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CWA-ABAC: Reducing Authorization Workload in ABAC through Exact Policy Certification and Attribute Ordering

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Abstract

Attribute-Based Access Control (ABAC) provides fine-grained authorization by evaluating multiple attributes of an access request against policy rules. We observe that this evaluation can perform unnecessary computation when a smaller set of attributes is already sufficient to determine the access decision. In this work, we propose CWA-ABAC (Computational-Workload-Aware Attribute-Based Access Control) to reduce such unnecessary authorization computation without changing the underlying policy. We first construct complete policy contexts from the Amazon Employee Access Challenge dataset and identify policy prefixes that are sufficient to determine an authorization decision. We then examine different attribute evaluation orders and select the order that minimizes the modeled authorization workload. We use exact policy certification to ensure that an authorization request stops only when its decision is uniquely determined. We also compare the workload of the optimized ordering with a fixed attribute ordering and with complete policy evaluation. Our observations show that a large portion of requests can be resolved before evaluating all available attributes and that the ordering of attributes affects the computational workload of authorization. We further observe that workload reduction can be achieved while maintaining the original authorization decisions. These findings indicate that ABAC efficiency can be improved by optimizing the authorization evaluation process rather than modifying the underlying policy structure.

Keywords: *Attribute-Based Access Control, Computational Workload, Policy Certification, Attribute Ordering*

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1. Introduction

Attribute-Based Access Control (ABAC) provides precise and in-depth control over access to resources. It makes an authorization decision by evaluating attributes of a request against an access policy. These attributes can describe the requester, resource, action, and other conditions of the access request. This approach gives more flexibility than access control models that depend only on fixed roles or identities. We can also apply ABAC to large and distributed systems where access conditions change across resources and users. However, this flexibility also increases the amount of information that an authorization system may need to evaluate for each request.

We focus on the computational workload of this evaluation. In a conventional ABAC process, the authorization engine evaluates the available attributes and checks the relevant policy conditions until it obtains a decision. In many cases, the complete set of attributes is not necessary to determine the result. A smaller subset of attributes may already provide enough information to distinguish an allowed request from a denied request. If the authorization engine continues to evaluate the remaining attributes, it performs computation that does not change the final decision. We consider this unnecessary computation as an authorization workload that we can reduce. Existing ABAC research addresses several problems related to policy management and policy optimization. Researchers study policy mining, policy refinement, redundancy removal, policy simplification, and policy pruning. These approaches mainly focus on the structure or representation of the policy. They try to reduce, reorganize, or improve the policy itself. We consider a different problem. We keep the underlying policy and its authorization semantics

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unchanged. Instead, we ask how much of the existing policy information we actually need to evaluate for a particular request. This difference is important because a policy can remain complete while the authorization process evaluates only the part that is sufficient for the current decision.

We propose CWA-ABAC (Computational-Workload-Aware Attribute-Based Access Control) to address this problem. We develop the framework around two main steps. First, we examine the policy contexts and identify prefixes that uniquely determine the authorization decision. We call such prefixes certified prefixes. Once a prefix provides a unique decision, we stop further evaluation for that request. Second, we examine different orders of the available attributes. We select the order that produces the lowest authorization workload while preserving the original decision. We therefore treat attribute ordering as a computational problem rather than selecting the order only from the semantic importance of an attribute.

2. Literature Review

We observe that while existing studies improve distinct stages of the authorization lifecycle, they do not address how to minimize the computation required for an exact decision.

