Using the decision support algorithms combining different security policies

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Abstract

During the development of the security subsystem of modern information systems, a problem of the joint implementation of several access control models arises quite often. Traditionally, a request for the user’s access to resources is granted in case of simultaneous access permission by all active security policies. When there is a conflict between the decisions of the security policies, the issue of granting access remains open. The proposed method of combining multiple security policies is based on the decision support algorithms and provides a response to the access request, even in case of various decisions of active security policies. To construct combining algorithm we determine a number of weight coefficients, use a weighted sum of the clearance levels of individual security policies and apply the analytic hierarchy process. The weight coefficients are adjustable parameters of the algorithm and allow administrator to manage the impact of the various security rules flexibly.

Keywords: Security policy, combining, clearance level.

1 Introduction

The problem of combining different security policies arises quite often in the administration of computer systems. For example, consider a database management system based on Windows family of operating systems. A role-based security policy is the most common in the database management systems, but the data is stored in files, access to which is controlled by the operating system. A discretionary security policy is basic for the operating systems, but at a certain level, a mandatory security policy is realized. Thus, conjugation of three different security policies is required.

If we consider the different standards of information security in automated systems, we could see that they also imply the existence of more than one security policy.
The possibility of combining discretionary and mandatory security policies is provided in the vast amount of information security standards. According to the Orange Book, a computer system using only discretionary access control belongs to one of the division C classes, while the addition of mandatory security policy allows it to qualify for a higher class of division B. Moreover, the Orange Book implies precisely the addition of mandatory security policy with retention of discretionary security policy capabilities.

The standard approach is to find a perfect solution so that the settings of one security policy do not conflict with other security policies. To date, there exists a number of different solutions. In [1] the expansion of discretionary Take-Grant model, taking into account the mechanism of mandatory access control, is considered. The article [2] proposed a universal language that allows to describe and implement a global integrated security policy for the system, consisting of a variety of IT environments, each has its own security model and management domain. This language is implemented by the event monitor. Resolving conflicts between the security policies is realized by an explicit call of the administrator for the adoption of the priority solution. In [3] the authors proposed to extend the security matrix of discretionary security policy to the security cube that in addition to traditional subjects and objects has a third dimension - users or groups of users. This additional dimension allows organizing a mechanism of group access control while remaining within the discretionary security policy. The paper [4] is devoted to the joint implementation of the role-based and the mandatory access control concepts. Theoretical-graph approach to the security lattice of the mandatory security policy allows combining the requirements of the role-based and the mandatory models for digraph of entities of computer system. The principal possibility of creating a security policy, which includes a mandatory and a role-based access control, is shown. The paper [5] presents a model of access control for working with XML-documents. This model combines the advantages of the role-based and the mandatory access control policies. In particular, it is proposed to use not access control lists but an approach based on security labels to determine the access rights.

However, there is a fundamental problem of the ideal approach realization consisting in the absence of evidence that there is a perfect solution. Moreover, the practical realization of the simultaneous administration of multiple security policies shows that it is not always possible to make adjustments to ensure the proper functioning of the system.

This article deals with a new approach in combining multiple security policies in a single
computer system based on decision algorithms.

2 Statement of the problem and a common approach to the solution

Let us consider a system in which both discretionary and mandatory security policies are implemented. According to conventional wisdom, which was embodied in virtually all information security standards, the mandatory security policy provides a high level of information protection and dominate the discretionary security policy that provides a basic level of data protection. When there is a conflict between the two settings of security policies, two approaches are used traditionally. According to the first approach, access is denied if it is prohibited at least by one security policy. In the second case, the mandatory security policy dominates, and the decision about access permission is received based on its settings. The first approach can easily lead to the complete failure of the system, the second approach virtually shut down discretionary security policy. Furthermore, the mandatory security policy is focused on the overall system. The administrator defines the security labels of system subjects and objects that can be changed only by changing the state of the system as a whole but not in a particular access. However, exceptions are possible. For example, the administrator need to allow access of a specific subject to a specific object, contrary to the mandatory security policy. The administrator monitors the contents of the object and can guarantee no leakage of information through the subject, but cannot guarantee no leakage through other subjects with the same level of access. This permission may be implemented with the introduction of some additional security labels for each case, which leads to a significant increase and entanglement of the security lattice and, consequently, to the complexity of system administration. Another approach is to use discretionary security policy, which in one case should dominate the mandatory security policy. In other words, the superstructure can be implemented in the system, and it will decide on the dominance of a particular security policy in each case.

We formulate the statement of the problem more strictly. Let the two security policies operate in the system and take decisions based on P1 and P2 algorithms. It is necessary to implement the algorithm P for taking a decision about what kind of security policy will be used for each request for access. It should be noted that using the algorithm P is really needed only
when the decisions of $P_1$ and $P_2$ are contradictory.

