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Mining Least Privilege Attribute Based Access Control Policies

ACSAC ’19

Definitions

- Access Control: the process of allowing only authorized privileged entities to observe, modify, or otherwise take possession of the resources of a computer system. It is also a mechanism for limiting the use of resources to authorized users.
- Principle of Least Privilege: an access control design principle where privileged entities operate using the minimal set of privileges necessary to complete their job. Least privilege policies protect against:
  - Compromise of privileged entities' credentials.
  - Accidental misuse.
  - Intentional misuse.

Motivation

All compliance standards have a requirement to implement "Least Privilege"

- DoD Information Assurance Certification and Accreditation Process (DIACAP), Control ECLP-1 Least Privilege: *Access procedures enforce the principles of separation of duties and "least privilege."*
- Payment Card Industry Data Security Standard (PCI-DSS), Requirement 7: "*Restrict access to cardholder data by business need to know.*"
- Health Insurance Portability and Accountability (HIPAA), §164.312(a)(3)(ii)(B): "*Implement procedures to determine that the access of a workforce member to electronic protected health information is appropriate.*"
- NIST SP 800-171 Protecting Controlled Unclassified Information in Nonfederal Systems, 3.1.7: "*Employ the principle of least privilege, including for specific security functions and privileged accounts.*"

Problem

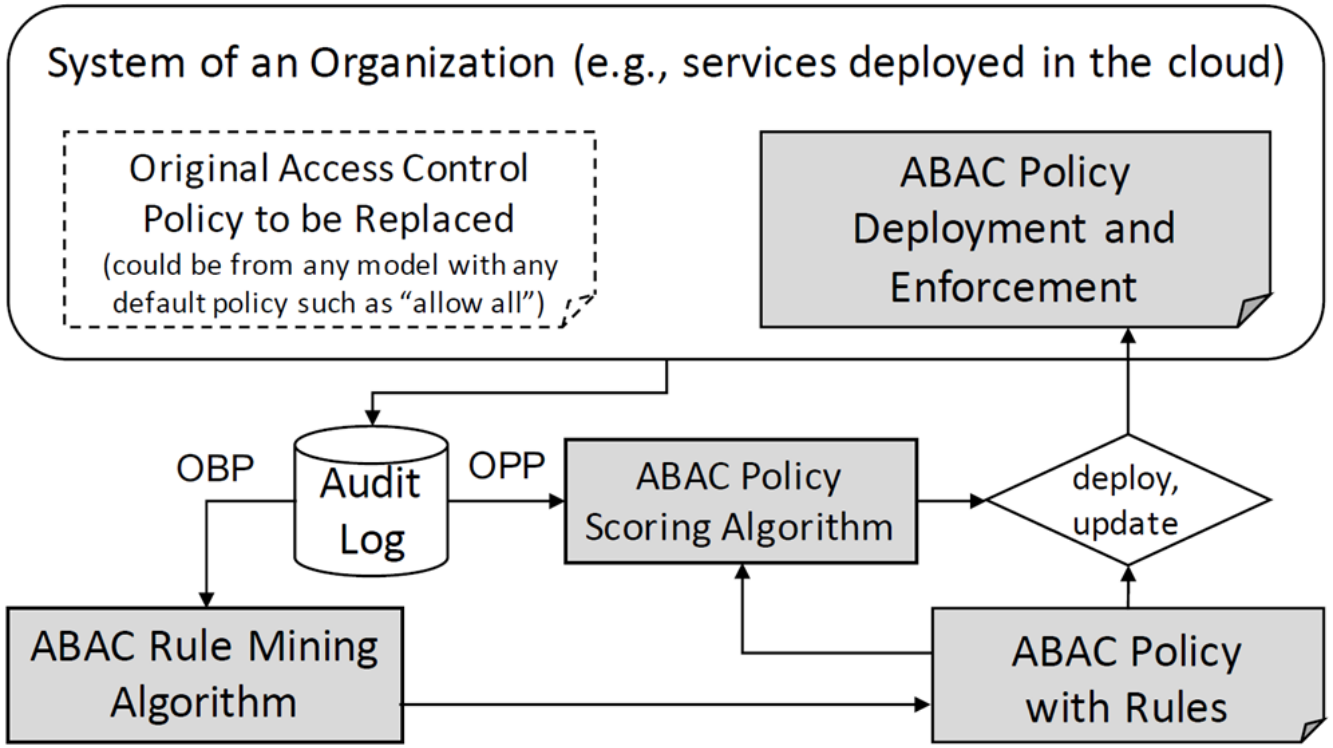
- Lack of quantified metrics to determine if least privilege is achieved, and to what degree.
- Least privilege is difficult to achieve.
- Privilege assignments and user behavior changes over time.
- ABAC privilege space is massive, difficult to create/manage good policies, overwhelming flexibility.

