

PRAXIS

Parametric Recursive Architecture for Transdisciplinary X-domain Integration in Systems

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Abstract

Gall's Law (1975) is an empirical observation of the highest importance for systems engineers: complex systems that work are invariably found to have evolved from simple systems that worked; complex systems designed from scratch do not work. This paper does not contradict Gall. It identifies the structural mechanism his law describes and shows how that mechanism can be instantiated deliberately rather than waited for.

The central claim is this: *there exists a minimal formal kernel K such that (a) K is a working simple system in Gall's sense, and (b) any system belonging to the well-defined class C_K can be expressed as a parametric instantiation $K(\theta)$ for some admissible $\theta \in \Theta$.* Complexity is not designed into the architecture; it is encoded in the parameter set θ , which is typed, constrained, and domain-specific.

K is the **Composable Belief Kernel (CBK)**: a Partially Observable Markov Decision Process over a Gaussian Process belief state, with HMM-modelled latent dynamics and a time-indexed opportunity-cost reward. Two admissible instantiations are constructed as boundary cases, establishing kernel isomorphism $S_1 \cong_K S_2$ and validating the composition operator $S_1 \oplus_K S_2$ through a shared population prior.

The paper introduces **PRAXIS**—*Parametric Recursive Architecture for Transdisciplinary X-domain Integration in Systems*—as the formal framework for constructing, validating, and composing CBK instantiations across typed system classes. PRAXIS is a belief-state architecture over typed systems. Domain language is not descriptive—it is admissible only as parameter binding within Θ , has no semantic authority outside instantiation scope, and cannot participate in any inference, proof, or operator definition at the kernel level.

Keywords: composable belief kernel; POMDP; Gaussian process; transdisciplinary systems engineering; Gall's Law; parametric complexity; hidden Markov model; opportunity-cost reward; system-of-systems.

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1 The Problem with Gall

Gall’s Law is a failure taxonomy, not a design guideline. Every large-scale systems failure it predicts follows a single pattern: architects mistake structural complexity for capability, design top-down without a working foundation, and discover that complexity without a working core is expensive fragility.

But Gall’s Law creates a trap. If working complexity must *emerge* from working simplicity, then deliberate design of complex systems is either impossible or requires iteration timescales that constrained programs cannot afford. The antidote is not to ignore Gall. It is to ask: *what is the minimal working system from which all required complexity in a given class can be generated by parametric instantiation?*

If such a kernel exists, Gall’s evolutionary process is compressible. The kernel is the working simple system. Domain complexity lives in θ , not in the kernel’s architecture. The kernel is specified once; the parameters are argued per deployment.

PRAXIS answers this question for the class of belief-state decision systems under time-indexed opportunity cost.

2 The Composable Belief Kernel

2.1 Formal Definition

Definition 2.1 (Composable Belief Kernel). The Composable Belief Kernel is the tuple

$$K = \langle S_K, \mathcal{A}_K, T_K, R_K, \Omega_K, O_K, \mathcal{B}_K \rangle$$

where each component is a *typed slot*—an interface specification, not a concrete implementation—defined as follows.

Slot	Type	Description
$\mathcal{S}_K$	Latent state space	Hidden system state: quality, trajectory, or integrity of the monitored entity; not directly observable
$\mathcal{A}_K$	Action space	Resource allocation decisions: intervention, monitoring, referral, or abstention
T_K	Transition kernel	$P(s_{t+1} \mid s_t, a_t)$; state dynamics under actions and time
R_K	Reward surface (time-indexed)	Value of action a in belief state $\mathbf{b}$ at time t , inclusive of opportunity-cost of delay
Ω_K	Observation space	Publicly or empirically accessible signals generated by the monitored entity
O_K	Emission model	$P(\mathbf{e}_t \mid s_t)$; likelihood of observation given latent state
$\mathcal{B}_K$	Belief update operator	Joint GP posterior update (Kalman correction) and HMM forward pass

Table 1: Typed slots of the Composable Belief Kernel K . Domain-specific content is bound at instantiation, not at kernel definition.

K is working in Gall’s sense under three reductions. It reduces to a standard POMDP when the GP belief is collapsed to a point estimate. It reduces to standard multi-objective Bayesian optimisation (MOBO) when the time-index is removed from R_K . It reduces to a tabular HMM when $\mathcal{S}_K$ is finite and $\mathcal{B}_K$ drops the GP component. Each degenerate form is an established working system; K generalises all three without introducing architectural novelty.

