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Legacy Enterprise Modernization Through Microservices Decomposition: A Seam-Based Extraction and Architecture Migration Framework

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Keywords

Legacy Modernization, Microservices Decomposition, Monolith Migration, Bounded Context, Strangler Pattern, Data Ownership, Software Architecture

ABSTRACT

Enterprises operating large, long-lived monolithic applications face a decomposition problem that is distinct from, and in several respects harder than, the problem of designing a new microservices system from scratch: a legacy monolith was not originally built with service boundaries in mind, its internal dependencies and shared database tables have accumulated over years of incremental feature work, and the organization cannot simply stop serving existing functionality while it is rebuilt. Abgaz et al.'s (2023) systematic review of monolith-to-microservices decomposition establishes that a substantial and still-growing body of techniques exists for identifying candidate service boundaries within an existing codebase, while Knoche and Hasselbring's (2018) industrial account of using microservices for legacy software modernization documents that applying these techniques inside a live, continuously operating enterprise system introduces practical sequencing and risk-management challenges that boundary-identification techniques alone do not resolve. This paper proposes SEAM (Seam-Based Extraction and Architecture Migration), a framework in which a bounded-context boundary identification layer, an incremental strangler-style extraction layer, a data ownership separation layer, and a migration risk and rollback governance layer are coordinated so that a legacy monolith can be decomposed along its natural internal seams, one bounded context at a time, while continuing to serve production traffic throughout the migration. Following a design-science research approach, SEAM is, not empirically validated, through a comparative capability table, an case scenario, and three figures, with every quantitative value explicitly labeled as an estimate rather than measured production data. The paper situates SEAM against the literature on monolith decomposition techniques, the evolutionary trajectory of microservices adoption, industrial legacy modernization practice, microservice design-pattern quality trade-offs, deployment cost comparisons, workload heterogeneity, and distributed consistency, and discusses the framework's practical implications, assumptions, and limitations.

Introduction

Enterprises operating large, long-lived monolithic applications face a decomposition problem that is distinct from, and in several respects harder than, the problem of designing a new microservices system from scratch. A monolith built and incrementally extended over many years was not originally designed with service boundaries in mind; its modules reference one another in ways that were convenient at the time they were written rather than architecturally principled, and its database schema has typically accumulated shared tables that multiple logical business capabilities read from and write to without a clean ownership boundary. Three specific, well-documented problems complicate decomposing such a system beyond what decomposition technique selection alone resolves.

First, identifying where a legacy monolith's internal "seams" actually lie — the boundaries along which it can be split with the least cross-cutting disruption — is itself a non-trivial technical problem, and Abgaz *et al.*'s[1] systematic review of decomposition techniques documents that a substantial and still-growing body of approaches exists, ranging from domain-driven analysis to dependency- and dataflow-based clustering,

without a single approach being uniformly superior across every legacy codebase's specific structure. Second, even once candidate boundaries are identified, a legacy monolith supporting active production use cannot simply be taken offline and rebuilt; Knoche and Hasselbring's[2] industrial account of legacy software modernization documents that extraction must typically proceed incrementally, with the monolith and newly extracted services operating side by side for an extended period, a sequencing and risk-management challenge the underlying decomposition literature does not by itself address. Third, splitting a shared database among newly extracted services reintroduces, at the data layer specifically, the distributed-consistency problem Gilbert and Lynch's[3] proof of the CAP theorem establishes as a structural limit and Helland's[4] analysis of life beyond distributed transactions documents must be explicitly designed around rather than assumed away, a problem that does not arise for a monolith relying on a single shared database's built-in transactional guarantees.