We highlight early efficiency developments across several operational domains. Batra et al. (2021) [2] reduce the cost of ABAC policy maintenance through incremental updates. Pan et al. (2021) [5] optimize policy retrieval using binary representations, while Liu et al. (2021) [4] employ a machine-learning decision engine to accelerate permission decisions. Gupta et al. (2021) [3] apply ABAC to cloud-enabled industrial smart vehicles, and Sheikhalishahi et al. (2021) [6] evaluate policy decisions while preserving privacy. Aghili et al. (2022) [7] introduce MLS-ABAC for multi-level security, and Pericherla et al. (2022) [8] integrate ABAC into Hyperledger Fabric blockchain networks. Sun (2022) [9] resolves policy constraints and detects conflicts during evaluation. We recognize that these works establish policy scale, retrieval mechanisms, and system placement as critical drivers of ABAC performance; however, none identify the minimal attribute prefix necessary to make a safe request decision.

We note that subsequent research focuses on reducing communication and system-level overhead. Anand Helil (2023) [10] recycle authorization states and use caching to lower communication between the Policy Enforcement Point (PEP) and Policy Decision Point (PDP). Yang (2023) [12] enforces separation-of-duty constraints directly within ABAC evaluation. De Oliveira et al. (2023) [11] implement ABAC for electronic medical records during acute care, while Zhang et al. (2023) [13] develop a traceable multi-authority ABAC scheme for secure data storage in the mineral industry. Bamberger and Fernández (2024) [14] advance automated access control policy mining by structuring attribute-based rules to simplify policy discovery. Perez-Haro and Diaz-Perez (2024) [16] mine ABAC policies using affiliation networks and biclique analysis. Varshith et al. (2024) [17] optimize algorithms and data structures for request resolution in Linux, and Kalaria et al. (2024) [15] leverage fog computing to accelerate context-aware IoT authorization. We find that while these techniques optimize retrieval, placement, or constraint processing, they leave the sequence of attribute evaluations unoptimized.

We see this focus on authorization efficiency continue in the most recent literature. Bui et al. (2025) [18] address missing attribute values in policy mining. Guo et al. (2025) [20] present an efficient fine-grained scheme utilizing policy protection in smart grids. Madkaikar et al. (2025) [21] formulate a queuing-theoretic framework to evaluate dynamic ABAC performance and resolution delays. Batra et al. (2025) [19] establish semantically correct policy mining and enforcement procedures. Finally, Waheed et al. (2026) [22] reduce energy consumption and blockchain load using an off-chain LightGBM approach for smart homes.

We summarize that current approaches change, retrieve, cache, mine, protect, or relocate policies. To solve this specific gap, we introduce CWA-ABAC. We identify certified prefixes when all matching policy entries lead to one decision, continue to evaluate uncertified prefixes, and search attribute orders that reduce the computational load.

3. Methodology

We consider an Attribute-Based Access Control (ABAC) authorization process in which an access request contains a resource and a set of authorization attributes. The policy repository contains complete attribute contexts associated with authorization decisions. During conventional evaluation, the authorization engine examines the available attributes and matching policy entries until it obtains a decision. We focus on the unnecessary computation that occurs when the decision becomes certain before the engine evaluates the complete context.

We represent an authorization request as

$$q = (R, A_1, A_2, \ldots, A_m), \quad (1)$$

where R denotes the requested resource and $A_1, \ldots, A_m$ denote the authorization attributes. Each complete policy context has an associated authorization decision $D \in \{0, 1\}$.

The order in which attributes are evaluated determines the sequence of partial policy contexts examined by the authorization engine. For a selected attribute ordering O, we define the prefix at depth d as

$$P_d(q) = (R, A_{\pi 1}, A_{\pi 2}, \ldots, A_{\pi d}), \quad (2)$$

where π represents the selected ordering and d represents the current evaluation depth.

For every prefix, we identify the policy entries that match the available attribute values. We then construct the set of distinct authorization decisions associated with the matching entries as

$$D(P_d) = \{D_i \mid P_i \text{ matches } P\}. \quad (3)$$

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We call a prefix *certified* when all matching policy entries produce the same authorization decision:

$$|D(P_d)| = 1. \quad (4)$$

A certified prefix gives sufficient policy evidence to determine the authorization decision. We therefore terminate the evaluation at that level. We call a prefix *uncertified* when

$$|D(P_d)| > 1. \quad (5)$$

In this case, different authorization decisions remain possible, and we continue the evaluation with the next attribute. We do not make a decision from the most frequent outcome or from an estimated probability.