Traditionally, within the security policy, a decision taken on the access request is the value from the set $\{0, 1\}$, where zero corresponds to an access denial, and one corresponds to an access permission. To make a decision about accessibility we extend the range of the algorithm values to the set $\{-m, ..., -1, 0, 1, ..., m\}$ where $m$ is the positive integer. The values of this range is called the clearance level, it is denoted by the letter $p$. Access is granted if $p > 0$. The clearance level refers to the probability of information leakage for a given access:

$$P(p) = 0.5 - \frac{p}{2m}.$$ 

The higher is the clearance level, the higher is the level of confidence in access. With this approach, algorithm $P$ takes a decision based on the clearance levels of individual security policies $p_1$ and $p_2$.

Consider a system in which security policy $P_1$ dominates security policy $P_2$. We introduce the dominance coefficient $r$, showing how many times the decision taken by $P_1$ is more important than the decision taken by $P_2$. In this case, the final decision can be calculated as a weighted sum of the decisions of the two security policies:

$$p = \frac{r}{r + 1}p_1 + \frac{1}{r + 1}p_2.$$ 

Equivalence of the security policies is achieved with $r = 1$. Access is granted if $p > 0$. Note that $p$ is not necessarily an integer: $p \in [-m, m]$.

### 3 The combination of the mandatory and discretionary security policies

We consider the most common case of combining the mandatory and discretionary security policies. For the mandatory security policy, we restrict ourselves to the simplest case of a linear security lattice with $l$ levels of security. In this case, the clearance level can be found as the difference between the level of confidence of the subject $C(S)$ and the level of secrecy of the object $C(O)$:

$$p_1 = (C(S) - C(O)) \frac{m}{l}.$$ 

For the discretionary security policy, the clearance level can be arbitrarily set by the administrator for each access. If the administrator wants to set a top priority for the access, he appoints
\[ p_2 = m. \] Therefore, only the case of appointment of the default clearance level is consider. We assume that the total number of possible types of access equal to \( M \). Let the subject requests access to the object for several types of access. In case of access denial, we assume that

\[ p_2 = -k \frac{m}{M}, \]

where \( k \) is the number of denied accesses from the list of requested accesses. If access is granted, then let

\[ p_2 = h \frac{m}{M}, \]

where \( h \) is the number of granted but not requested types of access.

**Example 1.** Consider the model example of such a system. Suppose that the mandatory security policy is based on a linear security lattice with four levels \( L = \{0, 1, 2, 3\} \). For discretionary security policy, we assume that four types of access are defined: \( R = \{r, w, a, f\} \). Suppose that at some point in time a request for access \((s, o, r)\) is received, which has the corresponding cell \( M[s, o] = \{r, w, a\} \) in the access matrix, the level of secrecy of the object is \( C(o) = 2 \), the level of confidence of the subject is \( C(s) = 1 \). In this case, \( p_1 = C(s) - C(o) = -1 \), \( p_2 = 2 \). When security policies are equal, then \( p = (p_1 + p_2)/2 = 1.5 > 0 \), i.e. access is granted despite the prohibition of the mandatory security policy. If we increase the priority of the mandatory security policy 3 times, then:

\[ p = \frac{3}{4} \cdot (-1) + \frac{1}{4} \cdot 2 = -\frac{1}{4} < 0. \]

In this case, access is denied.

### 4 Nonlinear security lattice

When combining the mandatory and the discretionary security policies, we considered the simplest case of a linear security lattice with \( L \) levels of security. However, in real systems, the mandatory security policy can be set by nonlinear security lattice, i.e. a variety of security labels will be partially ordered. With this approach to the implementation of security policies, the level of confidence of the subject \( C(S) \) and the level of secrecy of the object \( C(O) \) may be incomparable. In this case, it is impossible to define the clearance level as the difference between the level of confidence of the subject \( C(S) \) and the level of secrecy of the object \( C(O) \).
This means that we need a different approach to determining the clearance level given by the mandatory security policy.

The classical model of mandatory security policy defines an operator that specifies for each pair of elements \( l_1 \) and \( l_2 \) from the basic set of security levels \( L \) a single element of the least upper bound:

\[
\text{sup}(l_1, l_2) = l \iff (l_1, l_2 \leq l) \land (\forall l' \in L : (l' \leq l) \Rightarrow (l' \leq l_1 \lor l' \leq l_2)).
\]

We introduce the operator \( \text{dif}(l_1, \text{sup}(l_1, l_2)) \) showing the ”distance” from the security level \( l_1 \) to the least upper bound of the security levels \( l_1, l_2 \):

\[
\text{dif}(l_1, \text{sup}(l_1, l_2)) = \text{sup}(l_1, l_2) - l_1.
\]

This approach is possible because the lattice elements \( l_1 \) and \( \text{sup}(l_1, l_2) \) are by definition always comparable. This operator allows determining the number of levels of the security lattice from element \( l_1 \) to \( \text{sup}(l_1, l_2) \). Note that this value is always non-negative.