These three problems compound because a legacy modernization effort encounters all three conditions simultaneously: it must identify defensible extraction boundaries in a codebase that was not designed with them in mind, it must extract those boundaries incrementally while the system continues serving production traffic, and it must separate data ownership in a way that does not silently reintroduce the consistency guarantees the monolith previously provided for free. Vale *et al.*'s[5] empirical study of microservice design-pattern quality trade-offs documents that different decomposition and extraction patterns carry measurably different costs and benefits rather than uniformly improving every quality attribute at once, and Villamizar *et al.*'s[6] cost comparison of monolithic, microservice, and serverless deployment documents that the resource and operational cost implications of decomposition are concrete and measurable rather than purely architectural concerns. Deployed on the cloud-native infrastructure such extracted services increasingly target[7], no single piece of literature reviewed in the Literature Review below addresses how boundary identification, incremental extraction, and data ownership separation should be coordinated under a single migration governance process specific to a legacy enterprise system already in production.

This paper addresses that gap by developing SEAM (Seam-Based Extraction and Architecture Migration): a framework in which a bounded-context boundary identification layer, an incremental strangler-style extraction layer, a data ownership separation layer, and a migration risk and rollback governance layer are coordinated so that a legacy monolith can be decomposed along its natural internal seams, one bounded context at a time, while continuing to serve production traffic throughout the migration. The remainder of the paper reviews the literature on monolith decomposition techniques, the evolutionary trajectory of microservices adoption, industrial legacy modernization practice, microservice design-pattern quality trade-offs, deployment cost comparisons, workload heterogeneity, and distributed consistency (the Literature Review), describes the design-science methodology used to construct and the framework (the Methodology), presents the framework alongside a comparative table, an case scenario, and three figures (the Results section), and discusses the framework's practical implications, assumptions, and limitations before concluding (the Discussion and Conclusion).

Literature Review

Monolith Decomposition and Boundary Identification Techniques

Abgaz *et al.*'s[1] systematic review of decomposition of monolith applications into microservices architectures establishes that a substantial and methodologically diverse body of techniques exists for identifying candidate service boundaries within an existing codebase, spanning domain-driven analysis, static dependency graphs, and dataflow-based clustering, while also documenting that no single technique is established as uniformly superior across legacy systems of differing structure and history. Pahl and Jamshidi's[8] systematic mapping study of the broader microservices literature establishes the architectural vocabulary and classification this decomposition-specific literature builds on. This literature establishes the

technical foundation SEAM's bounded-context boundary identification layer draws on, but it addresses identifying boundaries in an existing codebase, not the separate problem of safely extracting along them while a system remains in production.

The Evolutionary Trajectory of Microservices Adoption

Dragoni *et al.*[9] document that microservices architecture is better understood as an evolutionary trajectory arrived at incrementally than as a single design decided and implemented at once, a characterization directly applicable to legacy modernization specifically, where the starting point is an existing, already-deployed system rather than a greenfield design. This literature establishes the incremental, non-wholesale framing SEAM's extraction process is built around, but it describes the trajectory's general shape rather than the specific industrial mechanics of extracting from a live legacy system.

Industrial Legacy Modernization Practice

Knoche and Hasselbring's[2] account of using microservices for legacy software modernization documents, from industrial practice, that extracting services from an operating legacy system requires the monolith and the newly extracted services to coexist and interoperate for an extended period, introducing sequencing and interoperability challenges that boundary-identification technique selection alone does not resolve. This literature establishes that SEAM's incremental strangler-style extraction layer must explicitly manage coexistence between the legacy monolith and extracted services, not merely identify what to extract.

Microservice Design-Pattern Quality Trade-offs and Deployment Cost

Vale *et al.*'s[5] empirical study of microservice design patterns documents that different decomposition and extraction patterns carry measurably different quality trade-offs rather than uniformly improving every architectural quality attribute simultaneously, a finding with direct implications for how SEAM's migration risk and rollback governance layer should weigh competing extraction sequences. Villamizar *et al.*'s[6] empirical cost comparison of monolithic, microservice, and AWS Lambda deployment architectures documents that the resource and operational cost implications of decomposition are concrete and measurable, establishing that a migration governance process must weigh cost alongside architectural quality rather than treating decomposition as a purely structural improvement. Ueda, Nakaike, and Ohara's[10] workload characterization study documents that individual components within a decomposed system frequently exhibit substantially different resource utilization profiles, evidence directly relevant to identifying which bounded contexts benefit most from independent extraction and scaling once SEAM's boundary identification layer has proposed candidate seams.