2.2 The Parameter Space and Admissibility

Θ is a typed constraint system, not a parameter set. An element $\theta \in \Theta$ binds concrete types to each slot in Definition 2.1, subject to the constraint that all bindings preserve slot typing. Explicitly:

$$\theta = (\mathcal{S}(\theta), \mathcal{A}(\theta), T(\theta), R(\theta), \Omega(\theta), O(\theta), \mathcal{B}(\theta))$$

Constraint 2.2 (Admissibility of Θ). Elements $\theta \in \Theta$ are admissible if and only if they preserve slot typing, satisfy $\mathcal{C}_K$ (Definition 3.1), and admit a validity proof (Definition 2.3). Substitutions that violate slot typing are not elements of Θ ; they are type errors. Parameter sets that satisfy slot typing but fail $\mathcal{C}_K$ or the validity proof are well-typed non-members: they do not constitute PRAXIS instantiations.

2.3 Valid Instantiation

Definition 2.3 (Valid Instantiation). For admissible $\theta \in \Theta$, the instantiation $K(\theta)$ is *valid* if and only if all four conditions hold:

- VI-1 Belief consistency.** $\mathcal{B}(\theta)$ produces calibrated posterior beliefs: $P(s \mid \mathbf{e}_{1:t})$ is well-defined for all non-empty observation sequences and converges as $t \rightarrow \infty$.
- VI-2 Markov sufficiency.** The belief state $\mathbf{b}_t = \mathcal{B}(\theta)(\mathbf{e}_{1:t})$ is a sufficient statistic for all prior observations. The optimal policy π^* depends only on $\mathbf{b}_t$, not on $\mathbf{e}_{1:t}$ directly.
- VI-3 Reward computability.** $R(\theta)(\mathbf{b}, a, t)$ is computable from $\mathbf{b}_t$ without access to the true latent state s_t .
- VI-4 Time-index non-degeneracy.** The opportunity-cost term $\Delta_{\text{OC}}(s_t) > 0$ for at least one action–time pair; i.e., at least one opportunity window with non-trivial foreclosure probability exists in the system being modelled.

2.4 Property Inheritance

Theorem 2.4 (Property Inheritance). *If $K(\theta)$ is a valid instantiation, then $K(\theta)$ inherits the following properties from K :*

- P1 Calibration.** *Posterior uncertainty is structurally honest: overconfident assessments cannot be produced by architectural choice. Uncertainty is a function of observation density, not of system configuration.*
- P2 Optimality trajectory.** *Thompson Sampling over the GP posterior achieves sublinear regret with respect to the fixed optimal policy (Srinivas et al., 2012).*
- P3 Graceful degradation.** *Under missing observations, posterior variance increases; the belief operator does not collapse to point estimates in the absence of evidence.*
- P4 Gall compatibility.** *The working properties of $K(\theta)$ derive from K , not from θ . Substituting a new admissible θ' does not require redesigning the kernel.*

Proof sketch. (P1)–(P3) follow from standard properties of Bayesian inference, GP regression under the Matérn-5/2 kernel, and the forward algorithm for HMMs respectively. (P4) follows by construction: the instantiation map $\iota : \Theta \rightarrow \text{Systems}(K)$ defined by $\iota(\theta) = K(\theta)$ preserves kernel structure as an invariant; θ varies, K does not. □ □

3 The System Class $\mathcal{C}_K$

Definition 3.1 (System Class $\mathcal{C}_K$). A decision system P belongs to class $\mathcal{C}_K$ if and only if all five membership conditions hold:

- C1 Latent state.** P has a latent state $s \in \mathcal{S}$ that is not directly observable but is inferable from noisy signals $\mathbf{e} \in \Omega$ via a well-defined emission model $P(\mathbf{e} \mid s)$.

- C2 Sequential interaction.** P requires sequential decisions whose effects interact over time; future decision value depends on prior actions.
- C3 Time-indexed opportunity cost.** P has a reward structure degraded by delay: $R(s, a, t) \neq R(s, a, t')$ for at least some $t \neq t'$, with the inequality driven by opportunity windows that open and foreclose independently of the decision-maker's actions.
- C4 Population structure.** P admits a population of structurally comparable entities from which a hierarchical prior μ_{pop} can be constructed to address the cold-start problem for entities with sparse observation histories.
- C5 Probabilistic output requirement.** P operates under ethical or institutional constraints that require probabilistic outputs: assessments are beliefs over $\mathcal{S}$, not determinations of the true state.

Remark 3.2. Conditions C1–C3 are necessary for the POMDP structure to be non-degenerate. C4 is necessary for the hierarchical GP prior to be identifiable. C5 is a design constraint, not a mathematical one; it ensures that $K(\theta)$ outputs are consumed as evidence by human decision-makers rather than substituted for them.

