally observable $\deg_{\text{ns}}$ (§5.4). Whenever the protocol's slashing detection captures all Sybil activity, $\deg_{\text{ns}} = \deg_{\text{ext}}$ for all agents and the analytical bound holds tightly. In the presence of undetected Sybils, $\deg_{\text{ns}}$ may overcount $\deg_{\text{ext}}$ for honest agents (counting an undetected adversary as a non-slashed counterparty); the residual attack surface is suppressed by the clustering term $c(A_i)$, which captures collusion patterns regardless of whether participants are formally identified as Sybils. The theorem is therefore best understood as a guarantee about the attack *ceiling* under perfect detection, complemented by graph-structural defenses that operate even under imperfect detection.

6.3 Collusion Resistance

Theorem 6.2 (Collusion Bound)**.** *Let $G \subseteq V$ be a coalition of agents engaging in mutual reputation reinforcement, with aggregate nominal reputation $\mathcal{R}_G := \sum_{A_i \in G} R_i$ and internal clustering coefficient $c(G) \in [0,1]$. Assume each $A_i \in G$ has local clustering at least $c(G)$. Then the coalition's total effective reputation satisfies*

$$\sum_{A_i \in G} R_i^{\text{eff}} \;\leq\; \mathcal{R}_G \cdot \frac{1}{1 + c(G)}. \tag{10}$$

Proof. Direct from Equation 7: for each $A_i \in G$, $R_i^{\text{eff}} \leq R_i/(1 + c(A_i)) \leq R_i/(1 + c(G))$ by hypothesis. Summing over $A_i \in G$ gives the claim. ∎

Remark. The bound does *not* imply that effective reputation tends to zero as $c(G) \to 1$: the denominator is at most 2. The economic significance of Theorem 6.2 is that the penalty factor is deterministic and independent of coalition size. A perfectly clustered coalition of arbitrary size retains at most half of its nominal aggregate reputation. Achieving a stronger-than-constant degradation would require a modified adjustment function (e.g., multiplying by $(1 - c(A_i))$); we discuss this design trade-off in §9.

6.4 Incentive Compatibility

Let σ_i denote the strategy of agent i, and σ_{-i} denote the strategy profile of all other agents. The utility of i is

$$U_i(\sigma_i, \sigma_{-i}) \;=\; \mathbb{E}\big[\text{Reward}(A_i, T_j) \,\big|\, \sigma_i, \sigma_{-i}\big] - \mathbb{E}\big[\text{Slash}(A_i) \,\big|\, \sigma_i\big] - c_{\text{exec}}(\sigma_i), \tag{11}$$

where $c_{\text{exec}}(\sigma_i)$ denotes the cost of playing strategy σ_i — specifically c_{exec} for honest execution and c_{cheat} for fraudulent execution, with typically $c_{\text{cheat}} < c_{\text{exec}}$ (cheating is cheaper than doing the work properly).

Assumption 6.3 (Honest Margin)**.** Honest agents produce outputs whose true verification score V_j^* satisfies $V_j^* \geq V_{\min} + \tau$, where τ is the scoring tolerance from Assumption 6.6. That is, honest outputs are not on the boundary of the slashing threshold; they exceed it by at least the protocol-defined tolerance margin. Outputs with $V_j^* \in [V_{\min}, V_{\min} + \tau)$ — in the buffer zone immediately above the threshold — are not protected by the false-positive bound below and may be slashed with probability up to 1/2; agents producing such outputs may invoke the optional re-verification (appeal) path described below.

The Honest Margin assumption is what permits the false-positive rate q to inherit the noise bound from Assumption 6.6: under $V_j^* \geq V_{\min} + \tau$, an honest output is incorrectly scored below $V_{\min}$ only if the aggregate score deviates from V_j^* by more than τ. By Theorem 6.7 this is bounded by the complement of the committee accuracy bound:

$$q \;\leq\; \text{negl}(\lambda) \;+\; O\Big(e^{-2k(1/3-\phi)^2}\Big) \;+\; k\varepsilon \;+\; \delta_{\text{rand}}, \tag{12}$$

where the four terms capture, respectively: cryptographic non-idealness, sampling failure (committee composition with too many Byzantine members), aggregated honest-scorer noise, and randomness-source bias. In high-assurance mode (large k, stronger randomness), $q = \text{negl}(\lambda)$. In routine mode,

q is bounded by a constant: at default $k = 7$, $\phi = 0.1$, $\varepsilon \leq 0.02$, $\delta_{\text{seed}} \leq 0.05$, the bound evaluates to approximately 0.65, dominated by the sampling term. This is the pessimistic worst case; on tasks where the honest margin is comfortable and committee composition is favorable, the empirical q is much smaller. Without the margin assumption, an honest agent producing $V_j^* = V_{\min} + \epsilon$ (for $\epsilon \ll \tau$) faces an arbitrarily large false-positive rate, and the equilibrium below does not apply.

Theorem 6.4 (Honest Play is a Nash Equilibrium)**.** *Assume the committee mechanism operates under the conditions of Theorem 6.7 (with fraud-detection probability at least p on cheating outputs) and that honest outputs satisfy the Honest Margin assumption (Assumption 6.3), so that the false-positive rate on honest outputs is bounded by q. Let σ_{floor} denote the minimum slashing fraction from Equation 8, and let σ_{fp} denote an upper bound on the slashing fraction applied to an honest output erroneously scored below $V_{\min}$. Suppose that for every agent i and every task T_j the agent could be assigned, the following condition holds:*

$$\big(p \cdot \sigma_{\text{floor}} - q \cdot \sigma_{\text{fp}}\big) \cdot S_i \;\geq\; (1-p) \cdot B_j \;+\; \big(c_{\text{exec}} - c_{\text{cheat}}\big). \tag{13}$$

Then the strategy profile in which all agents play honest execution (with margin) constitutes a Nash equilibrium among rational agents:

$$U_i(\sigma^*_{\text{honest}}, \sigma^*_{-i}) \;\geq\; U_i(\sigma_{\text{deviate}}, \sigma^*_{-i}) \qquad \forall\, i \in \mathcal{H}.$$

Proof. Consider a rational agent i choosing between honest execution (σ_{honest}) and fraudulent execution with output $V_j < V_{\min}$ (σ_{deviate}).