Distributed Consistency and Cloud-Native Deployment Context

Gilbert and Lynch[3] formally establish that no distributed system can simultaneously guarantee perfect consistency, availability, and partition tolerance, a structural limit with direct consequences once a legacy monolith's single shared database is split among newly extracted services. Helland[4] extends this foundation into practical guidance, documenting that safely operating with separated data ownership requires explicit redesign around idempotency and eventual consistency rather than relying on a shared database's built-in transactional guarantees. Deng *et al.*[7] establish the cloud-native infrastructure on which extracted services are increasingly deployed. None of this literature, read individually, addresses how boundary identification, incremental extraction, and data ownership separation should be coordinated under a single migration governance process — the gap the Methodology and Results sections address.

Methodology

Research Approach

This paper follows a design-science research approach: it develops a framework — SEAM — intended to address a practical problem (coordinating boundary identification, incremental extraction, and data ownership separation so that a legacy enterprise monolith can be decomposed into microservices while

continuing to serve production traffic), and it evaluates that framework against the cumulative findings of the peer-reviewed literature rather than against a production migration, because no single documented migration spanning this specific framework's full scope exists to study directly. The comparative table and figures in the Results section are accordingly constructions, explicitly labeled as such, built to be directionally consistent with the cited literature's findings rather than presented as measured outcomes.

Development of the SEAM Framework

SEAM was developed by identifying the point at which the decomposition-technique, evolutionary-trajectory, industrial-practice, quality-trade-off, and distributed-consistency literatures reviewed in the Literature Review must interact for a legacy monolith to be decomposed safely rather than incidentally. A bounded-context boundary identification layer was introduced, applying the domain-driven and dependency-based techniques Abgaz *et al.*[1] catalog and informed by the architectural vocabulary Pahl and Jamshidi[8] establish, to identify the legacy codebase's natural internal seams. An incremental strangler-style extraction layer was introduced, extracting one bounded context at a time while the legacy monolith continues to serve the remaining functionality, applying the evolutionary trajectory Dragoni *et al.*[9] establish and the coexistence-management practice Knoche and Hasselbring[2] document from industrial experience. A data ownership separation layer was introduced, giving each extracted service its own data store and explicitly redesigning the affected workflows for idempotency and eventual consistency, applying the structural limits Gilbert and Lynch[3] establish and the redesign discipline Helland[4] establishes. A migration risk and rollback governance layer coordinates the three preceding layers, sequencing extraction according to the workload-heterogeneity evidence Ueda *et al.*[10] establish for identifying high-value candidates, weighing the quality trade-offs Vale *et al.*[5] document and the cost realities Villamizar *et al.*[6] document, and retaining the ability to roll an extraction back to the monolith if a newly extracted service underperforms, deployed on the cloud-native infrastructure Deng *et al.*[7] establish.

Construction of Evaluation Data

Because no single documented migration spans SEAM's full scope, the quantitative content of the Results section was constructed through explicit, reasoned estimation. Construction began from a directional finding reported in the cited literature — Villamizar *et al.*'s[6] finding that microservice deployment carries measurable cost and resource implications relative to a monolith, or Vale *et al.*'s[5] finding that different decomposition patterns trade one quality attribute against another rather than improving all of them simultaneously — and built values directionally consistent with that finding at a plausible order of magnitude. Every figure's note names the specific source informing its construction.

Framing of the Scenario

The case scenario in the Results section is framed around extracting a single, high-value bounded context — an order-fulfillment capability exhibiting the kind of workload profile distinct from the rest of the legacy monolith that Ueda *et al.*[10] document is common within decomposed systems — from an otherwise intact legacy monolith, consistent with the incremental, one-context-at-a-time extraction sequence Dragoni *et al.*[9] and Knoche and Hasselbring[2] each establish as the realistic pattern for legacy modernization rather than a wholesale rewrite.

