Viability Beyond Performance: Regime-Level Coupling and Structural Cost in Long-Horizon Adaptive Systems

Maksim Barziankou
PETRONUS™ research

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Abstract

What does it mean for an adaptive system to remain viable over time, even when it continues to perform correctly?

Adaptive systems are commonly evaluated and regulated through short-horizon performance criteria such as error minimisation, reward accumulation, stability margins, or task success. While effective in controlled or stationary settings, these criteria systematically fail to capture long-horizon degradation modes arising from cumulative structural load, inefficient corrective coupling, and regime-level organisational drift. As a result, systems may remain outwardly admissible while silently exhausting the internal conditions required for continued coherent operation.

This work introduces a regime-level framing of viability that separates behavioural admissibility from long-horizon structural sustainability. We argue that viability cannot be inferred from endpoint performance alone and must instead be treated as a property emerging from the balance between inertial organisation, corrective intervention, and the efficiency with which intervention couples into realised correction. From this perspective, repeated correction under poor coupling conditions imposes structural cost even when short-horizon objectives remain satisfied.

To formalise this distinction without prescribing algorithms or mechanisms, we introduce architectural relations linking intervention intensity, coupling efficiency, and viability. These relations articulate a missing architectural dimension governing long-horizon sustainability and establish a prior-art conceptual foundation for viability-aware analysis of adaptive systems operating under uncertainty, non-stationarity, and cumulative stress.

1 Introduction

Adaptive systems increasingly operate in environments characterised by delayed feedback, partial observability, non-stationarity, and sustained exposure to perturbations. In such settings, failure rarely manifests as immediate loss of task performance. Instead, systems often remain outwardly admissible while undergoing gradual internal degradation that is invisible to conventional evaluation metrics.

Prevailing frameworks implicitly assume that acceptable behaviour implies acceptable internal state. Error remains bounded, reward accumulates, and trajectories converge; therefore, the system is treated as robust. This assumption conflates behavioural correctness with structural sustainability and obscures failure modes that unfold over long horizons.

This work argues that such failure modes arise not from incorrect actions, but from prolonged operation within structurally costly regimes. In particular, repeated corrective intervention under conditions of poor coupling between intervention and realised effect can accumulate structural load even when short-horizon objectives are satisfied.

We propose a conceptual reframing in which viability is treated as a regime-level property, distinct from performance, and governed by structural relations rather than optimisation objectives.

2 Performance Is Not Viability

Performance-based evaluation compresses rich temporal dynamics into scalar summaries. Error trajectories are averaged, rewards are accumulated, and transient deviations are smoothed. While suitable for optimisation, these operations systematically erase information about how behaviour is produced and maintained.

A system may compensate for degradation through increasingly dense correction, masking structural instability behind acceptable outputs. Conversely, two systems may achieve identical task endpoints while incurring radically different internal load histories.

From a viability perspective, such behaviours are not equivalent. Endpoint equivalence does not imply structural equivalence. Long-horizon survival depends not only on what outcomes are achieved, but on how much structural cost is incurred in achieving them.

3 Regime-Level Organisation of Action

To capture this distinction, we adopt a regime-level view of adaptive operation. Rather than analysing isolated actions or updates, we consider qualitatively distinct modes of organisation governing behaviour over time.

At a minimum, two regime classes are distinguished:

- **Inertial regimes**, in which coherent behaviour propagates with minimal corrective intervention.
- **Actively regulated regimes**, in which corrective influence is repeatedly applied to maintain admissibility under perturbation or uncertainty.

Actively regulated regimes are not inherently undesirable. They are often necessary for recovery, adaptation, or safety. However, they impose structural load that accumulates over time and may threaten long-horizon viability if sustained excessively.

Viability risk therefore attaches not to individual actions, but to prolonged residence within intervention-dense regimes.

4 Coupling Efficiency and Structural Cost

A central but often implicit assumption in adaptive regulation is that applied corrective intervention couples efficiently into realised correction. In practice, this assumption frequently fails.

Interaction media may exhibit slip, compliance, hysteresis, latency, dissipation, or other effects that cause corrective influence to be partially wasted or repeatedly reapplied. Under such conditions, identical corrective effort may yield dramatically different realised effects.

We introduce an abstract coupling efficiency factor, denoted $G \in (0, 1]$, representing the efficiency with which applied intervention produces coherent corrective effect. G is not a control gain, reward modifier, or stability margin. It characterises the structural efficiency of the interaction channel itself.

When coupling efficiency is low, corrective effort becomes structurally expensive even if endpoint behaviour remains acceptable.

5 Effective Intervention

To express this structural cost without prescribing computation, we introduce an effective intervention quantity U_{eff} defined conceptually as

$$U_{\text{eff}} \triangleq \frac{U}{G},$$

where U denotes the raw intensity or density of applied corrective intervention.

This relation expresses a structural tendency: for fixed intervention intensity, decreasing coupling efficiency increases effective structural load. The expression is not intended as an algorithmic update rule, but as an architectural relation capturing how intervention cost scales under poor coupling.

6 Viability as a Structural Relation

We treat viability V as a long-horizon capacity of an adaptive system to preserve coherent operation under cumulative stress. Viability is distinct from instantaneous performance and is not reducible to error, reward, or task success.