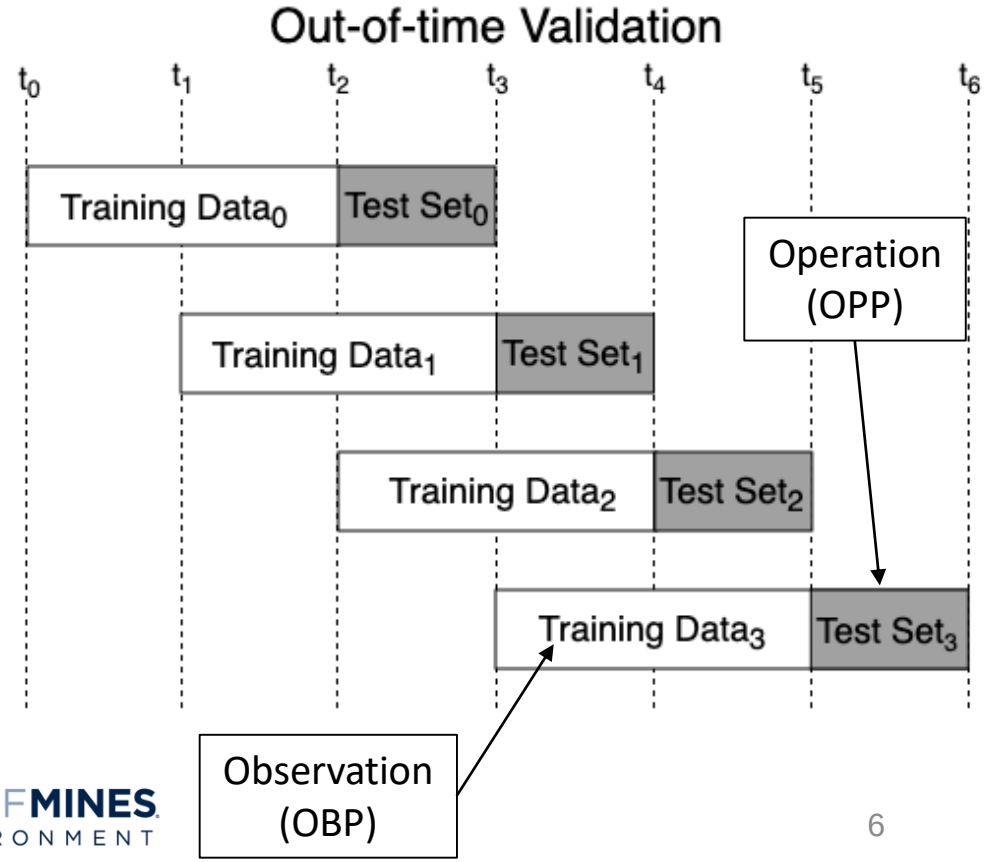
ABAC Privilege Error Minimization Problem

- OBP observation period, the time-period during which exercised permissions are observed and used for creating an access control policy.
- OPP operation period, the time-period during which the access control policy is to be considered in operation.
- ABAC Privilege Error Minimization Problem ($PEMP_{ABAC}$). *Given the universe of all valid attribute:value combinations, find the set of attribute:value constraints that minimizes the over-privilege and under-privilege errors for a given operation period OPP.*

General Approach

- Mine audit logs during an Observation Period (OBP) to create policies.
- Evaluate policies during an Operation Period (OPP) to score them.
- Privileged entities often already possess the privileges necessary to do their jobs, so policies can be derived from existing permissions.