Constraint 3.3 (Madlib Boundary Condition). Substitutions of domain terms into θ that do not induce a distinct belief operator $\mathcal{B}(\theta)$ and reward surface $R(\theta)$ are syntactic and are equivalent under PRAXIS: they do not define new systems, new membership claims in $\mathcal{C}_K$, or new instantiations, and are not admissible elements of Θ . Formally: $\theta \sim \theta'$ whenever $\mathcal{B}(\theta) = \mathcal{B}(\theta')$ and $R(\theta) = R(\theta')$; distinct admissible elements of Θ are equivalence classes under this relation, not individual domain labelings. PRAXIS operates over equivalence classes $[\theta]$, not individual parameterizations; all system properties are properties of the class, invariant to representative selection.

4 Symbolic Logic of Transdisciplinary Integration

4.1 The Instantiation Map

Definition 4.1 (Instantiation Map). The instantiation map $\iota : \Theta \rightarrow \text{Systems}(K)$ is defined by:

$$\iota(\theta) = K(\theta) = \langle \mathcal{S}(\theta), \mathcal{A}(\theta), T(\theta), R(\theta), \Omega(\theta), O(\theta), \mathcal{B}(\theta) \rangle$$

ι is *structure-preserving*: the kernel topology is invariant under ι ; only the type bindings vary.

4.2 Kernel Isomorphism Between Instantiations

Let S_1 and S_2 be two systems for which admissible parameter sets $\theta_{S_1}, \theta_{S_2} \in \Theta$ have been established by validity proof (Definition 2.3).

Definition 4.2 (Kernel Isomorphism). $S_1 \cong_K S_2$ (*K-isomorphic*) if and only if there exist admissible $\theta_{S_1}, \theta_{S_2} \in \Theta$ such that $\iota(\theta_{S_1}) = S_1$ and $\iota(\theta_{S_2}) = S_2$. *K-isomorphism* is defined

strictly over kernel structure and induced operators; domain correspondence is neither required nor admissible as evidence of isomorphism.

$S_1 \cong_K S_2$ does not assert that the systems are identical, or that observations from one are directly meaningful in the other. It asserts that they share the same formal architecture and therefore that cross-domain composition is structurally well-typed.

4.3 The Composition Operator

Definition 4.3 (Composition Operator). For K -isomorphic systems S_1 and S_2 whose latent state spaces admit a jointly identifiable component under a shared prior μ_{shared} , define:

$$S_1 \oplus_K S_2 = K(\theta_{S_1} \cup \theta_{S_2}, \mu_{\text{shared}})$$

The composed system uses a joint hierarchical prior pooling observations from both S_1 and S_2 . Cross-system evidence propagates through μ_{shared} ; individual posteriors remain separable. Joint identifiability of μ_{shared} from the observation streams $\Omega(\theta_{S_1}) \cup \Omega(\theta_{S_2})$ is both necessary and sufficient for admissible composition; absent this condition, $\oplus_K$ is undefined. All composition is defined over equivalence classes $[\theta]$; notation suppresses representatives.

Theorem 4.4 (Validity of Composition). *If $K(\theta_{S_1})$ and $K(\theta_{S_2})$ are valid instantiations and μ_{shared} is identifiable from the joint observation stream $\Omega(\theta_{S_1}) \cup \Omega(\theta_{S_2})$, then $S_1 \oplus_K S_2$ is a valid instantiation of K .*

Proof sketch. VI-1 holds because the joint GP prior is a valid Bayesian prior over the product state space; identifiability of μ_{shared} ensures the existence of a valid posterior over the shared component. VI-2 holds because the belief state of the composed system is the product of individual belief states, which is sufficient by the Markov property of each component. VI-3 holds because $R(\theta_{S_1} \cup \theta_{S_2})$ decomposes additively over the component reward surfaces. VI-4 holds if at least one component satisfies it, which is required by admissibility of each θ . □ □

4.4 Interpretive Invariance

Constraint 4.5 (Interpretive Invariance). Domain language is admissible only as parameter binding within Θ , has no semantic authority outside instantiation scope, and is causally inert with respect to all kernel-level operators. Domain language cannot participate in any inference, proof, or operator definition at the kernel level; propositions stated in domain-specific language hold only within the parameter scope θ_D of the named instantiation and do not constitute claims about K .

All valid reasoning in PRAXIS is invariant under domain renaming that preserves θ . Therefore, domain language is non-explanatory and formally eliminable: let σ be any bijection on domain labels that leaves $\mathcal{B}(\theta)$ and $R(\theta)$ unchanged; then $K(\theta) = K(\sigma(\theta))$ as systems, and every proof, theorem, and operator definition holds under all such σ . Any argument that fails under label permutation is inadmissible at the kernel level.