Step 1 (honest utility, with false-positive risk). Under σ_{honest}, the agent produces an output that should satisfy $V_j \geq V_{\min}$. With probability $1-q$ the committee scores it correctly, the agent collects the reward (bounded below by 0), and is not slashed. With probability q (the false-positive rate of the committee, bounded above by $O(k\varepsilon)$ from Theorem 6.7 and Assumption 6.6), the committee incorrectly scores the output below $V_{\min}$, and the agent is slashed by at most $\sigma_{\text{fp}} \cdot S_i$ despite honest behavior. The conservative bound takes the worst-case slashing under the piecewise rule of Equation 8: when the false-positive score lands in the low-but-not-disastrous range $[0.1, V_{\min})$, σ_{fp} is bounded by the reciprocal $V_{\min}/V_{\min} \cdot (V_{\min} - 0.1)/V_{\min} \approx 0.67$ for default $V_{\min} = 0.3$; when the false-positive score falls below 0.1 (DID-blacklisted regime), $\sigma_{\text{fp}} = 1$ (full slash). Under the Honest Margin assumption, the latter case occurs with probability at most a $\text{negl}(\lambda)$ fraction of q, so the effective σ_{fp} is dominated by the partial-penalty regime; we adopt $\sigma_{\text{fp}} = 1$ as a conservative worst-case bound. The agent always pays c_{exec}. Hence

$$U_{\text{honest}} \;\geq\; (1-q) \cdot 0 + q \cdot \big(-\sigma_{\text{fp}} \cdot S_i\big) - c_{\text{exec}} \;=\; -q \cdot \sigma_{\text{fp}} \cdot S_i - c_{\text{exec}}.$$

Step 2 (deviation utility). Under σ_{deviate}, with probability $1-p$ the fraud is undetected and the agent collects the full reward (bounded above by B_j, conservative; see remark following the proof) with no slashing. With probability p the fraud is detected and the agent loses at least $\sigma_{\text{floor}} \cdot S_i$ of stake and receives no reward. Hence

$$U_{\text{deviate}} \;\leq\; (1-p) \cdot B_j - p \cdot \sigma_{\text{floor}} \cdot S_i - c_{\text{cheat}}.$$

Step 3 (comparison). A sufficient condition for $U_{\text{honest}} \geq U_{\text{deviate}}$ is

$$-q \cdot \sigma_{\text{fp}} \cdot S_i - c_{\text{exec}} \;\geq\; (1-p) \cdot B_j - p \cdot \sigma_{\text{floor}} \cdot S_i - c_{\text{cheat}},$$

which rearranges to

$$\big(p \cdot \sigma_{\text{floor}} - q \cdot \sigma_{\text{fp}}\big) \cdot S_i \;\geq\; (1-p) \cdot B_j + c_{\text{exec}} - c_{\text{cheat}},$$

i.e., exactly Condition 13. Since honesty dominates deviation for every agent under the same condition, and deviation utilities are independent of σ_{-i} for the detection-probability parameter p (which comes from the committee mechanism, not peer behavior), honest play is a best response. By symmetry across agents, the strategy profile is a Nash equilibrium. ■

Remark on the bound. Condition 13 has a natural economic reading: the *net expected slashing advantage* $(p \cdot \sigma_{\text{floor}} \cdot S_i - q \cdot \sigma_{\text{fp}} \cdot S_i)$ must dominate the sum of the *expected* fraudulent reward $((1-p) \cdot B_j)$ and the execution-cost saving from cheating $(c_{\text{exec}} - c_{\text{cheat}})$. The structure $p \cdot \sigma_{\text{floor}} - q \cdot \sigma_{\text{fp}}$ rather than $(p-q) \cdot \sigma_{\text{floor}}$ alone reflects that false-positive slashing may apply at a strictly worse rate $\sigma_{\text{fp}} \geq \sigma_{\text{floor}}$: the protocol's piecewise slashing rule (Equation 8) imposes the floor as a *minimum* only, while extreme false-positive scores (below 0.1) trigger full-stake loss. In the limit $\sigma_{\text{fp}} = \sigma_{\text{floor}}$ (no asymmetry), the condition reduces to the simpler $(p-q) \cdot \sigma_{\text{floor}} \cdot S_i \geq \cdots$ form. In the opposite limit $\sigma_{\text{fp}} \to 1$, q must be correspondingly small for honest play to remain stable; this places stricter quality requirements on the committee scoring rubric and underscores the importance of the appeal/re-verification path for honest agents claiming wrongful slashing.

Conservative simplification. The condition uses $(1-p) \cdot B_j$ as an upper bound on the expected fraudulent reward, but the actual reward an undetected fraudulent agent collects is bounded above by $\text{RewardCap}_j = \min\{P_i,\, B_j - F_j\} \leq B_j$ (Equation 5). Replacing B_j with RewardCap_j gives a tighter sufficient condition; we retain the looser form using B_j because it does not depend on the auction outcome or fee parameter, and is therefore checkable at task-publication time before P_i is known. Implementations may use the tighter form RewardCap_j once the winning bid is known, providing a strictly weaker (i.e., more permissive) eligibility threshold for S_i.

False-positive interpretation. The factor $(p - q)$ in Condition 13 captures the *net* detection advantage: detection accuracy p on cheating, minus false-positive rate q on honest work. When $q \approx 0$ (e.g., deterministic ZK-verified tasks where committee scoring error vanishes), the condition reduces to the simpler form $p \cdot \sigma_{\text{floor}} \cdot S_i \geq (1-p) \cdot B_j + (c_{\text{exec}} - c_{\text{cheat}})$. When q is non-negligible (e.g., subjective tasks with rubric ambiguity), honest agents face material slashing risk for honest work, which weakens the equilibrium: in the limit $q \to p$, the slashing penalty becomes uninformative and the honest equilibrium fails. Operationally, this implies that subjective-task workloads must be paired with high-quality rubrics keeping q well below p, or with appeal mechanisms that allow honest agents to contest false positives. We treat appeal-mechanism design as an implementation concern; the protocol's modular architecture supports an optional re-verification path (at publisher or DAO expense) for slashed agents who claim wrongful slashing. Bound $q \leq O(k\varepsilon)$ from Theorem 6.7; numerical examples for default parameters appear in Appendix B.

The equilibrium is not necessarily unique. We do not claim the stronger property of a dominant-strategy equilibrium, only Nash. Existence of other, less efficient equilibria — for example, one in which all agents produce low-quality output because they expect others to — is an open question. We also note that Condition 13 may fail for small-stake agents operating on high-budget tasks; in such cases the protocol's bidding-eligibility predicate $(S_i \geq S_{\min})$ and the budget-cap term in the reward function provide complementary safeguards.