The minimum sufficient evaluation depth for request q is therefore

$$d^*(q) = \min\{d : |D(P_d)| = 1\}. \quad (6)$$

If no prefix produces a unique decision, we retain the complete ABAC evaluation. This condition ensures that the proposed method reduces computation without changing the authorization semantics. We construct the details of our CWA-ABAC's working methodology in the following subsections.

Algorithm 1 Exact Policy-Prefix Certification

Require: Request set Q, policy set P, attribute order O
Ensure: Certified depth $d^*(q)$, decision $\hat{D}(q)$, candidate count $N(q)$

Construct complete policy contexts from P
Build prefix decision maps for every level of O
for all $q \in Q$ **do**
    $resolved \leftarrow alse$ 5:
for $d \leftarrow 1$ to $|O|$ **do** 6:
$pre\ f\ ix \leftarrow P_d(q)$
    $C \leftarrow$ matching policy entries for $pre\ f\ ix$
    $S \leftarrow$ distinct decisions in C
    if $|S| = 1$ **then**
        $d^*(q) \leftarrow d$
$\hat{D}(q) \leftarrow$ unique decision in S
        $N(q) \leftarrow |C|$
        $resolved \leftarrow True$
        break
    end if
end for
if $resolved = False$ **then**
    $d^*(q) \leftarrow |O|$
$\hat{D}(q) \leftarrow$ CompleteABACEvaluation(q)
    $N(q) \leftarrow$ complete candidate count
end if
end for
return $d^*(q)$, $\hat{D}(q)$, $N(q)$

3.1 Exact Policy Certification

We first construct prefix-level representations of the existing policy. Each prefix stores the distinct authorization decisions associated with its matching policy entries. Algorithm 1 then evaluates each request progressively.

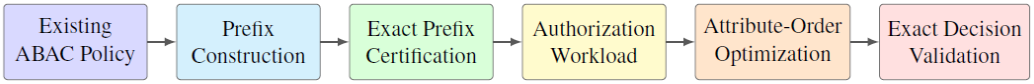
Algorithm 1 provides the exact stopping mechanism of CWA-ABAC. We stop a request only when the matching policy evidence contains one possible decision. An uncertified prefix therefore does not indicate an incorrect policy condition. It indicates that the current prefix does not contain sufficient information to distinguish the possible decisions. We consequently retain the unresolved candidates and evaluate the next attribute.

3.2 Authorization Workload

We measure the computational workload using both evaluation depth and the number of candidate policy entries considered at the stopping level. For request q, we define

$$W(q) = d^*(q) \times N(q) \quad (7)$$

For an attribute ordering O, the total workload becomes



Figre 1: Overall workflow of CWA-ABAC.

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$$W(O) = \sum_{q \in Q} d_O(q) N_O(q). \tag{8}$$

We use complete ABAC evaluation as the reference workload and calculate the workload reduction as

$$WR(O) = \left(1 - \frac{W(O)}{W_{\text{full}}}\right) \times 100. \tag{9}$$

This measure represents the reduction in the computational workload modeled by our authorization procedure. We do not interpret it as direct physical energy consumption.

3.3 Workload-Minimizing Attribute Ordering

The certification depth depends on attribute order. An attribute that separates authorization decisions early can produce a lower workload than an attribute that leaves several decisions unresolved. We therefore formulate attribute ordering as an optimization problem.

For an ordering

$$O = (_{\pi}1, A_{\pi}2, \ldots, A_{\pi}m), \tag{10}$$

we apply Algorithm 1 and calculate the resulting workload. We then select the ordering that minimizes the total workload:

$$O^* = \arg\min_{O \in \Omega} \mathcal{W}(O), \tag{11}$$

where Ω denotes the set of valid attribute permutations.