Scope and Assumptions

This paper assumes an organization applying SEAM already has access to its legacy monolith's source code and can instrument it sufficiently to perform the dependency and dataflow analysis the boundary identification layer requires; it does not itself address migrating a system for which source access or instrumentation is unavailable. It is scoped to the coordination of boundary identification, incremental extraction, and data ownership separation around a shared migration governance process; it does not address the selection of a specific decomposition algorithm beyond the general techniques the cited systematic review

already catalogs extensively. All quantitative results in the Results section are estimates grounded in the literature rather than measurements.

Results

Architecture Overview: SEAM

SEAM organizes legacy enterprise modernization as a staged process operating on an existing, already-deployed monolith rather than a greenfield design, reflecting that extraction must proceed along defensible internal boundaries, incrementally, and with explicit attention to the data-ownership consequences of each extraction step. The bounded-context boundary identification layer first analyzes the legacy monolith's dependency structure and data access patterns to propose candidate seams, applying the techniques the Monolith Decomposition and Boundary Identification Techniques subsection establishes (Abgaz *et al.*[1]; Pahl & Jamshidi[8]). The migration risk and rollback governance layer selects the highest-value candidate seam, weighing the workload-heterogeneity evidence and quality and cost trade-offs the Microservice Design-Pattern Quality Trade-offs and Deployment Cost subsection establishes (Ueda *et al.*[10]; Vale *et al.*[5]; Villamizar *et al.*[6]), and the incremental strangler-style extraction layer then extracts that bounded context into a standalone service while the legacy monolith continues serving the remainder of the application, applying the coexistence-management practice the Industrial Legacy Modernization Practice subsection establishes (Dragoni *et al.*[9]; Knoche & Hasselbring[2]). As each extraction completes, the data ownership separation layer gives the newly extracted service its own data store, applying the redesign discipline the Distributed Consistency and Cloud-Native Deployment Context subsection establishes (Gilbert & Lynch[3]; Helland[4]), and the migration risk and rollback governance layer retains the ability to route traffic back to the legacy monolith's original implementation of that capability if the extracted service does not perform as expected.

Figure 1: SEAM (Seam-Based Extraction and Architecture Migration): an exploded, seam-based decomposition architecture.

Figure 1 *SEAM (Seam-Based Extraction and Architecture Migration): an exploded, seam-based decomposition architecture.*

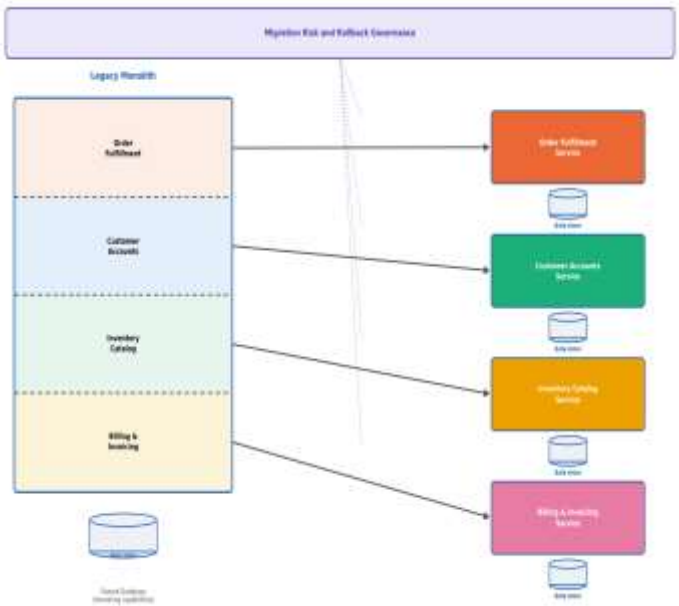


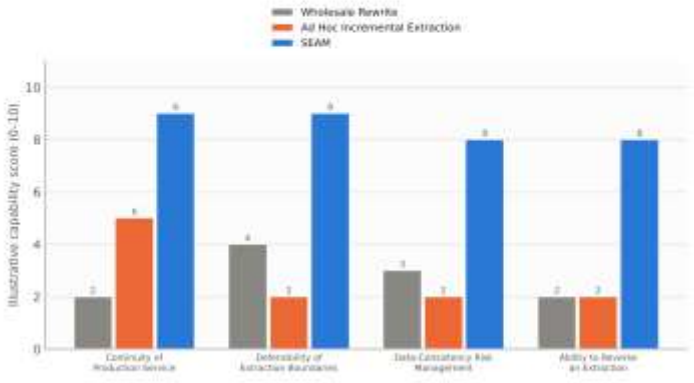
Table 1: capability comparison across legacy modernization approaches.