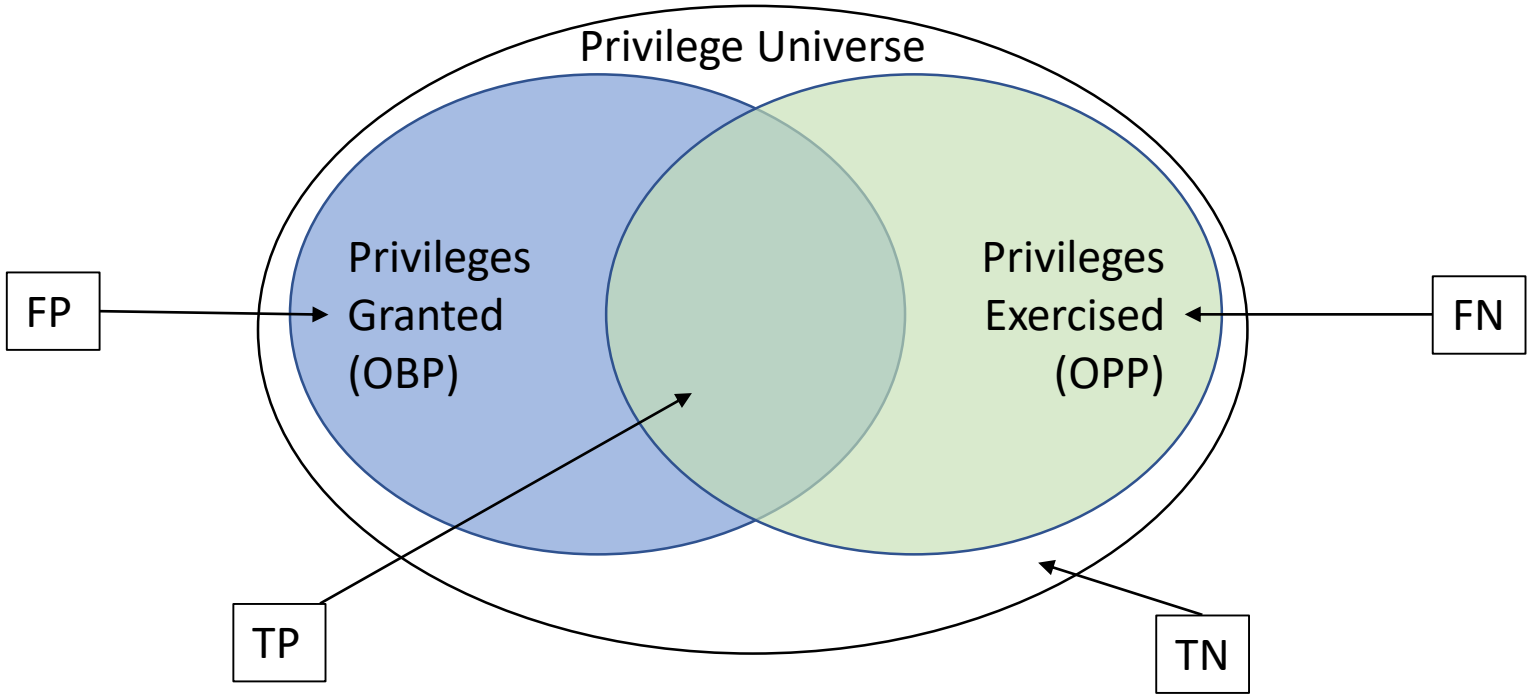




Quantifying Privilege Errors

Security policies are predictions about privilege usage:

- True Positives (TP): Granted privileges which were needed.
- False Positives (FP): Granted but unused privileges.
- False Negatives (FN): Denied privileges which were needed.
- True Negatives (TN): Denied and unused privileges.



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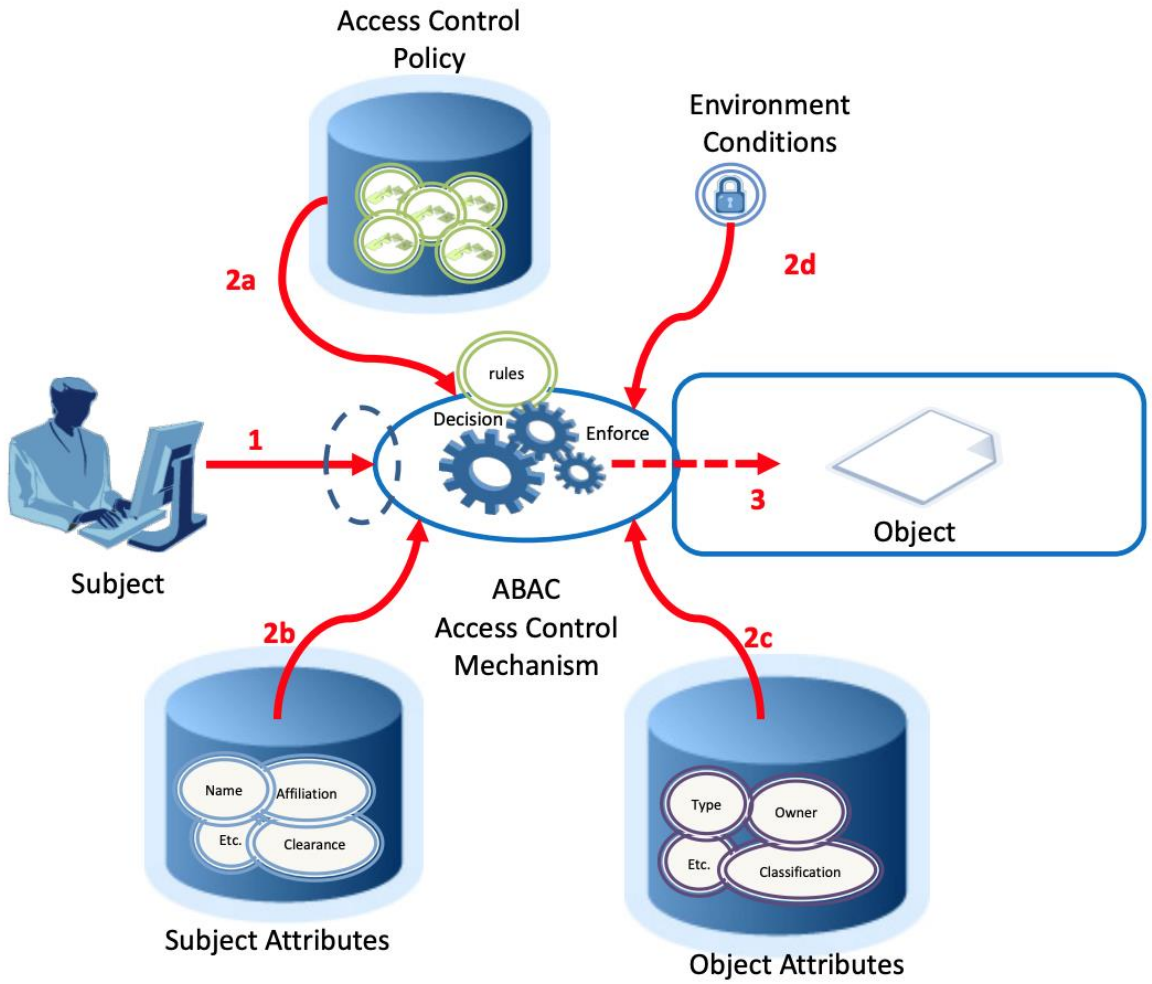
Attribute Based Access Control (ABAC)