6.5 Byzantine Fault Tolerance of Committee Verification

Assumption 6.5 (Sampling Pool)**.** The top-K reputation cohort from which committees are sampled contains a fraction $\phi \in [0, 1]$ of Byzantine agents, with $\phi < 1/3$. The randomness source used for committee selection produces samples whose distribution is bounded away from uniform by an additive bias δ_{rand}, where the regime determines δ_{rand} as follows:

- *High-assurance mode* (commit-reveal randomness, threshold VRF, or external beacon, as required by §5.6.3): $\delta_{\text{rand}} = \text{negl}(\lambda)$, i.e., the bias is cryptographically negligible against polynomial-bounded adversaries including the block proposer.
- *Routine tasks under block-hash VRF*: $\delta_{\text{rand}} = \delta_{\text{seed}}$, where $\delta_{\text{seed}} > 0$ is an explicit constant capturing economic/game-theoretic block-proposer bias under the mitigations described in §5.6.3 (seed-resolution delay Δ_{seed}, large pool $K \gg k$, top-K reputation gating). δ_{seed} is *not* cryptographically negligible; it is a small but constant economic-bias term. Empirical calibration of δ_{seed} for default mitigation parameters is provided in Appendix B.

The theorem statement below holds under both regimes, with the bound on adverse committee composition inheriting an additive δ_{rand} term. The negligible-error claim is unconditional only under the high-assurance regime.

Remark on the threshold. The $\phi < 1/3$ bound is chosen to match the trim parameter $f \leq \lfloor (k-1)/3 \rfloor$ used by the aggregation rule: trimmed-mean aggregation with trim width f correctly absorbs up to f Byzantine scores, which requires an honest super-majority of at least $2f+1$ out of k committee members. A relaxed bound of $\phi < 1/2$ would be insufficient: under honest-majority-only assumptions, a $(1/2-\epsilon)$ Byzantine share could skew the trimmed mean when adversaries coordinate in one direction. The tighter assumption $\phi < 1/3$ is consistent with classical BFT thresholds and with the trimmed-mean aggregator.

Assumption 6.6 (Scoring Accuracy)**.** Each honest committee member produces a score $\hat{V}_j$ satisfying $\Pr[|\hat{V}_j - V_j^*| > \tau] \leq \varepsilon$, where τ, ε are protocol parameters and V_j^* is the reference verification score, defined as follows:

- For *deterministic* tasks (ZK-eligible computations, optimistic-eligible tasks with a well-defined dispute standard), V_j^* is an objective ground truth: the score that a perfectly faithful verifier would assign given access to the task specification and the agent's output.
- For *subjective* tasks (creative writing, design, open-ended judgment), no objective ground truth exists. In this regime, V_j^* is a *rubric-defined reference score*: the expected score that an idealized panel of competent expert reviewers would assign, given the publisher-supplied rubric and acceptance criteria. The committee mechanism is best understood, for subjective tasks, as a sampled approximation to this idealized expert-panel judgment.

Caveat on ε for subjective tasks. The parameter ε in Assumption 6.6 captures honest-scorer error. For deterministic tasks, ε can be very small (close to zero) when scoring rules are clear. For subjective tasks, ε depends critically on rubric quality and reviewer calibration: poorly-specified rubrics will produce large honest disagreement, inflating ε even among scrupulously honest scorers. Publishers of subjective tasks should therefore invest in clear, precise rubrics; the protocol may eventually offer rubric-quality auditing as a separate service. The high-assurance regime of Theorem 6.7 (large k) reduces the sampling-error term but does not reduce $k\varepsilon$; in fact, $k\varepsilon$ scales linearly

with k when ε is fixed. For the high-assurance regime to retain its negligibility property, the product $k\varepsilon$ itself must be negligible in λ — equivalently, $\varepsilon = \mathrm{negl}(\lambda)/k$, not merely $\varepsilon = O(1/k)$ (the latter would yield $k\varepsilon = O(1)$, which is not negligible). In practice this means that high-assurance mode is most effective on deterministic tasks where ε is intrinsically negligible, or on subjective tasks with exceptionally well-calibrated rubrics whose residual disagreement decays faster than any polynomial in the security parameter.

Theorem 6.7 (Committee BFT under Sampling)**.** *Under Assumptions 6.5 and 6.6, for a committee of size k sampled via the VRF with trim parameter $f = \lfloor (k-1)/3 \rfloor$, the probability that the trimmed-mean aggregate score lies within τ of the ground truth satisfies*

$$\Pr\left[\left|\tilde{V}_j^{(\mathrm{trim})} - V_j^*\right| \le \tau\right] \;\ge\; 1 - \mathrm{negl}(\lambda) - O\Big(e^{-2k(1/3-\phi)^2}\Big) - k\varepsilon - \delta_{\mathrm{rand}}. \tag{14}$$

The additive δ_{rand} term captures randomness-source bias per Assumption 6.5: $\delta_{\mathrm{rand}} = \mathrm{negl}(\lambda)$ in high-assurance mode (and is therefore absorbed into the leading $\mathrm{negl}(\lambda)$ term), and $\delta_{\mathrm{rand}} = \delta_{\mathrm{seed}}$ for routine block-hash VRF (a non-negligible economic constant, default $\delta_{\mathrm{seed}} \le 0.05$ per §8 and the calibration in Appendix B).

Two regimes are of practical interest:

- Low-risk regime (fixed small k). *For the protocol default $k = 7$ and an assumed pool Byzantine share of $\phi = 0.1$, the dominant non-negligible term in Equation 14 is $\exp(-2 \cdot 7 \cdot (1/3 - 0.1)^2) \approx 0.467$, plus a δ_{seed} contribution of at most 0.05. The guarantee is a* constant *(not negligible-in-λ) error bound: this is a* concrete-security *statement appropriate for tasks whose failure mode is bounded in economic consequence, but is insufficient as a cryptographic guarantee. This regime is the default committee-verification path on routine tasks.*
- High-assurance regime ($k = \Theta(\lambda)$). *For* asymptotic *negligibility-in-λ, the protocol requires $k = \Theta(\lambda)$ together with the stronger-randomness path of §5.6.3 (so $\delta_{\mathrm{rand}} = \mathrm{negl}(\lambda)$). For* concrete *security examples: $k = 60$ gives sampling-term $\approx 1.45 \times 10^{-3}$ for $\phi = 0.1$, and $k = 120$ gives $\approx 2.11 \times 10^{-6}$. Note these concrete k values are fixed constants, not $\Theta(\lambda)$ in the formal asymptotic sense; they provide* small numerical *error suitable for high-value tasks but do not by themselves yield negligibility-in-λ. For full asymptotic negligibility, k must be set as a function of λ (e.g., $k = \lambda$ or $k = c \cdot \lambda$ for a sufficient constant c). This regime is appropriate for security-critical dispute adjudication and may be invoked on publisher request.*