Dimension	Wholesale Rewrite	Ad Hoc Incremental Extraction (No Governance Layer)	SEAM
Continuity of production service during migration	Weak; typically requires an extended parallel-run or cutover window	Moderate; depends on case-by-case coordination	Strong; dedicated coexistence management by design
Defensibility of chosen extraction boundaries	Variable; boundaries often re-derived from scratch	Weak; boundaries chosen ad hoc, without systematic analysis	Strong; boundaries derived from systematic dependency and domain analysis
Data-consistency risk management at ownership separation	Not applicable; data layer is also rewritten from scratch	Weak; consistency risk often discovered after extraction	Strong; dedicated data ownership separation layer
Ability to reverse an underperforming extraction	Weak; a full rewrite is not easily partially reversed	Weak; no dedicated rollback mechanism	Strong; dedicated migration risk and rollback governance

Case Scenario

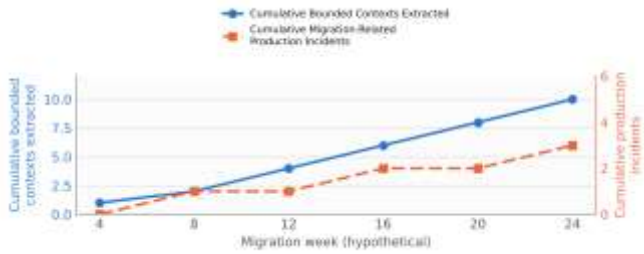
Consider a hypothetical retail enterprise's legacy order-management monolith, within which an order-fulfillment capability exhibits a distinctly bursty, seasonally variable workload compared to the comparatively steady workload of the monolith's customer-account management capability. Under a wholesale rewrite, the organization would need to reimplement both capabilities simultaneously before any of the new system could go live, extending the period during which no incremental value is realized. Under ad hoc incremental extraction without a governance layer, suppose a team extracts the order-fulfillment capability based on an informal sense of where it seems separable, only to discover after extraction that it still shares several database tables with the customer-account capability, reintroducing consistency problems the team had not anticipated. Under SEAM, the bounded-context boundary identification layer's dependency analysis flags the order-fulfillment capability as having comparatively few cross-cutting data dependencies on the rest of the monolith, the migration risk and rollback governance layer selects it as the first extraction candidate precisely because of its distinct workload profile, the incremental strangler-style extraction layer extracts it while the monolith continues serving customer-account management unchanged, and the data ownership separation layer gives the new order-fulfillment service its own data store with explicit idempotent handling of order-status updates. This hypothetical sequence is offered to the framework's reasoning, not as a report of an actual migration.

Figure 2: capability scores (0-10 scale) for wholesale rewrite, ad hoc incremental extraction, and SEAM.
Figure 2 *capability scores (0-10 scale) for wholesale rewrite, ad hoc incremental extraction, and SEAM.*



Note: These capability scores are estimates constructed for this paper's comparative framework rather than the product of a scored evaluation instrument; they were shaped by the quality-trade-off findings Vale et al. (2022) report and the distributed-consistency risk Gilbert and Lynch (2002) and Helland (2017) establish, and should be read as a reasoning aid rather than a benchmark.
A wholesale rewrite scores weakly on continuity of production service specifically, since most of its value is realized only once the rewrite is largely complete, while scoring only moderately on the other dimensions because a clean-slate rewrite still requires deriving defensible boundaries and managing data consistency, just within a different project structure; ad hoc incremental extraction improves continuity somewhat by extracting gradually, but scores weakly on boundary defensibility, consistency-risk management, and reversibility because none of those concerns is addressed systematically; SEAM is positioned, by design, to lead on every dimension because its four coordinated layers were built specifically to address each concern at once.