We keep the resource attribute at the first evaluation level and optimize the remaining attribute positions. Algorithm 2 performs this search and validates the selected order against the original authorization decisions.

For the studied configuration, seven role-related attributes remain after fixing the resource level. We therefore evaluate

$$7! = 5040 \tag{12}$$

possible attribute orders. We select the order with the lowest workload and then independently validate its authorization decisions. This separates workload optimization from authorization correctness.

3.4 CWA-ABAC Workflow

The complete process contains four main stages. We first construct the existing ABAC policy contexts. We then generate prefix maps and certify prefixes whose matching policy entries produce a unique decision. Next, we evaluate the possible attribute orders and select the order that minimizes the modeled authorization workload. Finally, we validate every resulting decision against the original ABAC decision.

Algorithm 2 CWA-ABAC Workload Optimization and Validation

Require: Policy set P, request set Q, attribute set A
Ensure: Optimal order O^* and minimum workload W^*
Construct complete policy contexts from P
2: Generate all valid attribute orders Ω
3: $W^* \leftarrow \infty$
4: $O^* \leftarrow \emptyset$
5: for all $O \in \Omega$ do
6: Run Algorithm 1 using O
7: Calculate $\mathcal{W}(O)$ using Eq. 8
8: if $\mathcal{W}(O) < W^*$ then
9: $W^* \leftarrow \mathcal{W}(O)$
10: $O^* \leftarrow O$
11: **end if**
12: **end for**
13: Run Algorithm 1 again using O^*
14: Compare $\hat{D}(q)$ with the original decision $D(q)$
15: **if** $\hat{D}(q) = D(q)$ for every $q \in Q$ then
16: Accept O^*
17: **else**
18: Reject O^*
19: **end if**
20: return O^*, W^*

As shown in Fig. 1, the proposed method does not modify or remove the underlying policy. We instead determine how much of the existing policy information is sufficient for the current authorization request. The certification stage provides the exact stopping condition, while the ordering stage reduces the expected computational workload across requests. The final validation

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stage ensures that the selected ordering does not change the original authorization decisions.

4. Experimental Evaluation and Results

We first preprocess the Amazon Employee Access Challenge dataset [1] to obtain a consistent ABAC representation. We retain the original authorization decision and use the resource and role-related attributes as the policy context. We do not modify the observed authorization decisions during preprocessing.

4.1 Dataset and Experimental Setup

After preprocessing, the dataset contains 55,396 access requests and 9 attributes. We use ACTION as the authorization decision and use RESOURCE, ROLE_ROLLUP_1, ROLE_ROLLUP_2, ROLE_DEPTNAME, ROLE_TITLE, ROLE_FAMILY_DESC, ROLE_FAMILY, and ROLE_CODE as ABAC attributes. We identify 27,978 unique resources and 55,303 complete ABAC contexts. We also identify 93 conflicting complete contexts involving 186 requests. We retain these requests and require complete evaluation when the available policy evidence does not uniquely determine the decision.

We construct the complete ABAC policy, generate the 128 exact policy subsets, and build request-level certification maps. We use complete ABAC evaluation as the reference workload. We keep RESOURCE as the first attribute and evaluate all permutations of the remaining seven attributes. Thus, we evaluate

$$7! = 5040 \quad (13)$$

possible attribute orders.

4.2 Evaluation Metrics

We evaluate CWA-ABAC using total workload, evaluation depth, certification coverage, workload reduction, and decision preservation. We calculate total authorization workload using Eq. 8 and workload reduction using Eq. 9. We also report mean and median request-level workload reduction and mean depth reduction. Certification coverage represents the percentage of requests that obtain an exact decision before complete evaluation. Finally, we compare every CWA-ABAC decision with the original ACTION value.