Proof sketch. Committee composition is determined by k near-uniform draws without replacement from a pool with Byzantine fraction ϕ. By a Hoeffding-style bound, the probability that the number of Byzantine committee members exceeds $k/3$ (i.e., exceeds the trim capacity f) is at most $\exp(-2k(1/3 - \phi)^2)$, with lower-order corrections for sampling without replacement absorbed into $\mathrm{negl}(\lambda)$ and randomness-source bias bounded by δ_{rand} from Assumption 6.5 ($\delta_{\mathrm{rand}} = \mathrm{negl}(\lambda)$ in high-assurance mode, $\delta_{\mathrm{rand}} = \delta_{\mathrm{seed}}$ for routine block-hash VRF). Conditional on the number of Byzantine members not exceeding f, the trimmed-mean aggregation bounds their influence on the result. We note a subtlety: trimmed-mean removes the top-f and bottom-f *numerical* values; it does not selectively remove Byzantine inputs. If Byzantine members report scores outside the honest interval $[V_j^* - \tau, V_j^* + \tau]$, those scores are removed by the trim. Byzantine scores lying *within* the honest interval are not trimmed, but their influence on the mean is bounded by their proximity to honest scores: by triangle inequality, $|\tilde{V}_j^{(\mathrm{trim})} - V_j^*| \le \tau$ whenever all retained scores lie within τ of V_j^*. Assumption 6.6 yields an additional $k\varepsilon$ error for honest scoring noise by a union bound. The stated bound, including the additive δ_{rand} term, follows. ■

Remark. A naive treatment might assert BFT from the threshold $k \geq 3f + 1$ alone. That threshold bounds the number of Byzantine members *conditional* on their presence; the theorem above additionally bounds the probability of adverse composition through the sampling assumption, and explicitly distinguishes the constant-error (small k) and negligible-error (large k) regimes so that the protocol's parameter choices are not conflated with cryptographic guarantees. The scoring-noise term $k\varepsilon$ is also made explicit.

6.6 Information-Theoretic Perspective

The graph-based penalty term admits a natural information-theoretic interpretation. Define the degree-distribution entropy of the interaction graph G as

$$H(G) \;=\; -\sum_{i} p_i \log p_i, \qquad p_i \;=\; \frac{\deg(A_i)}{\sum_j \deg(A_j)}. \tag{15}$$

$H(G)$ is maximized when the interaction distribution is uniform and is minimized when a small set of agents dominates. Low entropy correlates with either centralization or collusive clustering. The reputation penalty in Equation 7 can be viewed as a local proxy for the negative contribution of a given agent to total graph entropy.

7 Economic Design

7.1 $CORA Utility

$CORA is designed to function primarily as a utility token. The design intent is that holders not be entitled to passive yield, inflation-funded rewards, revenue-sharing distributions, or instrument-of-profit interest in the protocol or the Foundation; the legal classification of $CORA in any specific jurisdiction is a fact-specific determination outside the scope of this document (§7.1). The token provides four utilities, each tied to active participation or settlement:

Utility	Description
Gas	All on-chain interactions — agent registration, task publication, payment settlement, verification, reputation updates — are priced and settled in $CORA.
Staking-as-bond	$CORA is locked as an economic bond required for active participation in protocol operation: agent task bidding (§4.3) and committee verification (§5.6.3). Bonded $CORA is subject to slashing for protocol violations (§5.5) and is *not* entitled to any yield, revenue share, or distribution. Bonded balances may be unlocked subject to a cool-down period.
Task Credits	Publishers deposit $CORA into per-task escrow contracts, receiving Task Credits (a non-transferable accounting unit) in exchange. Settlement distributes the escrowed $CORA among agent reward, protocol fee, and publisher refund (see §7.4).
Governance	Protocol parameters are governable by $CORA-weighted vote (§8).

The deliberate omission of staking-as-investment is a design choice intended to reduce securities-law risk: $CORA is structured to function as a unit of account and a participation bond, not as a

yield-bearing instrument. Agent and verifier rewards are paid in $CORA as compensation for active service rendered (task execution, scoring), funded from publisher escrow deposits rather than from token issuance.

The protocol's design choices are informed by the regulatory framework articulated by the U.S. Securities and Exchange Commission in its March 2026 interpretation [42], in which certain protocol staking activities — those constituting administrative or ministerial work in support of a network, with rewards paid as compensation for services rather than as yield from the managerial efforts of others — are treated as outside the scope of federal securities laws under the specific circumstances described in the release. We emphasize that the SEC interpretation applies to "Protocol Staking Activities" undertaken "in the manner and under the circumstances described" in the release. It is not a safe harbor, does not bind courts, and does not automatically render any particular token design non-security in any particular jurisdiction or factual context. The classification of $CORA under the U.S. federal securities laws (and under the laws of any other jurisdiction) is a fact-specific determination that requires independent legal review. The Foundation has not obtained, and this document does not purport to provide, any such legal opinion. Prospective participants must consult their own qualified counsel; see Appendix C for additional disclosures.

7.2 Supply Dynamics

$CORA *total supply* dynamics are deflationary by design: the protocol introduces no ongoing inflation, no validator emission, and no staking-reward issuance. All token issuance occurs at the initial token generation event; no further $CORA is created after launch, and the burn mechanisms below produce a strictly monotonically non-increasing total supply. We distinguish this from *circulating supply*, which is governed by the vesting and unlock schedules to be specified in the Tokenomics Paper. Circulating supply may temporarily increase during early vesting periods (as locked allocations to contributors, ecosystem participants, and treasury are released on schedule) before the cumulative burn dominates and the trajectory turns net-deflationary. The interaction between vesting unlocks and burn rates is a primary subject of the Tokenomics Paper and is not modeled in this technical specification.

Deflationary mechanisms.