1. Subject requests access to object
2. Access Control Mechanism evaluates:
   a) Rules
   b) Subject Attributes
   c) Object Attributes
   d) Environment Conditions
3. Subject is given access to object if authorized



ABAC Advantages: Flexibility and granularity.
ABAC Challenges: Large privilege space. Flexibility can be overwhelming.

Example AWS CloudTrail Audit Log Entry


```
{"Records": [{
    "eventVersion": "1.0",
    "userIdentity": {
      "type": "IAMUser",
      "principalId": "EX_PRINCIPAL_ID",
      "arn": "arn:aws:iam::123456789012:user/Alice",
      "accessKeyId": "EXAMPLE_KEY_ID",
      "accountId": "123456789012",
      "userName": "Alice"
    },
    "eventTime": "2014-03-06T21:22:54Z",
    "eventSource": "ec2.amazonaws.com",
    "eventName": "StartInstances",
    "sourceIPAddress": "205.251.233.176",
    "userAgent": "ec2-api-tools 1.6.12.2",
....
```


Audit Log Entries	**4.7M**
Time Span	**16 Months**
Users	**38**

Policy Generation using Frequent Itemset Mining

	Features			
	User	Service	Action	Resource Type
Entry1	User1	IAM	Create	User
Entry2	User2	EC2	Update	Instance
Entry3	User3	S3	Delete	Bucket
Entry4	User3	EC2	Update	Volume
Entry5	User1	EC2	Create	Instance
Entry6	User2	S3	Read	Object
Entry7	User1	EC2	Read	Instance
Entry8	User3	IAM	Read	User

Itemset	Support	Coverage
Service=EC2	4	50%
Service=EC2, Type=Instance	3	37.5%
User=User1	2	37.5%
Service=EC2, Action=Update	2	25%

- Itemset: A collection of one or more *Attribute:Value* Conditions
- ε: threshold value for minimum itemset frequency.
- Support: Frequency of occurrence of an itemset.
- Coverage: The % of transactions an itemset is present in.

Evaluating Candidate Rules

Definitions:

- r is a rule consisting of one or more ABAC *attribute:value* constraints.
- p is an ABAC policy consisting of one or more rules.
- $\mathbb{L}_{OBP}$ The set of log entries representing user actions during the observation period OBP.
- ξ is the set of all possible *attribute:value* combinations.
- $\xi`$ is the set of all valid *attribute:value* combinations when considering the dependency relationships between all attributes and values.

Metrics:

- $\text{CoverageRate}(r, p, \mathbb{L}_{OBP}) = \frac{|\mathbb{L}_{OBP}(r) \setminus \mathbb{L}_{OBP}(p)|}{|\mathbb{L}_{OBP} \setminus \mathbb{L}_{OBP}(p)|}$
- $\text{OverPrivilegeRate}(r, p, \mathbb{L}_{OBP}, \xi`) = \frac{|\xi`(r) \setminus (\mathbb{L}_{OBP}(p) \setminus \mathbb{L}_{OBP}(r))|}{|\xi`|}$
- $C_{score}(\text{rule}, \text{policy}, \mathbb{L}_{OBP}, \xi`, \omega) = \text{CoverageRate}(r, p, \mathbb{L}_{OBP}) + \omega \times (1 - \text{OverPrivilegeRate}(r, p, \mathbb{L}_{OBP}, \xi`))$

Algorithm 1 ABAC Policy Generator

Input: $\mathbb{L}_{OBP}$ The set of log entries representing user actions during the observation period OBP.
Input: ω under-privilege vs. over-privilege weighting variable.
Input: ϵ Threshold value for minimum itemset frequency.
Input: ξ‘ The set of all valid *attribute:value* combinations that comprise the privilege universe.
Output: *policy* The set of ABAC rules that make up the policy to be applied during the operation period OPP.