We determine the clearance level \( p_1 \) for incomparable in the lattice level of confidence of the subject \( C(S) \) and the level of secrecy of the object \( C(O) \) as a negative modulus of the difference of distances between the levels \( C(S) \) and \( C(O) \) and the least upper bound \( \text{sup}(C(S), C(O)) \):

\[
p_1 = -|\text{dif}(C(S), \text{sup}(C(S), C(O))) - \text{dif}(C(O), \text{sup}(C(S), C(O))))| \cdot \frac{m}{L}.
\]

If the level of confidence of the subject \( C(S) \) and the level of secrecy of the object \( C(O) \) are incomparable, access is not granted, so the value should be negative. In this case, because the difference of ”distances” between the levels of the lattice is defined, the absolute value of the difference is calculated.

**Example 2.** Consider the model example of such a system. Suppose that the mandatory security policy is based on a nonlinear security lattice with eight levels \( L = 0, 1a, 1b, 1c, 2ab, 2c, 3, 4 \). In addition, \( 0 \leq 1a, 0 \leq 1b, 0 \leq 1c \) and levels \( 1a, 1b, 1c \) are incomparable, \( 1a \leq 2ab, 1b \leq 2ab, 1c \leq 2c \) and levels \( 2ab, 2c \) are incomparable. Also \( 2ab \leq 3, 2c \leq 3, 3 \leq 4 \). For discretionary security policy, we assume that four types of access are defined: \( R = \{r, w, a, f\} \). Suppose that at some point in time a request for access \((s, o, r)\) is received, which has the corresponding cell \( M[s, o] = \{r, w, a\} \) in the access matrix, the level of secrecy of the object is \( C(o) = 1c \), the level of confidence of the subject is \( C(s) = 2ab \). In this case, \( \text{sup}(C(s), C(o)) = 3, \text{dif}(C(s), \text{sup}(C(s), C(o))) = 1, \text{dif}(C(o), \text{sup}(C(s), C(o))) = 2 \). Hence \( p_1 = -1 \times |1 - 2| = -1 \times |1 - 2| = -1 \times 1 = -1 \).
−1 and \( p_2 = 2 \). When security policies are equal, then \( p = p_1 + p_2 = 1 > 0 \), i.e. access is granted despite the prohibition of the mandatory security policy. If we increase the priority of the mandatory security policy 3 times, then:

\[
p = \frac{3}{4} \cdot (-1) + \frac{1}{4} \cdot 2 = -\frac{1}{4} < 0.
\]

In this case, access is denied.

5 Application of the analytic hierarchy process

Two mandatory and two discretionary security policies often operate in the same system: one is related to confidentiality, the other is related to integrity. In this case, to calculate the clearance level it is more convenient to use the analytic hierarchy process with decision tree shown in Figure 1.

![Decision Tree](image)

Figure 1: The decision tree for calculating the clearance level \( p \)

It is necessary to fill three pairwise comparison matrices: one is for the level of criteria and two are for the level of alternatives. Suppose, as before, \( r (r > 0) \) is the dominance coefficient, showing how many times the decision taken by the mandatory security policy (MSP) is more important than the decision of the discretionary security policy (DSP). Preference for the confidentiality policy over the integrity policy is evaluated by two similar parameters: \( r_1 (r_1 > 0) \) for the discretionary model, \( r_2 (r_2 > 0) \) for the mandatory model. Then the pairwise comparison matrices are given in table:

|   | DSP   | MSP   | DSP  | int.  | conf. | MSP  | int.  | conf. |
|---|-------|-------|------|-------|-------|------|-------|-------|
| DSP| 1     | 1/r   | int. | 1     | 1/r_1 |     | int.  | 1     |
| MSP| r     | 1     | conf.| r_1   | 1     | conf.| r_2   | 1     |
The ideal consistency of these matrices comes from the fact that for two-dimensional reciprocal matrix $M$ there always is the condition: $\forall i, j, k$ comes the equation $[M]_{ij} = [M]_{ik} \times [M]_{kj}$.

In this case, the relative weight coefficients are determined by the normalized columns (for example, the first) of all three pairwise comparison matrices, and the formulas for calculating the relative priorities of the integrity policy and the confidentiality policy have the following forms:

$R^{\text{int}} = \frac{1}{1 + r_1} \cdot \frac{1}{1 + r} + \frac{1}{1 + r_2} \cdot \frac{r}{1 + r}$, $R^{\text{conf}} = \frac{r_1}{1 + r_1} \cdot \frac{1}{1 + r} + \frac{r_2}{1 + r_2} \cdot \frac{r}{1 + r} = 1 - R^{\text{int}}$.

