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Declarative IaC with Policy Enforcement for On-Prem to Cloud

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ABSTRACT: Declarative Infrastructure-as-Code (IaC) orchestration enables reproducible, policy-driven deployments across diverse environments. However, migrating applications from on-premises datacenters to public cloud platforms such as Azure, AWS, and GCP presents ongoing challenges in real-time enforcement of corporate security, networking, and governance policies. This paper introduces PolyCloudOrch-PC, an enhancement of PolyCloudOrch, which incorporates on-premise integration capabilities and cloud-agnostic policy libraries. In a case study involving the migration of three stateful microservices from VMware to Azure and AWS, the following outcomes were observed:

- Policy compliance increased from 81% to 100%
- Manual remediation efforts decreased - 0.4 fixes/run (vs. 6.1)
- Total migration time was reduced - 31.5 ± 3.8 min (vs. 54.3 ± 5.1 min)
- Orchestration overhead was maintained below 9.2%.

This work also provides comprehensive policy-category tables, a feature-parity assessment, a sequence diagram illustrating the migration workflow, and an analysis of limitations related to dynamic policy expressiveness and cache scaling.

KEYWORDS: Declarative IaC, Multi-Cloud Orchestration, On-Prem to Public Cloud, Policy-as-Code, Azure, AWS, Compliance Automation, Cybersecurity

I. INTRODUCTION

Deploying infrastructure as Code (IaC) delivers repeatability and versioning but policies (e.g., AES-256 disk encryption, network ACLs, required resource tags) differ across VMware, Azure, and AWS. Without integrated checks, manual reviews cause up to 40 % migration delays which result in lot of rework in later phases of delivery.

This work addresses three research questions:

- Q1: How can we enforce a unified set of policies across heterogeneous clouds in real time?
- Q2: What is the performance overhead of policy-as-code integration in IaC workflows?
- Q3: Can caching validation results sustain large-scale migrations?

PolyCloudOrch-PC framework combining an on-prem agent, OPA policy engine, and distributed cache. Quantitative evaluation over 40 runs showing 42 % faster migrations and 94 % fewer manual fixes. Open-source policy library covering encryption, networking, tagging, cost, and monitoring.

II. LITERATURE REVIEW

Multi-cloud orchestration has attracted significant research, and still real-time policy enforcement remains unexplored. Heinrich et al. (2021) proposed an abstraction layer over cloud APIs, enabling declarative provisioning across AWS, Azure, and GCP. However, their work focused solely on functional provisioning and omitted compliance considerations, leaving security and governance checks to downstream processes.

Li & Patel (2023), Amar Gurajapu (2026) integrated Open Policy Agent (OPA) into CI/CD pipelines, demonstrating how policy-as-code can gate deployments in GitLab and Jenkins. Their approach, while effective for single-cloud applications, lacked cross-cloud abstractions and did not address on-prem state extraction.

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Steimann & Doe (2022) highlighted OPA's runtime governance capabilities, enforcing policies within Kubernetes admission controllers and service meshes. Although valuable for cloud-native workloads, their model did not extend to Terraform-driven IaC workflows, which remain prevalent in enterprise migrations.

Wang & Zhang (2024) developed reusable Terraform modules for hybrid cloud deployments, emphasizing modularity and maintainability. Yet, they did not incorporate policy-validation hooks, relying on teams to perform manual audits.

In summary, prior work either abstracts multi-cloud provisioning without enforcing policies or embeds policy checks in narrow CI/CD contexts. A unified framework that exports on-prem state, applies cloud-agnostic policies before provisioning, and caches validation results for scale remains an open challenge—one that PolyCloudOrch-PC addresses.

III. RESEARCH METHODOLOGY

The research focuses on four main elements, all examined within a controlled test environment.

On-Prem Agent
A lightweight Python service that parses Terraform HCL from on-prem repositories, renders provider-specific JSON, and computes a content hash.

Policy Engine
Open Policy Agent (OPA) with a library of 25 Rego rules covering encryption, networking, tagging, cost governance, and logging. Rules are authored once and applied uniformly across clouds.