5 Mathematical Specification

5.1 GP Belief State

For each of d latent quality dimensions indexed by k , the GP surrogate maintains:

$$g_k(\mathbf{x}) \sim \mathcal{GP}(\mu_k(\mathbf{x}), k_{\text{M52}}(\mathbf{x}, \mathbf{x}')) \quad (1)$$

$$k_{\text{M52}}(\mathbf{x}, \mathbf{x}') = \sigma_f^2 \left(1 + \frac{\sqrt{5}r}{\ell} + \frac{5r^2}{3\ell^2} \right) \exp\left(-\frac{\sqrt{5}r}{\ell}\right), \quad r = \|\mathbf{x} - \mathbf{x}'\|$$

The Matérn-5/2 kernel is appropriate for latent quality surfaces that can exhibit rapid transitions without discontinuity. The posterior variance $\sigma_n^2(\mathbf{x})$ is elevated for entities with sparse observation history, providing explicit uncertainty quantification in all downstream outputs.

5.2 Hierarchical Population Prior (Cold-Start Mechanism)

$$g^{(i)} \sim \mathcal{GP}(\mu_{\text{pop}}(\mathbf{x}), k_{\text{pop}}) + \delta^{(i)}, \quad \delta^{(i)} \sim \mathcal{GP}(0, k_{\text{ind}}) \quad (2)$$

An entity entering the monitored population with no observation history receives its initial belief state from the population prior calibrated to its typed configuration. The posterior converges toward entity-specific inference as observations accumulate. Elevated posterior variance is explicitly reported for cold-start entities; it is not suppressed.

5.3 Population-Normalized Anomaly Score

$$\bar{A}_k^{(i)}(t) = \frac{y_k^{(i)}(t) - \text{median}\{y_k^{(j)}(t) : j \in \mathcal{P}_i\}}{\text{IQR}\{y_k^{(j)}(t) : j \in \mathcal{P}_i\}} \quad (3)$$

Median and IQR normalization is used because observable signal distributions in the target observation spaces are characteristically non-normal. Parametric normalization would systematically understate anomaly in the tails that are analytically most relevant. All assessments are expressed relative to the distribution of structurally comparable peers, not against absolute thresholds.

5.4 HMM Latent State Estimator

Each monitored entity occupies a latent state $G_{i,t} \in \mathcal{G}$ evolving under the transition matrix A^{lat} :

$$b_{i,g}(t) \propto P(e_{i,t} \mid G_{i,t} = g) \sum_{g'} P(G_{i,t} = g \mid G_{i,t-1} = g') \cdot b_{i,g'}(t-1) \quad (4)$$

The forward belief runs in $\mathcal{O}(n)$ per observation. The transition matrix A^{lat} and emission model B^{lat} are estimated from the historical record of entities whose true latent states were subsequently revealed through external verification—the ground-truth calibration dataset.

5.5 Time-Indexed Detection Reward

The time-indexed reward for resource allocation action a at time t in belief state $\mathbf{b}_t$ is:

$$R(\mathbf{b}_t, a, t) = \Phi^{(i)} \cdot \left[\alpha_{\text{EHVI}}(x_i; \mathcal{D}_n) \cdot \prod_j \hat{P}_j(x_i) + \sum_{k=1}^W b_k(t) \cdot \eta_k(x_i) - \lambda \cdot c(x_i) \right] \quad (5)$$

The urgency score for entity i under window k :

$$U_k^{(i)}(t) = b_k(t) \cdot \eta_k(x_i^*) \cdot P(\text{foreclosure before } t + \Delta \mid A^{\text{lat}}, b_{i,g}(t)) \quad (6)$$

$\Phi^{(i)}$ is an entity-level structural weight defined in instantiation parameter binding; its computation is domain-specific and lives in θ , not in K .

6 Membership Proofs: Boundary Cases for $\mathcal{C}_K$

Section 6 does not provide examples; it provides boundary proofs establishing membership in $\mathcal{C}_K$. Domain labels are placeholders indexing admissible θ , not objects of analysis. Each subsection verifies Conditions C1–C5 of Definition 3.1 for a named system class, establishing admissibility of a corresponding $\theta \in \Theta$ and triggering the validity proof obligation of Definition 2.3. Per Constraint 3.3, a domain label that does not change the induced belief operator $\mathcal{B}(\theta)$ relative to an existing admissible instantiation does not constitute a new membership proof. Domain nouns appear only within these proofs, as parameter bindings. They do not modify the kernel.

6.1 Proof that $S_1 \in \mathcal{C}_K$: Systems with Sequential Resource Allocation over a Compounding Opportunity Surface

Boundary Proof 6.1 ($S_1 \in \mathcal{C}_K$). Consider a system class in which: a decision-maker allocates finite resources across intervention configurations $\mathbf{x} \in \mathcal{X}$; outcomes are noisy observations of a latent performance surface; and the value of an intervention sequence depends on which opportunity windows are currently open.