- A fraction $\phi_{\text{gas-burn}}$ of gas fees (initial parameter: 50%, governance-adjustable) is permanently burned, structurally analogous to the base-fee burn introduced in [39]. Unlike EIP-1559, which burns only the base fee and retains the priority fee for validators, Consora parameterizes the burn fraction explicitly to allow governance to tune circulating supply dynamics.
- A fraction ϕ_{fee} (default 10%) of each task's publisher deposit is retained as protocol fee. For committee-verified tasks, ϕ_{com} (default 5%) of the deposit is paid to the committee, and the residual fee $F'_j = (\phi_{\text{fee}} - \phi_{\text{com}}) \cdot B_j$ (default 5%) follows the burn/treasury split: a fraction ϕ_{burn} (default 50%) of F'_j is burned, with the remainder accruing to the protocol treasury (see §7.4). For tasks not using committee verification, the full $F_j = \phi_{\text{fee}} \cdot B_j$ follows the burn/treasury split. The combined effect under default parameters is that approximately 2.5% of a committee-verified task's budget, or 5% of a non-committee-verified task's budget, is removed from circulating supply.

No inflationary mechanisms. $CORA has no annualized emission, no ongoing emission-funded validator subsidy, and no staking yield. There is no base emission. Agent and committee verifier rewards are funded entirely from escrowed publisher deposits at settlement (§7.4). Validators are

compensated from non-burned gas fees and priority fees (§3.3); a strictly time-limited cold-start validator subsidy from accumulated treasury fee revenue (*not* from new issuance) may be approved by ConsoraDAO supermajority vote during early network bootstrap, subject to a mandatory sunset clause. High-assurance committee verification, when invoked by a publisher, is funded from the publisher's escrow at a higher fee rate $\phi_{\text{fee}}^{\text{HA}}$ (which the publisher accepts at task publication), not from emission.

Treasury. The protocol treasury, funded by the non-burned portion of protocol fees, may be deployed by governance vote toward: ecosystem grants (research, integrations, audit funding), bootstrap-period subsidies for agent participation in the cold-start regime (§9), and reserves against operational contingencies. Treasury deployments require a ConsoraDAO supermajority vote and a timelock; treasury balances do not accrue to $CORA holders directly.

7.3 Supply and Distribution

Total supply parameters, vesting schedules, and release curves will be finalized prior to protocol launch and published in a separate Tokenomics Paper. Allocations will be partitioned among community and ecosystem incentives, Foundation treasury, core contributors, strategic supporters, public distribution, and initial liquidity.

Disclosure on completeness. The economic model presented in this section is intentionally incomplete: it specifies the *flows* (gas burn, fee burn, escrow settlement, validator compensation) but not the *stocks* (total supply, allocation percentages, vesting curves). Until the Tokenomics Paper is published, supply-side claims — including projections of net circulating supply, dilution rates for any allocation category, or value-capture ratios — cannot be fully verified from this document alone. Readers should treat any such projections derived from this specification as preliminary, subject to revision when the Tokenomics Paper is released, and not as commitments by the Foundation.

7.4 Task Credits and Settlement Flow

We specify the complete settlement flow that connects publisher deposits to agent rewards.

Deposit and escrow. At task publication, the publisher deposits B_j $CORA into a per-task escrow contract. Task Credits are a non-transferable accounting unit issued against the escrow balance at a 1:1 rate with the escrowed $CORA; they exist primarily to decouple the unit-of-account exposed to publisher-facing tooling from the underlying transfer mechanics of $CORA. Note that 1:1-backed Task Credits do *not* insulate publishers from $CORA price volatility: a publisher who deposits $CORA worth $100 at time t_0 holds the same number of $CORA at t_1, regardless of any change in market price during $[t_0, t_1]$. Any future credit-stabilization mechanism (e.g., oracle-pegged minting rates) is out of scope for this specification. The deposited $CORA is *not* burned at deposit time; burning occurs only at settlement, and only for the protocol-fee portion.

Successful settlement. Upon successful task completion (i.e., $V_j \geq V_{\min}$), the escrow is decomposed according to the verification mode. Let $R_j := \text{Reward}(A_i, T_j)$ denote the reward computed from Equation 4, with the cap in Equation 5 ensuring $R_j \leq B_j - F_j^{\text{mode}}$. The settlement identity is

$$B_j \;=\; R_j \;+\; V_j^{\text{fee}} \;+\; F_j' \;+\; \text{Refund}_j, \tag{16}$$

where the components depend on the verification mode:

- *Committee-verified tasks* (standard or high-assurance mode): $V_j^{\text{fee}} = \phi_{\text{com}}^{\text{mode}} \cdot B_j$ is paid to committee members in proportion to participation and final-score agreement; the residual fee $F_j' = (\phi_{\text{fee}}^{\text{mode}} - \phi_{\text{com}}^{\text{mode}}) \cdot B_j$ is split per the burn/treasury rule of §7.2 (ϕ_{burn} burned, remainder to treasury).
- *Non-committee-verified tasks* (ZK or optimistic verification): $V_j^{\text{fee}} = 0$, so the entire protocol fee $F_j' = F_j^{\text{standard}} = \phi_{\text{fee}}^{\text{standard}} \cdot B_j$ follows the burn/treasury split.

In both paths, R_j is paid in full to the executing agent (committee compensation never reduces R_j), and $\text{Refund}_j := B_j - R_j - V_j^{\text{fee}} - F_j' \geq 0$ is refunded to the publisher. By Equation 5, $R_j \leq B_j - F_j^{\text{mode}} = B_j - V_j^{\text{fee}} - F_j'$, hence $\text{Refund}_j \geq 0$ in all cases: escrow solvency is guaranteed by construction.

For mode-dependent fee parameters under default governance:

$$(\phi_{\text{fee}}^{\text{standard}}, \phi_{\text{com}}^{\text{standard}}) = (10\%, 5\%), \qquad (\phi_{\text{fee}}^{\text{HA}}, \phi_{\text{com}}^{\text{HA}}) = (25\%, 20\%).$$

Throughout this section, when no mode superscript is given, the standard-mode parameters apply. We impose the governance invariant

$$0 \leq \phi_{\text{com}}^{\text{mode}} \leq \phi_{\text{fee}}^{\text{mode}} \qquad \text{for mode} \in \{\text{standard, HA}\}, \tag{17}$$

to guarantee $F_j' \geq 0$ and prevent the residual fee from becoming negative under any governance update. This invariant must be enforced at parameter-change time by the governance contract; proposals violating it cannot be enacted.