The final decision on granting the access can now be calculated according to the formulas:

$p = R^{\text{int}} \cdot p^{\text{int}} + R^{\text{conf}} \cdot p^{\text{conf}}$.

$p^{\text{int}} = \frac{1}{1 + r} \cdot p^{\text{int}}_{\text{DSP}} + \frac{1}{1 + r} \cdot p^{\text{int}}_{\text{MSP}}$, $p^{\text{conf}} = \frac{1}{1 + r} \cdot p^{\text{conf}}_{\text{DSP}} + \frac{1}{1 + r} \cdot p^{\text{conf}}_{\text{MSP}}$.

where the superscript denotes the confidentiality policy or the integrity policy, and the subscript denotes the discretionary access control or the mandatory access control. Analyzing the given formulas, we can draw the following conclusions:

1. Since $R^{\text{int}}$ and $R^{\text{conf}}$ belong to the range $(0, 1)$, then using the analytic hierarchy process in case $p^{\text{int}}$ and $p^{\text{conf}}$ have the same sign will not change the decision of granting the access.

2. If $r_1 \geq 1$ and $r_2 \geq 1$, then $R^{\text{int}} \leq R^{\text{conf}}$. If $r_1 < 1$ and $r_2 < 1$, then $R^{\text{int}} > R^{\text{conf}}$. In both cases, the analytic hierarchy process formulas can be replaced by the formula

$p = \frac{1}{1 + r'} \cdot p^{\text{int}} + \frac{r'}{1 + r'} \cdot p^{\text{conf}}$,

where $r'$ is the parameter characterizing how many times the decision taken by the confidentiality policy is more important than the integrity policy decision.

3. Application of the analytic hierarchy process gives the most interesting results in case $p^{\text{conf}}$ and $p^{\text{int}}$ have different signs and $(r_1 > 1) \land (r_2 < 1)) \lor ((r_1 < 1) \land (r_2 > 1))$.

Access will be granted and the integrity policy will receive the priority.

Consider the other embodiment of a decision tree. Suppose the system still has two pairs of security policies. Now we consider the decision tree of the analytic hierarchy process shown in Figure 2.

Let the decision taken by the confidentiality policy $x$ times more important than the integrity policy decision. Preference for the mandatory access control model over the discretionary access control model is evaluated by two parameters: $x_1$ for the integrity policy, $x_2$ for the confidentiality policy. Then the pairwise comparison matrices are given in table:
Figure 2: The decision tree for calculating the clearance level $f$

The formulas for calculating the relative priorities of the integrity policy and the confidentiality policy have the following forms:

$$X_{DSP} = \frac{1}{1 + x_1} \cdot \frac{1}{1 + x} + \frac{1}{1 + x_2} \cdot x \cdot \frac{1}{1 + x}, \quad X_{MSP} = \frac{x_1}{1 + x_1} \cdot \frac{1}{1 + x} + \frac{x_2}{1 + x_2} \cdot \frac{x}{1 + x} = 1 - X_{DSP}.$$  

The final decision on granting the access can now be calculated according to the formulas:

$$f = X_{DSP} \cdot f_{DSP} + X_{MSP} \cdot f_{MSP},$$

$$f_{DSP} = \frac{1}{1 + x} p_{DSP}^{\text{int}} + \frac{x}{1 + x} p_{DSP}^{\text{conf}}, \quad f_{MSP} = \frac{1}{1 + x} p_{MSP}^{\text{int}} + \frac{x}{1 + x} p_{MSP}^{\text{conf}},$$

where the superscript denotes the confidentiality policy or the integrity policy, and the subscript denotes the discretionary access control or the mandatory access control. It is not difficult to prove the following statement.

**Statement 1.** If $r = x_1 = x_2$ and $r_1 = r_2 = x$, then $p = f$.

Thus, in case of equality of priorities in the context of the selected access control model and in the context of confidentiality and integrity policies, both approaches to the construction of decision tree of the analytic hierarchy process lead to the same clearance level.

6 Conclusion

The proposed approach to the construction of a joint security policy has several advantages compared to the traditional requirement of simultaneous access permission by all active security
policies. The presence of the weight coefficients allows the administrator to configure the degree of influence of various security rules flexibly. Using two different types of security policies make sense if they cover the different channels of information leakage. Therefore, the choice of the weight coefficients in the decision algorithm must be based on analysis of the probability of different attacks.

It should be noted that the need for a decision on the dominance of one security policy over another arises only in case of conflict of permissions for the same access request. On the one hand, in systems, which allow a consistent security administration, such conflicts do not arise. On the other hand, if the two security policies never have a conflict, then one of the security policies can be disabled without affecting the security of the system.

The proposed approach can be applied in the design of the additional information security systems, as well as in software systems with their own security subsystem.

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