C1 (Latent state): The true performance surface $f : \mathcal{X} \rightarrow \mathbb{R}^K$ is not directly observable; only noisy realisations $y = f(\mathbf{x}) + \varepsilon$ are available. Bind $\mathcal{S}(\theta_{S_1})$ to the space of performance surfaces over $\mathcal{X}$; bind $O(\theta_{S_1})$ to the Gaussian likelihood $P(y \mid f, \mathbf{x}) = \mathcal{N}(f(\mathbf{x}), \sigma_n^2)$. C1 satisfied. ✓

C2 (Sequential interaction): An intervention at t affects the feasible surface at $t + 1$ through constraint propagation and capacity accumulation. C2 satisfied. ✓

C3 (Time-indexed opportunity cost): In systems where observable signals indicate that external windows are opening or closing independently of the decision-maker, $\Delta_{\text{OC}}(s_t) > 0$ at all non-final periods under non-trivial window beliefs $b_k(t)$. C3 satisfied. ✓

C4 (Population structure): In systems with a population of comparable entities, the hierarchical GP prior μ_{pop} is identifiable from cross-entity observations. C4 satisfied. ✓

C5 (Probabilistic output): All recommendations are candidates with projected Pareto performance and uncertainty bounds; accept, modify, and override responses are all valid policy actions. C5 satisfied. ✓

Therefore $S_1 \in \mathcal{C}_K$, and θ_{S_1} is admissible. □

6.2 Proof that $S_2 \in \mathcal{C}_K$: Systems with Population-Normalized Anomaly Detection over Streaming Regulatory Signals

Boundary Proof 6.2 ($S_2 \in \mathcal{C}_K$). Consider a system class in which: a population of entities generates periodic observable signals through mandatory disclosure; an investigative resource allocator seeks to identify latent state deterioration; and intervention windows (regulatory, enforcement, funding-cycle) foreclose on externally determined schedules.

C1 (Latent state): The governance state $G_{i,t} \in \mathcal{G}$ is latent; mandatory disclosures provide noisy emissions. Bind $\mathcal{S}(\theta_{S_2})$ to $\mathcal{G}^N$ over N entities; bind $O(\theta_{S_2})$ to the HMM emission model B^{gov} calibrated from the historical ground-truth record. C1 satisfied. ✓

C2 (Sequential interaction): The investigative allocation decision at period t determines which entities receive enhanced monitoring at $t + 1$, changing the observation stream and therefore the posterior. C2 satisfied. ✓

C3 (Time-indexed opportunity cost): In systems where regulatory intervention windows close at externally fixed filing deadlines, $\Delta_{\text{OC}}(s_t) > 0$ whenever a window is believed open and foreclosure probability is non-trivial. C3 satisfied. ✓

C4 (Population structure): In systems with a registered population of entities required to file periodic disclosures, μ_{pop} is estimated from the cross-sectional distribution of observable filing features, stratified by entity type and budget tier. C4 satisfied. ✓

C5 (Probabilistic output): All outputs are probabilistic assessments—beliefs over $\mathcal{G}$ —not legal or factual determinations. Outputs support human investigative judgment and do not replace it. C5 satisfied. ✓

Therefore $S_2 \in \mathcal{C}_K$, and θ_{S_2} is admissible. □

6.3 Kernel Isomorphism: $S_1 \cong_K S_2$

Proposition 6.3 ($S_1 \cong_K S_2$). S_1 and S_2 are K -isomorphic.

Proof. By Examples 6.1 and 6.2, both θ_{S_1} and θ_{S_2} are admissible elements of Θ , and $K(\theta_{S_1})$ and $K(\theta_{S_2})$ are valid instantiations. By Definition 4.2, $S_1 \cong_K S_2$.

The slot-level binding that establishes the isomorphism is tabulated in the instantiation appendix (Section A). Note that domain nouns appear only in the appendix table, as parameter bindings. They do not appear in the proof. □ □

6.4 Candidate Membership: Further System Classes

The following system classes are claimed to satisfy C1–C5 under appropriate parameter binding. Formal boundary proofs are deferred to companion working papers.

- Systems in which treatment selection depends on partially observable patient state and enrollment windows close on regulatory schedules.
- Systems in which capability allocation depends on latent readiness trajectories and deployment windows foreclose on operational tempo.
- Systems in which intervention sequencing depends on latent developmental trajectories and selection events occur at externally fixed calendar points.
- Systems in which species viability depends on latent population dynamics and conservation funding cycles close on annual budget timelines.

In each case, the argument structure of Examples 6.1 and 6.2 applies directly. The domain nouns in the preceding list are informal pointers to parameter-binding problems; they do not appear in any formal claim about K .