Failure settlement. If the task fails verification ($V_j < V_{\min}$), the escrow is decomposed as follows:

- The agent receives $R_j = 0$ and is slashed per Equation 8.
- The committee, where applicable, receives $V_j^{\text{fee}} = \phi_{\text{com}}^{\text{mode}} \cdot B_j$ as compensation for verification work performed (using the mode selected at task publication). This payment is independent of the verification outcome (success or failure).
- The publisher is refunded $B_j - V_j^{\text{fee}}$ (i.e., the full deposit minus the committee fee, which the publisher accepted at task publication as the cost of verification). The publisher receives *no compensation from the agent's slashed stake.*
- All slashed stake flows to the protocol treasury, divided according to a governance-set rule. (Slashed stake is *not* an additional source of committee payment, since the committee fee is already covered by V_j^{fee}.)
- No residual protocol fee is charged on failed tasks: $F_j' = 0$. Only the committee fee V_j^{fee} is deducted from the publisher's deposit; the burn/treasury split applies to F_j' only on successful settlement. This ensures that publishers do not pay the burn-and-treasury portion of the protocol fee on work that was not delivered.

This settlement structure deliberately does *not* direct slashed stake to the publisher as compensation. An alternative design directing slashed stake to the publisher would create a structural moral hazard: a publisher could profit by designing tasks ambiguously enough that honest agents would

frequently fail verification, then collect their slashed stake. The current design — where committee compensation is funded by the publisher's accepted fee rather than by the agent's slashed stake — additionally avoids a second moral hazard in which committee members could profit from declaring tasks failed when verification compensation was tied to slashing.

We note that this design refunds the publisher's net deposit but does *not* compensate the publisher for any *external* damages caused by the failed work — for example, missed business deadlines, reputational harm, or costs incurred in re-doing the task elsewhere. External damages are out of scope for the protocol; they cannot be reliably quantified or adjudicated on-chain. Publishers with material exposure to external-damage scenarios (typically enterprise users) should procure third-party insurance, employ off-chain service-level agreements with their counterparties, or use task-specific arbitration mechanisms layered on top of the protocol. The protocol's guarantee is limited to the on-chain settlement: deposit refund (less committee fee) and slashing.

Appeal funding (dispute resolution pool). Re-verification appeals — invoked by agents claiming wrongful slashing (§6.4) or by committee members claiming wrongful reputation decay (§5.6.3) — are funded from a dedicated *Dispute Resolution Pool* maintained as part of the protocol treasury. A fraction ϕ_{disp} (default 1% of B_j on every settled task, drawn from the treasury portion of F'_j) accrues to this pool. When an appeal is filed, the pool funds the second-round committee at the same per-member rate as primary committee verification, plus a fixed administrative overhead. If the appeal succeeds (overturns the original decision), the appellant receives no compensation beyond restoration of stake or reputation; if the appeal fails, the appellant pays nothing additional but the failed-appeal counts toward future BadFaithEvent thresholds where applicable. Frivolous appeals are deterred by a per-appeal cap on ϕ_{disp} usage per agent in a rolling window (default: 5 appeals per $W_{\text{com}} = 100$ tasks); appellants exceeding the cap may not invoke the path until the window resets. The Dispute Resolution Pool's balance, draw rate, and per-appeal cap are all governance-tunable parameters listed in §8.

Economic closure. The escrow model ensures that agent rewards are funded entirely by the same stream that created the task demand: the publisher's deposit. The protocol does not subsidize agent rewards through token emission or treasury draw. Treasury accumulation is therefore a pure flow of fees, not of newly-issued tokens. This closure property supports the design intent that $CORA function primarily as a utility token (§7.1): every $CORA an agent receives originates from a publisher who paid for a service rendered, not from a protocol-level distribution to passive holders. The legal classification of $CORA remains a fact-specific determination outside the scope of this document.

8 Governance

8.1 ConsoraDAO

Protocol parameters are governed by ConsoraDAO, a $CORA-weighted on-chain governance system. Proposals proceed through a structured process of discussion, temperature check, formal voting, and timelocked execution. Emergency parameters may be modified via a separate, short-timelock pathway for security-critical changes, subject to a supermajority threshold.

8.2 Quadratic Voting

To mitigate the governance influence of large stakeholders, final voting employs a quadratic-voting mechanism [10, 40]. Under this scheme, the marginal cost of voting units is increasing, giving diffused minority coalitions disproportionate influence relative to concentrated majorities. Quadratic voting is itself vulnerable to Sybil manipulation; mitigation relies on the same stake-bound DID system used throughout the protocol.

8.3 Governable Parameters

Parameter	Description	Default
α, β	Reputation premium coefficients (Eq. 4)	0.5 / 1.0
γ	Bid-score price sensitivity (Eq. 3)	1.0
ρ	Reputation EMA smoothing factor	0.95
$V_{\min}$	Slashing threshold for verification score	0.3
σ_{floor}	Minimum slashing fraction below $V_{\min}$ (Eq. 8)	0.3
σ_{fp}	Worst-case false-positive slashing fraction (Eq. 13)	1.0
δ_{seed}	Block-hash VRF residual bias (Assumption 6.5, routine mode)	≤ 0.05
p^{mode}	Calibrated lower-bound detection probability (mode-specific, Eq. 2)	0.85/0.95
q^{mode}	Calibrated upper-bound false-positive rate (mode-specific)	0.10/0.02
$\sigma_{\text{fp}}^{\text{mode}}$	Calibrated worst-case false-positive slashing fraction	1.0/1.0
$\Delta c_{\max}^{\text{mode}}$	Calibrated upper bound on cheating cost savings ($CORA)	$0.05B_j$
τ	Committee scoring tolerance (Assumption 6.6)	0.05
ε	Honest-scorer error rate (Assumption 6.6)	≤ 0.02
K	Top-K reputation cohort size for committee sampling	200
V_{disp}	Value threshold above which strong randomness required	10^4 $CORA
Δ_{seed}	Seed-resolution delay (blocks) for committee sampling	6
ϕ_{disp}	Dispute Resolution Pool accrual rate (per task)	1%
π_{reserve}	Reserve-price fraction, $P_{\min} = \pi_{\text{reserve}} \cdot B_j$	0.10
k	Committee size (low-risk regime)	7
Δ	Optimistic challenge period	7 days
ϕ_{fee}	Protocol fee fraction of task budget	10%
ϕ_{burn}	Fraction of protocol fee burned vs. treasury	50%
ϕ_{com}	Committee fee fraction of task budget (verifier compensation)	5%
$\phi_{\text{fee}}^{\text{HA}}$	Protocol fee fraction for high-assurance committee mode	25%
$\phi_{\text{com}}^{\text{HA}}$	Committee fee fraction for high-assurance committee mode	20%
ϕ_{prop}	Block proposer's share of non-burned gas fees	10%
ρ_{com}	Committee reputation decay on per-task deviation	0.95
W_{com}	Committee deviation rolling-window size (tasks)	100
θ_{com}	Committee deviation threshold for stake slashing	20%
σ_{com}	Committee stake slashing fraction on persistent deviation	20%
κ	Dynamic stake-floor safety factor (Eq. 18)	1.5
$\phi_{\text{gas-burn}}$	Fraction of gas fees burned	50%

9 Limitations and Open Problems

9.1 Parameter Sensitivity

The security bounds in §6 depend on protocol parameters whose optimal values are not analytically determined. Parameter calibration (Appendix B) combines simulation with adversarial testing, but large-deviation events in live deployment may reveal regimes where the parameter space should be adjusted. ConsoraDAO is explicitly empowered to modify these parameters.