4.3 Overall Workload Results

Complete ABAC evaluation produces a modeled workload of 17,982,080. The fixed attribute order is

O_{fixed} = (RESOURCE, ROLE_CODE, ROLE_FAMILY, ROLE_FAMILY_DESC, ROLE_TITLE, ROLE_DEPTNAME, ROLE_ROLLUP_2, ROLE_ROLLUP_1). (14)

This order produces a workload of 464,161 and a workload reduction of 97.418758%. We then evaluate all 5,040 possible orders. The optimal order is

O^* = (RESOURCE, ROLE_DEPTNAME, ROLE_FAMILY_DESC, ROLE_ROLLUP_2, ROLE_CODE, ROLE_ROLLUP_1, ROLE_FAMILY, ROLE_TITLE). (15)

The optimal order produces a workload of 334,449 and a workload reduction of 98.140098% relative to complete evaluation. It also reduces the remaining workload by 27.945476% compared with the fixed order. Table 1 presents this comparison.

Table 1. Aggregate computational workload comparison

Measure	Fixed Order	CWA-ABAC
Workload	464,161	334,449
Workload reduction (%)	97.418758	98.140098
Improvement over fixed (%)	--	27.945476

4.4 Evaluation Depth and Certification

The optimized order gives a mean evaluation depth of 1.435501 and a mean depth reduction of 82.056241%. We resolve 35,302 requests at depth 1 and 17,599 requests at depth 2. Therefore, 95.496065% of requests obtain an exact decision within the first two depths. Table 2 presents the complete depth distribution.

Table 2. Optimal evaluation-depth distribution

Depth	Requests	Percentage	Depth Reduction (%)
1	35,302	63.726623	87.500000
2	17,599	31.769442	75.000000
3	1,871	3.377500	62.500000
4	272	0.491010	50.000000
5	164	0.296050	37.500000
6	2	0.003610	25.000000

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8	186	0.335764	0.000000

4.5 Request-Level Workload Results

CWA-ABAC achieves a mean workload reduction of 90.049618% and a median workload reduction of 87.500000%. Certification coverage reaches 99.664236%, while only 0.335764% of requests require complete evaluation. Table 3 summarizes the request-level results.

Table 3. Request-level computational results

Measure	CWA-ABAC
Mean optimal depth	1.435501
Mean depth reduction (%)	82.056241
Mean workload reduction (%)	90.049618
Median workload reduction (%)	87.500000
Certification coverage (%)	99.664236
Full evaluation rate (%)	0.335764

4.6 Decision Preservation

We compare every CWA-ABAC decision with the original authorization decision. We obtain 100% decision preservation and zero incorrect decisions across all 55,396 requests. The 186 requests associated with conflicting contexts require complete evaluation. Table 4 confirms that we preserve every authorization decision.

Table 4. Authorization correctness

Measure	Result
Requests evaluated	55,396
Decision preservation (%)	100.000000
Incorrect decisions	0
Conflicting complete contexts	93
Requests requiring full evaluation	186

Overall, we reduce the modeled authorization workload without pruning policy rules, removing requests, or replacing policy decisions with predictions. We measure computational workload rather than physical energy consumption, so we do not claim direct energy savings from this experiment. The results instead show that exact certification and attribute ordering can substantially reduce authorization computation while preserving the original authorization outcome.

5. Conclusion and Future-Work

We present CWA-ABAC as a workload-aware approach that reduces unnecessary ABAC evaluation while preserving authorization correctness. We identify exact policy prefixes that determine decisions and optimize the attribute order to reach these prefixes earlier. Our evaluation shows 99.664236% certification coverage, 90.049618% mean request-level workload reduction, and 98.140098% aggregate workload reduction, while preserving 100% of the original authorization decisions. We therefore show that CWA-ABAC reduces authorization computation without modifying policies or changing their decisions. Future work will extend the evaluation to larger policy environments and measure execution cost and actual energy consumption.

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