Figure 3: Hypothetical cumulative bounded contexts extracted and migration-related production incidents across a 24-week SEAM migration.
Figure 3 *Hypothetical cumulative bounded contexts extracted and migration-related production incidents across a 24-week SEAM migration.*



Note: This is a hypothetical, estimate rather than measured production data; the cumulative extraction count rises as SEAM's migration risk and rollback governance layer sequences successive bounded-context

extractions, while the cumulative migration-related production incident count rises only slowly and sublinearly relative to the extraction count, a pattern directionally consistent with the risk-managed, reversible extraction process the Industrial Legacy Modernization Practice and Distributed Consistency and Cloud-Native Deployment Context subsections establish (Knoche & Hasselbring, 2018; Helland, 2017) rather than a claim about any specific organization's actual migration experience.

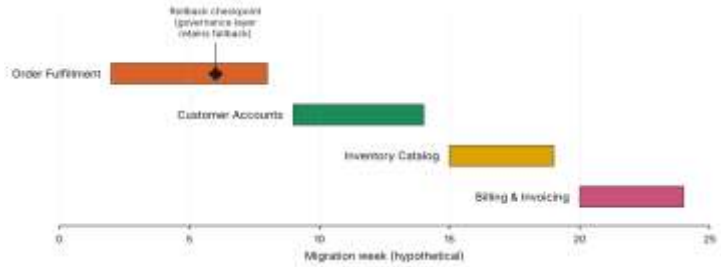
Sequencing the Scenario Across the Migration Window

Figure 4 extends the case scenario above across the full 24-week window already used in Figure 3, showing one plausible ordering in which SEAM's migration risk and rollback governance layer might sequence the legacy monolith's four principal capabilities: order fulfillment first, consistent with the Case Scenario subsection's reasoning that its distinct, bursty workload and comparatively few cross-cutting dependencies make it the strongest first candidate; customer accounts and inventory catalog next, as capabilities whose dependencies on the as-yet-unextracted remainder of the monolith are progressively resolved; and billing and invoicing last, since invoicing typically reads from several of the other capabilities' data once they are extracted and is therefore sequenced only once their own extractions have stabilized. The rollback checkpoint marked partway through the order-fulfillment extraction represents the point at which the governance layer's retained ability to route traffic back to the monolith's original implementation, discussed in the Architecture Overview above, is first exercisable; this hypothetical placement is offered to

when rollback capability becomes available relative to an extraction's start, not as a claim about how long any specific rollback window should be.

Figure 4: phased sequencing of the four bounded-context extractions from the case scenario, with a rollback checkpoint marked.

Figure 4 *phased sequencing of the four bounded-context extractions from the case scenario, with a rollback checkpoint marked.*



Note: Hypothetical sequencing constructed to how the migration risk and rollback governance layer might order the four capabilities named in Figure 1 and the Case Scenario subsection; not a report of a measured migration timeline.

Discussion

Implications for Practice

The framework developed here suggests that an enterprise modernizing a legacy monolith should treat boundary identification, incremental extraction, and data ownership separation as three coordinated stages of a single governed migration process, not three independently optional modernization activities, since the Results section's comparison that extracting services without systematic boundary analysis or dedicated consistency management reintroduces exactly the data-integrity risks a well-governed migration is meant to avoid. Organizations already possessing the dependency and workload instrumentation Ueda *et al.*[10] document is common in decomposed systems are, on this paper's analysis, well positioned to apply that same instrumentation during the boundary-identification stage of modernization rather than only after extraction is complete.