Distributed Cache
A Redis cluster stores <*template_hash, validation_result*> pairs. By reusing cached "PASS/FAIL" results, we minimize OPA invocations under repeated migrations.

Provisioner
A wrapper around terraform apply that only executes if OPA validation passes for the given template. Failures trigger a human-readable error message with policy violation details.

Testbed Configuration
- On-Prem: VMware vSphere 7.0
- Public Clouds: Azure (East US), AWS (us-west-2)
- Workloads: NGINX web server, in-memory Redis cache, stateful PostgreSQL
- Trials: 40 independent migration runs per cloud

Metrics Collected
- End-to-end migration time (agent render to provision complete)
- Policy-compliance rate (templates passing all Rego rules)
- Manual remediation count (violations fixed by operators)
- Policy-check latency (OPA eval and cache lookup)

IV. RESULTS AND DISCUSSION

The 9.2 % orchestration overhead is a modest trade-off for 94 % fewer human interventions and guaranteed policy compliance. Architecturally, decoupling policy evaluation via OPA and caching enables horizontal scaling without instrumenting cloud providers themselves.

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TABLE 1. SUMMARIZES COMPARATIVE OUTCOMES OVER 40 RUNS

Metric	Ad-hoc Scripts	PolyCloudOrch-PC	Improvement
Migration Time (min)	54.3 ± 5.1	31.5 ± 3.8	–42 %
Policy-Compliance Rate (%)	81.0	100.0	+19 %
Manual Remediations per Run	6.1	0.4	–94 %
Policy-Check Latency (ms)[1]	N/A	45 ± 10	–

V. CONCLUSION

PolyCloudOrch-PC demonstrates that combining on-premises state export, cloud-agnostic policy-as-code, and distributed caching within declarative IaC workflows enables repeatable and auditable cloud migrations. The solution achieves full policy compliance by enforcing governance consistently across environments. Execution efficiency is significantly improved, delivering up to 42% faster provisioning workflows. Manual intervention is drastically reduced, with 94% fewer post-deployment fixes required. The architecture maintains high performance, achieving validation latencies below 50 ms even under load. These results highlight the robustness of integrating policy enforcement directly into infrastructure workflows. By addressing limitations of earlier multi-cloud provisioning frameworks, PolyCloudOrch-PC ensures end-to-end governance. Overall, it provides a unified and enterprise-ready approach for securely migrating workloads to public cloud platforms.

Limitations

Declarative Infrastructure as Code (IaC) with policy enforcement for on-prem to cloud environments has several limitations that must be addressed for effective adoption. One key challenge is policy complexity, as translating diverse organizational and regulatory requirements into declarative rules can be difficult. Inconsistent policy interpretation across hybrid environments may lead to enforcement gaps. Tooling maturity is another limitation, as not all IaC platforms provide uniform policy validation across on-prem and multi-cloud setups. Additionally, drift detection between declared and actual infrastructure states can be unreliable. Performance overhead may arise from continuous policy checks during provisioning and updates. Limited visibility into policy violations can hinder rapid remediation. Addressing these limitations is critical for achieving consistent, secure, and scalable infrastructure governance.

VI. FUTURE WORK

The PolyCloudOrch-PC solution can be further enhanced through several forward-looking capabilities that address evolving enterprise cloud requirements. AI-assisted policy generation will leverage NLP to translate high-level organisational security charters into executable Rego policies, enabling non-technical stakeholders to contribute effectively to governance. Deeper CI/CD pipeline integration with platforms such as Jenkins and GitLab will shift compliance validation earlier in the delivery lifecycle, reducing deployment risk and accelerating feedback. Extended cloud support will introduce compatibility with additional providers, including Google Cloud Platform (GCP) and DCU adapters. The framework will also expand to support Kubernetes-native cluster migrations across multi-cloud and containerised environments. Continuous drift detection will monitor deployed infrastructure against desired configurations in real time. When deviations or policy violations are identified, automated remediation will be triggered to restore compliance. Together, these enhancements strengthen governance, scalability, and operational resilience across heterogeneous cloud ecosystems.

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