7 PRAXIS as Architectural Framework

7.1 Layer Architecture

PRAXIS is an architectural grammar—a structured process for constructing valid instantiations of K , verifying their working properties, and composing them across typed system boundaries. It has five layers.

Layer 0 — The Kernel (K). The minimal working system. Defined once by Definition 2.1. Never modified. All working properties flow downward from this layer.

Layer 1 — The Instantiation Specification (θ). Admissible parameter set binding concrete types to each slot in K . This layer is the site of domain expertise. Its deliverable is a validity proof establishing $K(\theta)$ as a valid instantiation.

Layer 2 — The Validity Proof. Formal verification that $K(\theta)$ satisfies VI-1 through VI-4 (Definition 2.3). The validity proof is the primary engineering deliverable of a PRAXIS deployment, analogous to a requirements trace in SysML v2.

Layer 3 — The Interface Layer. Natural language access to the $K(\theta)$ belief state for appropriately authorized actors. The language model is an access layer translating natural language queries into API calls against the GP posterior and HMM state distribution. It is not the source of inference and does not generate determinations of latent state. This principle is invariant across all instantiations.

Layer 4 — The Composition Surface. Cross-system connections between valid instantiations via shared population priors, cross-domain window signals, and composed belief

updates (Definition 4.3). The composition surface is where transdisciplinary integration becomes computationally tractable.

7.2 SysML v2 Specification

```
package PRAXIS {

  // -- The Kernel (invariant; never modified at instantiation)
  -----
  block def ComposableBeliefKernel {
    value beliefState      : GPPosterior;
    value windowBeliefs    : HMMForwardBelief[*];
    value opportunityCostR : TimeIndexedReward;
    perform action instantiate {
      in  params  : InstantiationParameters; // theta in Theta
      out system  : ValidInstantiation;      // K(theta) if valid
      // Precondition: params satisfies C_K (Def. 3.1)
      //               and passes VI-1 through VI-4 (Def. 2.3)
    }
    perform action compose {
      in  inst1    : ValidInstantiation;
      in  inst2    : ValidInstantiation;
      in  prior    : SharedHierarchicalPrior; // mu_shared
      out composed: ValidInstantiation;      // Theorem 4.2
    }
  }

  // -- Admissibility constraints (Constraint 2.2)
  -----
  requirement <'REQ-K-001'> BeliefConsistency {
    doc /* VI-1: GP posterior calibrated; posterior variance
         honest under all observation densities. */
  }
  requirement <'REQ-K-002'> MarkovSufficiency {
    doc /* VI-2: Belief state B_t is sufficient statistic.
         Optimal policy depends only on B_t. */
  }
  requirement <'REQ-K-003'> GallCompatibility {
    doc /* P4: Working properties derive from K, not theta.
         Complexity lives in parameters, not architecture. */
  }
  requirement <'REQ-K-004'> DomainLanguageAdmissibility {
    doc /* Constraint 4.2: Domain language is parameter binding only
         .
         No domain noun modifies a kernel slot definition.
         Propositions about K hold for all valid theta. */
  }
}
```

```

// -- Instantiation S1 (parameter binding; see Appendix A)
-----
block def S1_Instance refines ComposableBeliefKernel {
  value theta : S1_Parameters;
  // theta_{S1}: typed slot bindings per Example 5.1 boundary
  proof
}

// -- Instantiation S2 (parameter binding; see Appendix A)
-----
block def S2_Instance refines ComposableBeliefKernel {
  value theta : S2_Parameters;
  // theta_{S2}: typed slot bindings per Example 5.2 boundary
  proof
}

// -- Composition S1 (+K) S2 (Theorem 4.2)
-----
block def S1_S2_Composition {
  part s1          : S1_Instance;
  part s2          : S2_Instance;
  value sharedPrior : HierarchicalGPPrior; // mu_shared
  // Cross-system evidence propagates through sharedPrior only.
  // Individual posteriors remain separable.
  // Validity: Theorem 4.2 (composition of valid instantiations).
}
}

```

Listing 1: SysML v2 – PRAXIS Kernel and Instantiation (core blocks)

7.3 The Antidote to Gall’s Law, Formally Stated

Theorem 7.1 (The PRAXIS Antidote). *Let K be the Composable Belief Kernel and let $\mathcal{C}_K$ be the class of decision systems admitting valid instantiation. Then for any system $P \in \mathcal{C}_K$, a working complex system $S_P = K(\theta_P)$ can be constructed from specification rather than evolved from iteration, provided θ_P is admissible (Constraint 2.2). The construction is defined over equivalence classes $[\theta_P]$; any two representatives in the same class yield identical systems under K .*

Proof. K is a working system by the degenerate-reduction argument of Section 2. By Theorem 2.4 (Property Inheritance), $K(\theta_P)$ inherits K ’s working properties under any admissible θ_P . The complexity of S_P lives in θ_P , which is domain-specified and empirically grounded. The kernel architecture is fixed; only parameters vary. $\square$ $\square$

Corollary 7.2 (Gall’s Law Restated). *Gall’s Law correctly characterises the failure mode of systems that design structural complexity. It does not apply to systems that confine domain complexity to admissible parameter binding within a structurally simple working kernel. The*

failure Gall describes is the mistake of placing domain specificity in the architecture rather than in θ .