Migration Governance and Rollback Risk

A second implication concerns how enterprises should weigh the migration risk and rollback governance layer's own dependency on the legacy monolith. Because the governance layer's rollback capability, discussed in the Architecture Overview above, depends on the monolith's original implementation of an extracted capability remaining available and consistent with the extracted service's data during the coexistence period, organizations should budget for maintaining that original implementation, not simply deprecating it the moment extraction completes, for as long as the governance layer's rollback option is meant to remain exercisable. Knoche and Hasselbring's[2] industrial account documents this coexistence-maintenance burden as an ongoing engineering effort rather than a one-time cost, a characterization consistent with Figure 4's placement of the rollback checkpoint partway through, rather than at the end of, the first extraction: the window during which rollback is genuinely available is itself a governance decision with a carrying cost, not a feature that comes for free once a rollback mechanism exists in principle.

Cost and Sequencing Trade-offs

A third implication concerns how SEAM's governed approach compares, on cost and sequencing grounds specifically, to ad hoc incremental extraction. Villamizar *et al.*'s[6] cost comparison establishes that decomposition carries concrete, measurable resource and operational cost, and Vale *et al.*'s[5] quality-trade-off findings establish that different extraction sequences carry different costs along different quality dimensions rather than one sequence dominating on every dimension at once; read together, these findings imply that the migration risk and rollback governance layer's sequencing decisions are themselves a cost-relevant design choice, not a purely risk-management overlay added after a sequence has already been chosen on other grounds. An organization that selects its extraction order using the workload-heterogeneity evidence Ueda *et al.*[10] document, as the Case Scenario subsection's order-fulfillment-first choice does, is, on this paper's analysis, more likely to realize Villamizar *et al.*'s[6] documented cost benefits early in the migration than an organization that sequences extractions in an order not informed by workload-heterogeneity evidence, since the components most likely to benefit from independent scaling are extracted first rather than last.

Limitations

No production SEAM migration or measured modernization data informed this study; the Results section's table and figures are explicitly constructions. The bounded-context boundary identification layer's effectiveness depends on the legacy codebase being sufficiently instrumentable to support dependency and dataflow analysis, a precondition the cited systematic review documents is not uniformly available across legacy systems of differing age and documentation quality[1]. The migration risk and rollback governance layer's rollback capability depends on the legacy monolith's original implementation of an extracted capability remaining available and consistent with the extracted service's data during the coexistence period, a coordination requirement the cited industrial literature documents as a genuine, ongoing engineering effort rather than a solved problem[2].

Future Research

Empirical work instrumenting an actual legacy enterprise modernization using SEAM's four coordinated layers, compared against a matched modernization effort using ad hoc incremental extraction without a governance layer, would directly test this paper's central claim about production continuity and consistency-risk management. Research specifically comparing the boundary-identification techniques Abgaz *et al.*'s[1] systematic review catalogs against one another, within the specific context of a governed, rollback-capable extraction process rather than as standalone techniques, would meaningfully extend the decomposition literature into the coordination problem SEAM addresses.

Conclusion

This paper has argued that decomposing a legacy enterprise monolith into microservices requires more than selecting a boundary-identification technique from the substantial catalog the literature already provides (Abgaz *et al.*[1]; Pahl & Jamshidi[8]), because a legacy system in active production use cannot simply be rebuilt wholesale (Dragoni *et al.*[9]; Knoche & Hasselbring[2]), and separating a shared database among newly extracted services reintroduces the distributed-consistency problem a monolith's shared database previously resolved for free (Gilbert & Lynch[3]; Helland[4]). This paper has developed SEAM as a framework in which a bounded-context boundary identification layer, an incremental strangler-style extraction layer, a data ownership separation layer, and a migration risk and rollback governance layer are coordinated, weighing the quality trade-offs and cost realities the literature documents (Vale *et al.*[5]; Villamizar *et al.*[6]) and deployed on cloud-native infrastructure[7], so that a legacy monolith can be decomposed along its natural internal seams while continuing to serve production traffic throughout the migration. The framework was, validated, through a comparative table, a case scenario, and four figures, with every quantitative value explicitly labeled as an estimate. Future empirical work instrumenting a real migration would be necessary before an organization could adopt SEAM with confidence in its specific thresholds, but the underlying argument — that boundary identification, incremental extraction, and data ownership separation should be coordinated under a single governed migration process rather than addressed independently — rests on peer-reviewed evidence this paper has synthesized specifically for that coordination problem.

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