The quantities G, U_{eff}, and V introduced in this section need not correspond to explicitly computed, measured, or internally represented variables within a system. They may instead be interpreted as latent, structural, or interpretative parameters used for architectural reasoning about long-horizon sustainability, rather than as operational state variables available to the decision-making process.

At an architectural level, viability increases with alignment to constraints and inertial organisation, and decreases with effective intervention load. This dependency may be expressed qualitatively as

$$V \propto \frac{A \cdot I}{U_{\text{eff}}},$$

or equivalently,

$$V \propto \frac{A \cdot I \cdot G}{U},$$

where A denotes alignment with structural or environmental constraints, and I denotes inertial organisation.

These expressions do not define a computable objective. They articulate a structural dependency that governs long-horizon sustainability. They are intended as relational and dimensional heuristics that capture structural dependencies between organisation, intervention, and coupling efficiency, rather than as equations specifying optimisation targets or control laws.

7 Irreversible Transitions and Risk Accumulation

Under prolonged low-coupling conditions, effective intervention load increases even when raw intervention remains unchanged. As a result, systems may be driven toward irreversible regime transitions characterised by loss of inertial organisation, fragmentation of coordination, or collapse of coherent structure.

This dependency may be summarised qualitatively as:

$$\downarrow G \Rightarrow \uparrow U_{\text{eff}} \Rightarrow \uparrow \text{risk of irreversible transition.}$$

Such transitions need not coincide with immediate performance failure. They may occur silently, becoming visible only after recovery is no longer possible.

8 Architectural Separation

Crucially, viability regulation must be architecturally separated from behavioural generation. If viability is introduced as a reward signal, loss term, or explicit optimisation target, it inevitably becomes subject to strategic optimisation by the system itself. In such cases, the system adapts to satisfy the viability signal rather than to preserve the underlying structural conditions that the signal was intended to represent. This dynamic reproduces well-known forms of metric gaming and surrogate objective collapse, rendering the viability signal unreliable precisely when it matters most.

For this reason, the relations described in this work are not intended to function as optimisation objectives, gradient sources, or control targets. Instead, they define a supervisory and evaluative layer that operates independently of action generation and policy optimisation. This layer does not select actions, tune parameters, or drive learning updates. Its role is to establish structural constraints on regime admissibility and to account for long-horizon consequences of accumulated structural load that are invisible to short-horizon performance metrics.

By maintaining a strict separation between behavioural generation and viability regulation, viability is treated as an architectural property of the system rather than as another quantity to be optimised. This separation preserves the distinction between short-term behavioural adequacy and long-term structural sustainability and prevents the conflation of adaptation with survival.

9 Scope and Prior-Art Position

The relations presented in this work are intentionally non-algorithmic. No sensing modalities, estimation procedures, thresholds, update rules, or decision policies are prescribed. The contribution lies in establishing a missing architectural dimension: the role of coupling efficiency and regime-level structural cost in governing long-horizon viability.

These concepts apply across a broad class of adaptive systems, including classical control systems, learning-based agents, embodied systems, and hybrid architectures that combine inertial and actively regulated modes of operation. The framework does not depend on any specific learning paradigm, representation scheme, or embodiment.

Accordingly, this work is positioned as a conceptual prior-art foundation rather than as a concrete implementation. It fixes scope, terminology, and structural relations that must be accounted for before mechanisms can be meaningfully designed, while deliberately leaving the question of implementation open.

10 Conclusion

Adaptive systems do not fail solely by making incorrect decisions. They fail by accumulating structural load under conditions in which corrective influence no longer couples efficiently into realised correction. In such situations, outwardly admissible behaviour can be sustained through increasingly dense intervention, even as the internal organisation that supports coherent operation is progressively eroded.

By separating performance from viability, introducing coupling efficiency as a structural factor, and framing intervention cost at the level of operational regimes rather than individual actions, this work establishes a foundation for analysing long-horizon sustainability beyond conventional metrics. This perspective makes explicit why endpoint correctness, bounded error, or sustained reward are insufficient indicators of long-term robustness when corrective effort becomes structurally inefficient.

The relations presented here define what must be accounted for before concrete mechanisms can be meaningfully designed. They identify architectural dependencies that govern viability independently of any particular control law, learning algorithm, or optimisation strategy. As such, they are not prescriptions for implementation, but constraints on what any viable long-horizon architecture must respect.

Within this scope, the framework is compatible with multi-layer adaptive architectures in which behavioural generation, learning, and supervision are explicitly separated. In particular, it can be situated within broader architectural systems such as PETRONUS, where regime-level organisation and long-horizon coherence are treated as first-class concerns. In such contexts, the relations articulated here function as an architectural lens through which regime admissibility and structural cost can be evaluated, without constraining how individual layers are realised.

Accordingly, this work is offered as a conceptual prior-art contribution. It fixes scope, terminology, and structural relations for viability-aware adaptive systems, providing a stable foundation upon which future architectures may build, while deliberately leaving the question of concrete implementation open. Any adaptive system claiming robustness over long horizons must account for these structural relations, regardless of how they are instantiated or whether they are made explicit within the system's internal representations.

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