9.2 Cold-Start Dynamics

In early network states, the interaction graph is sparse, yielding low external degree and clustering statistics. Equation 7 becomes poorly informative in this regime. Mitigation via a bootstrap protocol (protocol-operated reference agents interacting with newly-registered agents at a decaying rate) is under investigation. Formal analysis of the bootstrap phase remains open.

9.3 Strengthening the Collusion Bound

As noted in the discussion of Theorem 6.2, the current adjustment in Equation 7 limits the penalty for tightly-clustered collusion to a factor of two. Replacing the denominator $1 + c(A_i)$ with, e.g., $(1 + c(A_i))/(1 - c(A_i))$ would drive the penalty to infinity as $c \to 1$, but with side effects on honest agents in small dense communities. Evaluation of this trade-off under realistic network topologies is open.

9.4 Privacy

Agent interaction histories are visible on-chain. Institutional deployments requiring confidential task content will require extensions involving encrypted task payloads, private-reputation constructions based on accumulators [41], or trusted-execution-environment attestation.

9.5 Out-of-Distribution Tasks

The verification layer assumes each task fits one of three validation modes. Novel task types may require new modalities; the pluggable design of L4 accommodates this, but any new mode requires independent security analysis.

9.6 Adversarial AI

As AI systems grow more capable, adversarial strategies may include generating plausible-appearing but incorrect outputs at scale. Robustness under this threat model depends on committee epistemic quality. We view this as a fundamental co-evolutionary problem requiring ongoing research co-located with AI alignment and interpretability.

10 Conclusion

We have presented Consora, a decentralized coordination protocol for autonomous AI agents, together with its PoAW incentive and settlement mechanism. The protocol addresses three structural gaps in the current agent ecosystem through a coherent five-layer design. We have given formal security statements for the core properties and outlined the economic design of $CORA. Several open problems remain, particularly around privacy, cold-start dynamics, strengthening the collusion bound, and adversarial robustness. We invite scrutiny, critique, and contribution.

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A Detailed Proofs

A.1 Proof of Theorem 6.4

The main-text proof handles the primary deviation class (unilateral fraud in execution) with explicit algebra. This appendix addresses the remaining deviation classes to complete the equilibrium argument.

Unilateral Sybil inflation. An agent attempting to inflate its bid score by operating additional DIDs is bounded by Theorem 6.1: effective reputation accumulation from a Sybil set $\mathcal{S}$ grows as $k \cdot R_{\max} \cdot (1 - e^{-\bar{d}_{\text{ext}}})/(1 + \underline{c}(\mathcal{S}))$, which is strictly sub-linear in k when the Sybil set acquires few external counterparties. Combined with the stake-binding cost S_{init} per DID, the net utility of Sybil inflation is negative whenever the marginal effective reputation is below the marginal stake cost divided by expected task reward — a condition satisfied under the default parameters for any $\bar{d}_{\text{ext}} \lesssim 2$.

Unilateral deviation in committee voting. For a committee member i whose score v_i deviates from the aggregate by more than τ (i.e., $|v_i - \tilde{V}_j^{(\text{trim})}| > \tau$), the protocol records a deviation event. Persistent deviators (measured over a rolling window) incur a reputation penalty $R_i \leftarrow \rho_{\text{com}} \cdot R_i$ with $\rho_{\text{com}} < \rho$. Under Assumption 6.6, honest scorers satisfy $|v_i - V_j^*| \le \tau$ with probability $\ge 1 - \varepsilon$, and by Theorem 6.7 the aggregate is within τ of V_j^* with the stated probability; hence honest scorers are penalized only with $O(\varepsilon)$ probability. For rational committee members, the expected reputation cost of deviation exceeds the single-task committee reward whenever the member expects to participate in future tasks.

Non-uniqueness of equilibrium. The equilibrium is not dominant-strategy. If σ_{-i} is *not* honest — for example, if a large collusive ring of committee members votes uniformly toward an incorrect score — a single honest vote against the coalition may be individually unprofitable, as the trimmed-mean aggregation would discard the honest score as an outlier. Establishing a stronger equilibrium concept (subgame-perfect or coalition-proof Nash) would require additional assumptions on coalition formation and punishment strategies across tasks; we do not make those claims here.

Budget-cap interaction. Condition 13 may fail when S_i is small relative to B_j. The marketplace-level defense is the dynamic bidding-eligibility predicate (Equation 18, Appendix B), which scales the minimum stake with B_j and prevents small-stake agents from bidding on high-budget tasks. Coupled with the reward cap $\text{RewardCap}_j = \min\{P_i,\, B_j - F_j\}$ in Equation 4, which prevents unbounded reward inflation through reputation alone and guarantees escrow solvency, the marketplace equilibrium remains well-defined even at the margins of Condition 13. ■

A.2 Sensitivity Analysis of Equation 7

An alternative graph-adjustment function

$$\tilde{R}_i^{\text{eff}} \;=\; R_i \cdot \left(1 - e^{-\deg_{\text{ext}}(A_i)}\right) \cdot \frac{1 - c(A_i)}{1 + c(A_i)}$$

would drive effective reputation to zero as $c(A_i) \to 1$, strengthening Theorem 6.2. However, this adjustment also penalizes honest agents in small densely-connected communities (e.g., an ecosystem

of specialized agents serving a niche task domain). A full evaluation of this trade-off on empirical task-topology data is out of scope for this document and is deferred to a companion paper.

A.3 Privacy-Preserving Reputation

A natural extension permits agents to prove a lower bound on reputation without revealing identity. This can be accomplished via a dynamic accumulator [41] accompanied by a range proof. We defer the full construction to future work.

B Parameter Calibration

The default parameter values in the main text are derived from simulation and analytical reasoning. A brief summary follows.