1 $policy \leftarrow \emptyset$;
2 $\mathbb{L}_{uncov} \leftarrow \mathbb{L}_{OBP}$;
3 **while** $|\mathbb{L}_{uncov}| > 0$ **do**
4 $itemsets \leftarrow FP{-}growth.frequentItemsets(\mathbb{L}_{uncov}, \epsilon)$;
5 $candidateRules \leftarrow \emptyset$;
6 **for** $itemset \in itemsets$ **do**
7 $rule = createRule(itemset)$;
8 $coverageRate = \frac{|\mathbb{L}_{uncov}(rule)|}{|\mathbb{L}_{uncov}|}$;
9 $overAssignmentRate = \frac{|\xi\text{‘}(rule)| - |\mathbb{L}_{uncov}(rule)|}{|\xi\text{‘}|}$;
10 $rule.C_{score} = coverageRate + \omega \times (1 - overAssignmentRate)$;
11 $candidateRules \leftarrow candidateRules \cup rule$;
12 **end**
13 $bestRule = sortDescending(candidateRules, C_{score})[0]$;
14 $policy \leftarrow policy \cup bestRule$;
15 $\mathbb{L}_{uncov} \leftarrow \mathbb{L}_{uncov} \setminus \mathbb{L}_{uncov}(bestRule)$;
16 **end**
17 **return** *policy*

Algorithm 2 ABAC Policy Evaluator

Input: $\mathbb{L}_{OPP}$ The set of log entries representing user actions during the operation period OPP.
Input: ξ‘ The set of all valid *attribute:value* combinations that comprise the privilege universe.
Input: *policy* The set of ABAC rules that make up the policy to be applied during the operation period OPP.
Output: TPR, FPR The true positive and false positive rates of the *policy* evaluated against the operation period OPP.

$TP = FN = 0$;
$exercisedGrantedEvents \leftarrow \emptyset$;
for $event \in \mathbb{L}_{OPP}$ **do**
  if $policyAllowsEvent(policy, event)$ **then**
    $TP = TP + 1$;
    $exercisedGrantedEvents \leftarrow exercisedGrantedEvents \cup event$;
  else
    $FN = FN + 1$;
  end
end
$eventsAllowedByPolicy \leftarrow \emptyset$;
for $r \in policy$ **do**
  $eventsAllowedByPolicy \leftarrow eventsAllowedByPolicy \cup \xi‘(rule)$;
end
$FP = |eventsAllowedByPolicy \setminus exercisedGrantedEvents|$;
$TN = |privUniverse| - (TP + FN + FP)$;
if $TP + FN == 0$ **then**
  $TPR = 1$;
else
  $TPR = TP/(TP + FN)$;
end
$FPR = FP/(FP + TN)$;
return TPR, FPR

Optimizations for large ABAC privilege spaces

Feature Selection:

- Use attributes that occur frequently with high uniqueness, but not unique values with every request (ex. *RequestId*). Remove redundant attributes (1:1 correlation).
- Apply binning to highly unique attributes like IP addresses and client library versions.

Policy Mining Optimizations:

- Divide privilege space into independent partitions for 1) user attributes, 2) environment attributes, and 3) operation & resource attributes. Use inverted indexes to calculate over-privilege rate of a rule quickly.
- Algorithm 1 only counts the number of privileges covered by a rule, does not enumerate full privilege space.

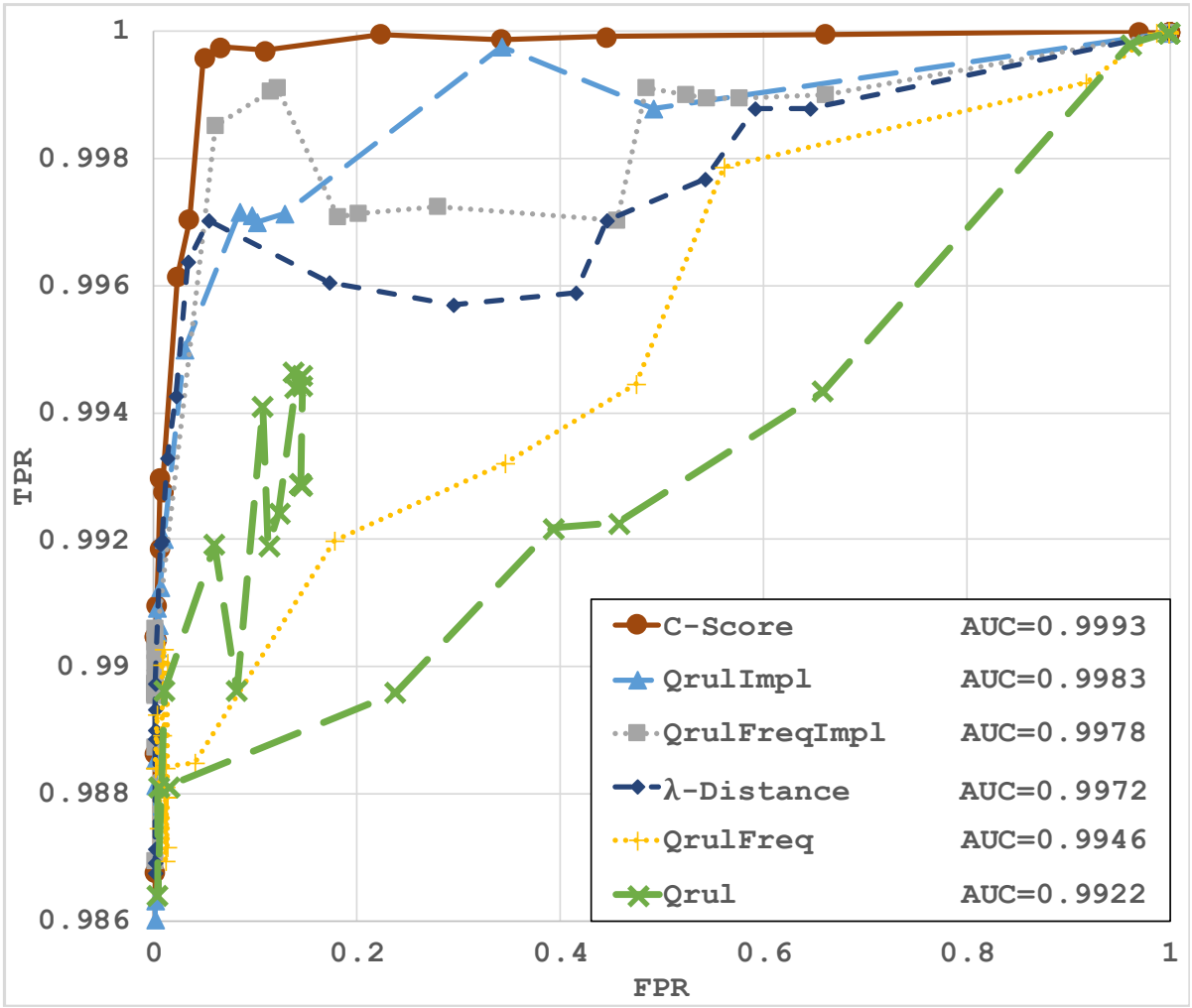
Policy Scoring Optimizations:

- Algorithm 2 must enumerate all privilege combinations covered by a rule to find if they are also covered by other rules in the policy.
- Partition ξ` by attribute values to create one partition per processor core, distribute OPP evaluation on AuN (“Golden”) with 144 compute nodes, 2,304 cores.

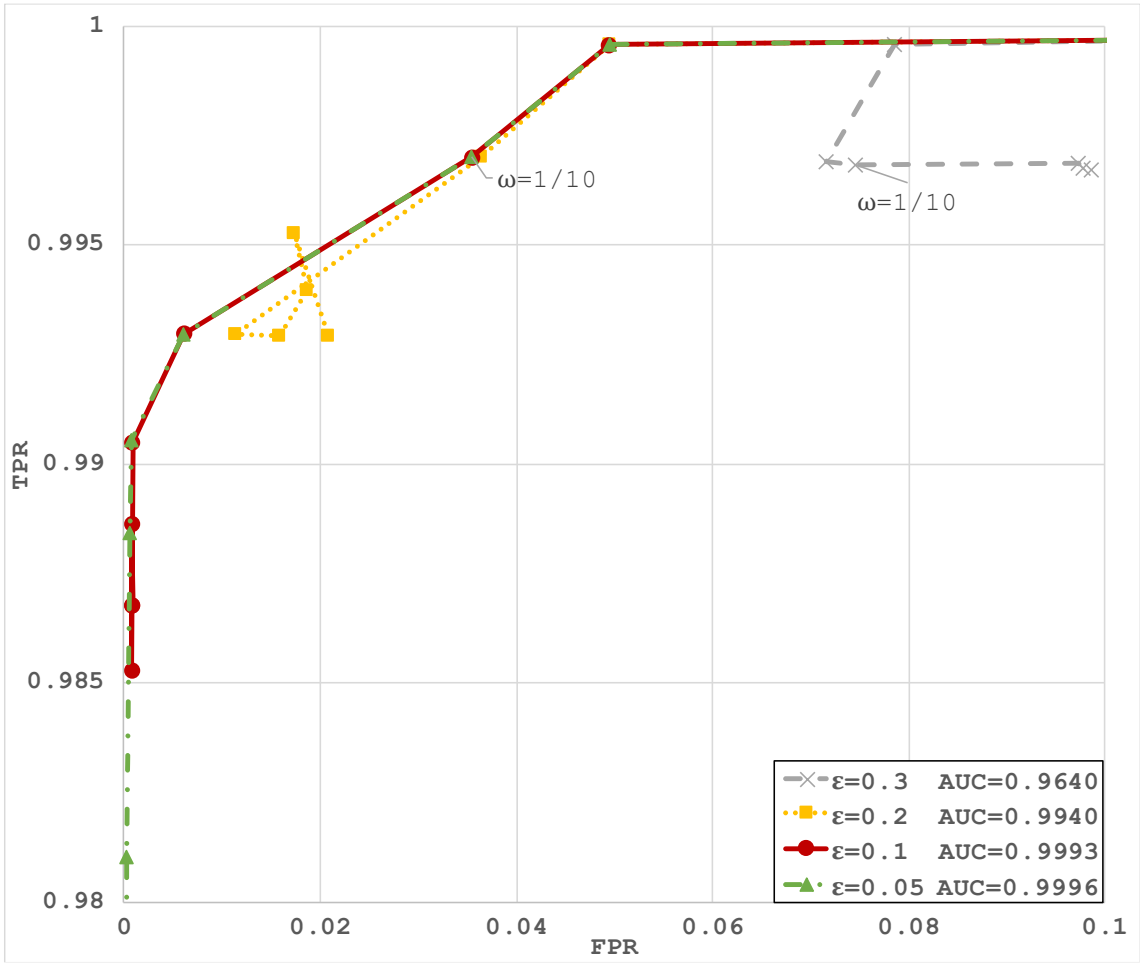
C-Score Analysis