8 Connections to Foundational Systems Theory

The PRAXIS framework can be located precisely within second-order cybernetics and systems theory. The connections below are stated as formal correspondences, not analogies.

Ashby (1956), Law of Requisite Variety. The law requires that the control system have at least as much variety as the system it governs. In PRAXIS, the GP belief state provides variety proportional to observation richness: posterior variance $\sigma_n^2(\mathbf{x})$ is exactly the measure of variety deficit at configuration $\mathbf{x}$. A belief operator with insufficient variety (elevated posterior variance across the full state space) satisfies Ashby’s condition for control failure.

Beer (1972), Viable System Model. The VSM’s recursive autonomy—that systems at every scale must have equivalent functional structure—corresponds in PRAXIS to the invariance of K under instantiation. Every valid $K(\theta)$, whatever the scale or domain of θ , has the same kernel architecture. Recursive instantiation is structurally well-defined.

Ackoff (1999), Idealization. Ackoff distinguishes optimization (improve the system that exists) from idealization (design the system you would have if unconstrained). PRAXIS enables idealization within a formally tractable structure: the kernel is designed from first principles; the parameters are optimized to the domain. Optimization lives in θ ; idealization lives in K .

Illich (1973), Conviviality and Radical Monopoly.

Constraint 8.1 (Illich Stability Constraint). A valid $K(\theta)$ instantiation must not generate radical monopoly over the domain it monitors. The Layer 3 interface must remain a tool for human investigators, not a replacement for the distributed epistemic network that makes the domain observable.

This constraint is not merely ethical. It is a stability condition: a $K(\theta)$ system that displaces the human expertise network it depends on for ground-truth calibration will progressively degrade its own emission model B^{lat} . Radical monopoly induces model collapse. The Illich Constraint is a Lyapunov condition on the belief operator’s long-run validity.

9 The PRAXIS Research Programme

9.1 Paper Series

The full PRAXIS research programme is structured as follows.

Paper I (complete): CBK instantiation in systems with sequential resource allocation over a compounding opportunity surface (S_1). Establishes θ_{S_1} , the time-indexed reward, HMM window belief, and the cold-start mechanism.

Paper II (complete): CBK instantiation in systems with population-normalized anomaly detection over streaming regulatory signals (S_2). Establishes θ_{S_2} , the structural weight $\Phi^{(i)}$, the enterprise coordination surface, and the network-level composition.

Paper III — PRAXIS (this paper): The kernel K . The instantiation map ι . Theorem 2.4 (Property Inheritance). The composition operator $\oplus_K$. Theorem 7.1 (The PRAXIS Antidote). The class $\mathcal{C}_K$. Constraint 4.5 (Interpretive Invariance).

Paper IV (proposed): Empirical validation of composition via detection lift under shared prior μ_{shared} . Domain-specific observation streams serve only as admissible realizations of $\Omega(\theta)$; all claims are expressed over the induced operators $\mathcal{B}(\theta_{S_1} \cup \theta_{S_2})$ and $R(\theta_{S_1} \cup \theta_{S_2})$.

Paper V (proposed): The Illich Stability Constraint (Constraint 8.1) as a Lyapunov condition on belief-operator validity. Formal analysis of radical monopoly failure in $K(\theta)$ systems. Governance design for PRAXIS deployments.

9.2 Validation Requirements

The PRAXIS programme requires two validation contributions.

V1 — Structural validation. Show formally that θ_{S_1} and θ_{S_2} satisfy Definition 2.3. This is a theorem; it follows from the specifications in Papers I and II. The boundary proofs of Section 6 constitute its skeleton.

V2 — Compositional validation. Execute the synthetic injection experiment specified in Paper II within the composed system $S_1 \oplus_K S_2$. Hypothesis: detection lag is reduced when the observation stream of S_1 contributes to the shared prior μ_{shared} , providing a leading signal for latent state deterioration in S_2 that the S_2 observation stream alone cannot supply. A confirmed hypothesis establishes that $\oplus_K$ produces genuine detection lift—that transdisciplinary composition is mechanism, not metaphor.