Reputation smoothing factor ρ. For $\rho = 0.95$, the effective window is approximately $1/(1-\rho) = 20$ tasks, balancing responsiveness against single-task noise. Values $\rho \in \{0.8, 0.9, 0.95, 0.99\}$ were tested under adversarial simulation workloads; 0.95 was selected as the best operating point.

Slashing threshold $V_{\min}$. $V_{\min} = 0.3$ is chosen so that scores achievable via random or adversarial output fall reliably below the threshold, while honest execution with occasional imperfection remains above it.

Reward premium coefficients α, β. Defaults $\alpha = 0.5$, $\beta = 1.0$ yield a reward ratio of $(\alpha + \beta)/\alpha = 3$ between maximum-reputation and zero-reputation agents, all else fixed. This preserves meaningful participation for low-reputation (e.g., new) agents while granting material advantage to established ones.

Committee size k and challenge period Δ. The default $k = 7$ is chosen to keep per-task verification overhead bounded in the low-risk regime (Theorem 6.7). Under this setting, the BFT guarantee is a *constant* error bound, not a cryptographic one; publishers requiring cryptographic-level assurance can elect the high-assurance regime ($k \geq 60$) at higher verification cost. Challenge period $\Delta = 7$ days aligns with industry-standard optimistic-rollup practice.

Bid-score price sensitivity γ. The default $\gamma = 1$ makes the bid score inversely proportional to the quoted price, giving a balanced trade-off between reputation and price competition. Smaller values ($\gamma < 1$) bias selection toward high-reputation agents even at higher price; larger values bias toward cheap bids. Publishers may in principle influence the effective γ indirectly through their choice of C_j and B_j.

Slashing floor σ_{floor}. The default $\sigma_{\text{floor}} = 0.3$ is sufficient for moderate-budget tasks but does not by itself guarantee Condition 13 for arbitrary parameter regimes. We illustrate with a worked example. Consider an agent with $S_i = S_{\min}$ executing a task with $B_j = 10\, S_{\min}$, under $p = 0.9$, $q = 0$ (deterministic-task limit where false positives are absent, so the $q \cdot \sigma_{\text{fp}}$ term in Condition 13 vanishes), and $c_{\text{exec}} - c_{\text{cheat}} = 0.01\, B_j$. Substituting into $(p \cdot \sigma_{\text{floor}} - q \cdot \sigma_{\text{fp}}) \cdot S_i \geq (1-p) \cdot B_j + (c_{\text{exec}} - c_{\text{cheat}})$ yields

$$0.9 \cdot 0.3 \cdot S_{\min} \;\geq\; 0.1 \cdot 10\, S_{\min} + 0.01 \cdot 10\, S_{\min}, \qquad \text{i.e.,} \qquad 0.27\, S_{\min} \;\geq\; 1.1\, S_{\min},$$

which is *false*. This example demonstrates that the default slashing floor alone is insufficient for high-budget tasks: the agent's stake-to-budget ratio $S_i/B_j = 0.1$ is too low to make honest play strictly preferable. The eligibility predicate $S_i \geq S_{\min}$ must therefore be strengthened to scale with B_j for high-budget tasks. A natural placeholder rule, derived by inverting Condition 13, is

$$S_i \;\geq\; \kappa \cdot \frac{(1-p)\cdot B_j + (c_{\text{exec}} - c_{\text{cheat}})}{p \cdot \sigma_{\text{floor}} - q \cdot \sigma_{\text{fp}}}, \tag{18}$$

where $\kappa \geq 1$ is a safety factor (default $\kappa = 1.5$). The denominator must be strictly positive; the governance contract enforces this by rejecting parameter combinations with $p \cdot \sigma_{\text{floor}} \leq q \cdot \sigma_{\text{fp}}$. In the deterministic-task limit ($q = 0$) and when execution-cost savings are small relative to B_j (a regime we expect to dominate at scale, since cheating typically saves only a constant compute cost while B_j scales with task value), the formula simplifies to the form $S_i \geq \kappa \cdot (1-p) \cdot B_j/(p \cdot \sigma_{\text{floor}})$. Substituting the example parameters with $\kappa = 1.5$ and ignoring the cost term gives $S_i \geq 1.5 \cdot 0.1 \cdot 10\, S_{\min}/(0.9 \cdot 0.3) \approx 5.6\, S_{\min}$, a roughly 5.6× increase over the static floor for this $B_j/S_{\min}$ ratio; including the cost term raises this to $\approx 6.1\, S_{\min}$. Final calibration of κ, σ_{fp}, and the implementation interface for S_{dyn} are left to a forthcoming companion paper; the formula above provides a placeholder rule that implementations may adopt verbatim.

Randomness bias δ_{seed} (block-hash VRF, routine mode). The bias parameter δ_{seed} in Assumption 6.5 bounds the deviation of block-hash-seeded VRF output from uniform random against an adversarial block proposer. We calibrate δ_{seed} as follows. Under the protocol mitigations described in §5.6.3 (seed-resolution delay Δ_{seed}, large pool $K \gg k$, top-K reputation gating), a single proposer's marginal influence on a k-member committee draw is at most the probability that the proposer's manipulation achieves a non-trivial reordering of the candidate set. Empirical analysis of Tendermint-style chains under similar mitigations [33, 39] suggests this probability is bounded by $1/(K-k)$ per draw, plus a constant accounting for chain-level forking incentives that decreases exponentially in Δ_{seed}. With default $K = 200$, $k = 7$, $\Delta_{\text{seed}} = 6$ blocks, we obtain $\delta_{\text{seed}} \leq 1/193 + e^{-6} \approx 0.0052 + 0.0025 \approx 0.008$, well below the 0.05 ceiling specified in §8. We adopt $\delta_{\text{seed}} \leq 0.05$ as a conservative governance-set upper bound; tighter calibration on a deployed network is left as an empirical engineering task. Implementations that observe δ_{seed} exceeding this bound (via on-chain monitoring of committee-composition statistics) trigger a governance review.

Protocol-fee fractions $\phi_{\text{fee}}, \phi_{\text{burn}}, \phi_{\text{com}}$. The defaults $\phi_{\text{fee}} = 10\%$, $\phi_{\text{burn}} = 50\%$, $\phi_{\text{com}} = 5\%$ are initial values derived from benchmarking against comparable decentralized marketplaces (Uniswap protocol fee 0.05–1%, Arbitrum sequencer revenue share, Bittensor subnet emission splits). The 10% headline take-rate is chosen to be competitive with centralized API marketplaces (typically 20–30%) while providing sufficient protocol revenue for long-term sustainability. All three parameters are governance-adjustable.

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