Candidate evaluation metrics should:

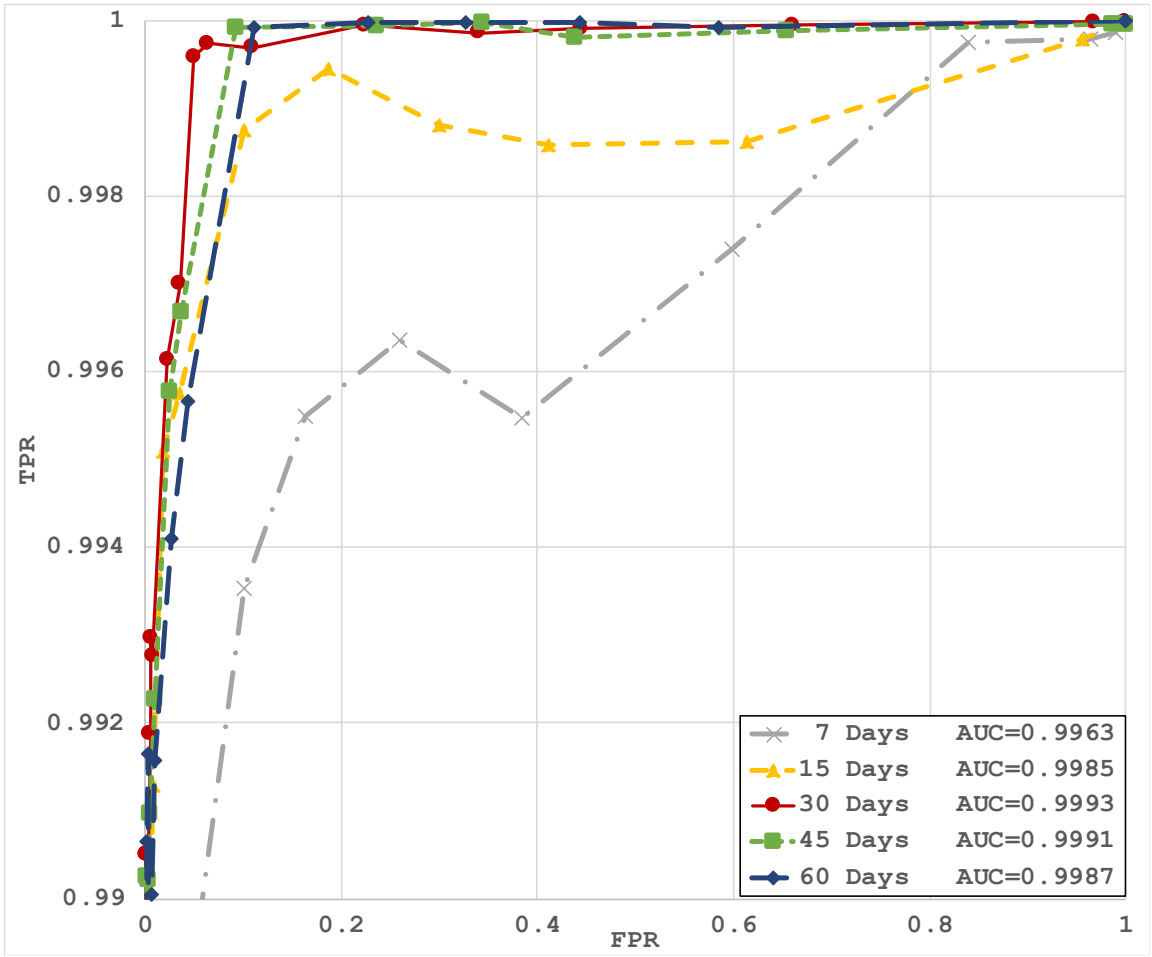
1. Have a high Area Under The ROC Curve (*AUC*) value.
2. Exhibit *Smoothness*, TPR values should increase monotonically as FPR increases.
3. Be *Interpretable*, changing the weighting variable show a proportionate change in TPR & FPR and easy to understand for policy creators.