10 Positioning

PRAXIS is not general systems theory, which describes structure without formal mechanism. It is not applied category theory, which provides mechanism without empirical grounding. It is not an ISO 42010 style framework, which provides vocabulary without formal content.

PRAXIS is a working architecture: a kernel that can be deployed, an instantiation process that can be executed, a composition operator that can be empirically tested. Its primary theoretical contribution is Theorem 7.1 (The PRAXIS Antidote), establishing that Gall's

failure mode is avoidable through parametric design within a formally simple kernel. Its engineering contribution is the instantiation process and the validity criteria (Definition 2.3) that make that design tractable.

The kernel K is the working simple system from which all complexity in $\mathcal{C}_K$ can be generated by parameter instantiation. PRAXIS keeps the kernel and the parameters structurally separate, and therefore keeps the working properties of the kernel intact across all valid deployments.

11 Conclusion

Gall’s Law describes a failure mode that is avoidable. The avoidance requires identifying the minimal working kernel from which domain-specific complexity can be generated by admissible parameter instantiation. That kernel—the Composable Belief Kernel K —is a POMDP over a GP belief state with HMM latent dynamics and a time-indexed opportunity-cost reward. It is a working system in Gall’s sense. Its working properties are inherited by all valid instantiations. Its complexity is confined to the parameter set θ , which is typed, constrained, and domain-specific. No claim about system behavior, validity, or composition is expressible outside the kernel and its admissible parameterizations; domain naming introduces no additional explanatory power and is formally eliminable without loss of any provable property of the system.

Three claims are made. First, any system in class $\mathcal{C}_K$ can be expressed as $K(\theta)$ for admissible θ , and the resulting system inherits the kernel’s working properties by Theorem 2.4. Second, K -isomorphic systems can be composed through the operator $\oplus_K$, enabling cross-domain evidence propagation through a shared population prior. Third, the belief-operator’s long-run validity requires satisfaction of the Illich Stability Constraint: radical monopoly induces model collapse.

PRAXIS is the architectural grammar that instantiates, validates, and composes. Papers I and II demonstrate two working rooms. This paper specifies the shared foundation they both stand on. PRAXIS converts transdisciplinary analogy into algebra: systems are not ‘like’ one another—they are members of the same equivalence class under admissible instantiation.

A Instantiation Slot-Binding Table: $S_1 \cong_K S_2$

This appendix contains the only admissible occurrence of domain language, as slot-binding realizations of θ_{S_1} and θ_{S_2} . These terms have no interpretive role and do not modify any claim about K . Their sole function is to establish the concrete type bindings that support the boundary proofs of Section 6 and the isomorphism established by Proposition 6.3.

K Slot	θ_{S_1} binding	θ_{S_2} binding
$S(\theta)$	Latent performance surface $f : \mathcal{X} \rightarrow \mathbb{R}^K$ over intervention configurations	Latent governance state $G_{i,t} \in \{0, 1, 2, 3\}$ per registered entity
$\mathcal{A}(\theta)$	Intervention configuration x_{n+1} selected for next period	Investigative resource allocation: enhanced monitoring, targeted extraction, regulatory referral
$T(\theta)$	GP posterior update: Kalman correction under Matérn-5/2	HMM transition matrix A^{gov} , empirically estimated from ground-truth record
$R(\theta)$	Time-indexed EHVI augmented by open window beliefs $b_k(t)$	Time-indexed detection value weighted by structural weight $\Phi^{(i)}$ and regulatory window urgency $U_k^{(i)}(t)$
$\Omega(\theta)$	Noisy outcome observations $y = f(\mathbf{x}) + \varepsilon$ from executed intervention sequences	Mandatory regulatory filing features extracted from periodic public disclosure records
$O(\theta)$	GP likelihood: $P(y \mid f, \mathbf{x}) = \mathcal{N}(f(\mathbf{x}), \sigma_n^2)$	HMM emission model: $P(\text{filing pattern} \mid G_{i,t})$, calibrated from revealed ground-truth states
$\mathcal{B}(\theta)$	Kalman-GP posterior correction; $\mathcal{O}(n)$ per streaming observation under Matérn-5/2 equivalence	HMM forward algorithm over four-state governance lattice; $\mathcal{O}(n)$ per filing period
μ_{pop}	Population prior calibrated to entity type, development phase, and observable entry profile	Population prior calibrated to entity type, budget tier, and mission category from registration data
$\Phi^{(i)}$	Phase-transition urgency derived from window foreclosure probability (Eq. 6)	Perfect storm index: joint product of resource dependency, audit vacuum, community trust, and sub-threshold scale

Table 2: Slot-level parameter bindings for θ_{S_1} and θ_{S_2} . These are the only admissible occurrences of domain language in this paper. They appear as type realizations, not as objects of analysis, and carry no semantic authority beyond their binding scope.

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