Frequency and Observation Period Analysis



Itemset Frequency (ε) Varies



Observation Period Size Varies

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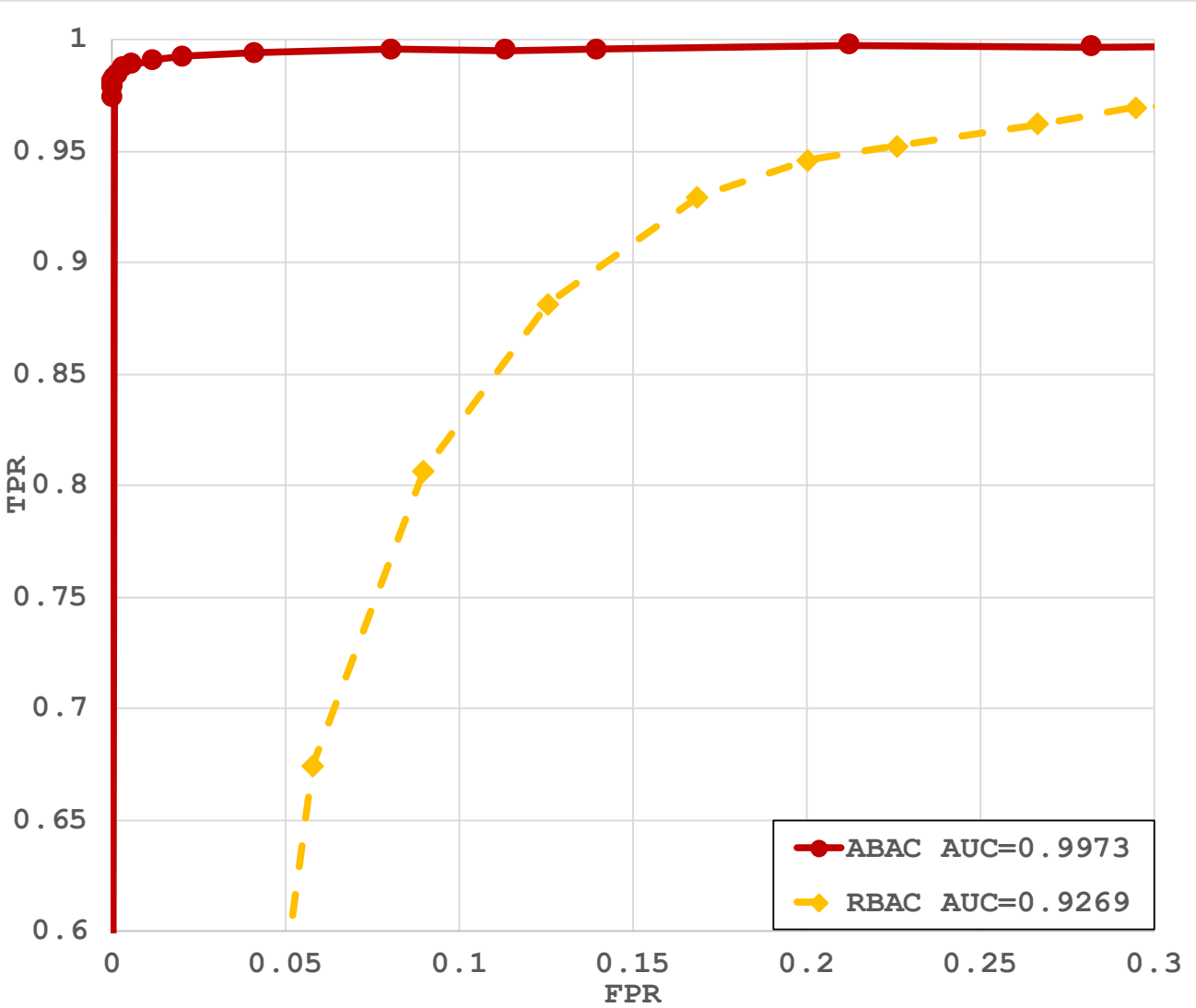
ABAC vs. RBAC Performance



Comparison of ABAC mining and naïve RBAC algorithm for RBAC policy generation.

- ABAC Fixed $|\mathbb{L}_{\mathrm{OBP}}|$ = 30 days
- ABAC varied $\omega = [\frac{1}{8192}, \ldots, 16]$
- RBAC varied $|\mathbb{L}_{\mathrm{OBP}}| = [3,\ldots,120]$ days
- Used ABAC policy scoring (Algorithm 2)

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Contributions / Conclusion

- Our optimization methods for feature selection, policy generation and policy evaluation enabled us to work on a real world dataset of millions of audit events with a privilege space spanning billions of possible entries.
- Our candidate evaluation metric (C_{score}) provides better AUC, smoothness, and predictability than metrics from related works.
- Our policy generation algorithm provides significant flexibility by varying itemset frequency (ε) and under- vs. over-privilege weighting (ω).
- Our methodology addresses changes in user behavior over time.
- The granularity of the ABAC model allows for mining policies that have much fewer assignment errors than RBAC policies.

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source code:
https://github.com/mwsanders/AssociationAbacMiner

Questions?