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Comprehensive life cycle support for access rules in information systems: the CEOSIS project

Stefanie Rinderle-Ma* and Manfred Reichert

Institute of Databases and Information Systems, Ulm University, Ulm, Germany

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The definition and management of access rules (e.g. to control access to business documents and business functions) is a fundamental task in any enterprise information system (EIS). While there exists considerable work on how to specify and represent access rules, only little research has been spent on access rule changes. Examples include the evolution of organisational models with need for subsequent adaptation of related access rules as well as direct access rule modifications (e.g. to state a previously defined rule more precisely). This paper presents a comprehensive change framework for the controlled evolution of role-based access rules in EIS. First, we consider changes of organisational models and elaborate how they affect existing access rules. Second, we define change operations which enable direct adaptations of access rules. In the latter context, we define the formal semantics of access rule changes based on operator trees. Particularly, this enables their unambiguous application, i.e. we can precisely determine which effects are caused by respective rule changes. This is important, for example, to be able to efficiently and correctly adapt user worklists in process-aware information systems. Altogether this paper contributes to comprehensive life cycle support for access rules in (adaptive) EIS.

Keywords: enterprise information system; change; access control; access rule life cycle

1. Introduction

A fundamental aspect in the design of any enterprise information system (EIS) concerns *access control*, i.e. granting certain rights to specific users (e.g. the right to access a certain business document for a restricted group of users). There exists a multitude of models for defining access control mechanisms, e.g. GRANT/REVOKE statements in Database Management Systems or Role Based Access Control (RBAC) in process-aware information systems (PAIS). Usually such models comprise a set of *access rules* which are defined based on an organisational model capturing organisational entities as well as their relationships. Access rules then control which rights shall be granted to which users. In the context of PAIS, for example, access rules specify which tasks shall be offered as *work items* to which users in their worklists during the execution of a particular process instance.

*Corresponding author. Email: stefanie.rinderle@uni-ulm.de

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1.1. Problem statement

Due to changes of organisational structures or evolving security policies, access rules have to be frequently adapted. This, in turn, must be effectively handled by the EIS in order to be able to cope with these organisational or policy changes in a quick, flexible, and secure way. So far, only little research has been spent on the evolution of access rules and the resulting effects on the underlying EIS. In particular, access rules might be subject to the following kinds of changes:

- *Organizational change:* Access rule adaptations often become necessary when changing an organization and its organisational model respectively. For instance, assume that access control within a PAIS (i.e. the assignment of work items to user worklists) is based on the simple access rules depicted in Figure 1. Assume further that these rules are based on organisational model OM. To streamline the organization, units `LoanM` and `LoanH` are merged into organisational unit `LoanH`′, and role `Clerk` is deleted from OM resulting in organisational model OM′. Obviously, access rule AR1 is not affected by this organisational change, whereas access rules AR2 and AR3 now refer to entities no longer being present in OM′. If the affected access rules were not adapted this would threaten robustness or security constraints of the PAIS. Worst case, for access rules which cannot be resolved properly, the associated task is offered to unauthorised users (e.g. process administrators, actors of preceding tasks, and so forth).
- *Direct access rule changes:* Generally, it must be also possible to directly adapt access rules within EIS (cf. Figure 2). This will become necessary, for example, if access rules are not specified precisely enough. Either the access rule covers a too broad range of users (i.e. only a subset of the users qualifying for the access rules actually work on the associated work items) or it is too narrow (e.g. the related task is always delegated to substitutes). In both cases, the specified access rules do not reflect the real situation. As a consequence, task assignment

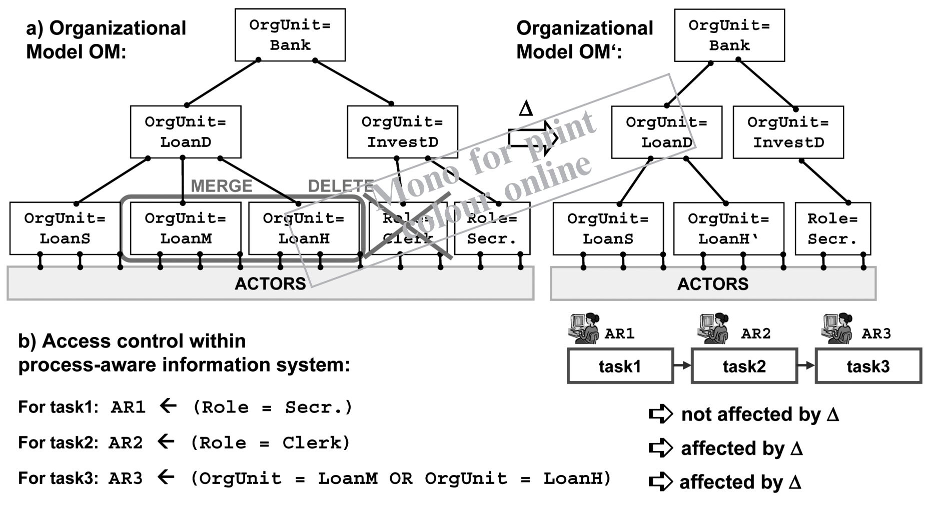


Figure 1. Organizational changes affecting access rules.

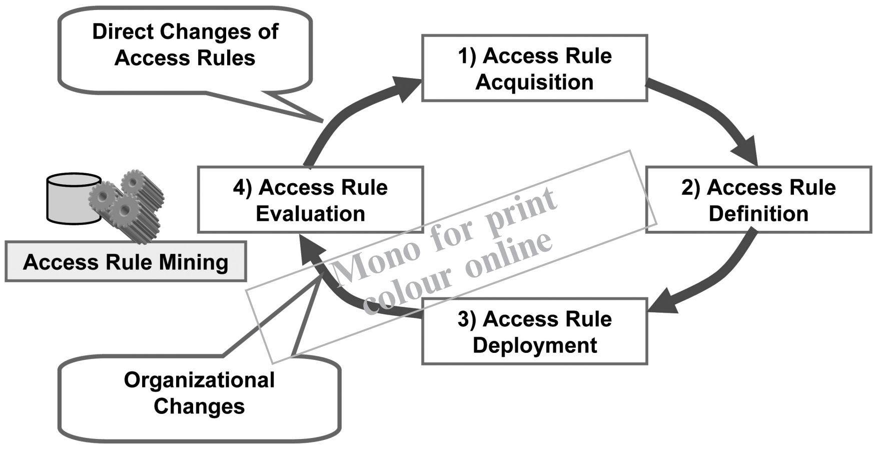

Direct Changes of Access Rules
1) Access Rule Acquisition
2) Access Rule Definition
3) Access Rule Deployment
4) Access Rule Evaluation
Access Rule Mining
Organizational Changes

Figure 2. Access rule life cycle.

is handled outside the system and thus might be not properly documented. Furthermore, manual task assignment or adaptation can be complex, time-consuming and error-prone.

1.2. Contribution

In this paper we present our CEOSIS[1] framework for evolving access rules within EIS in a controlled and secure way. We first consider changes of organisational models and evaluate how they affect existing access rules. Then we cope with issues related to direct changes of access rules. As discussed in Section 1.1 both scenarios are highly relevant in practice and should therefore be adequately supported by an EIS.

There are two basic requirements for changes of access rules in EIS. First of all, they must be conducted in a *correct* way, i.e. they must not violate any structural constraints set out by the formalism for access rule specification. To fulfil this requirement we base the definition of access rule changes on an operator tree representation and equip respective operators with formal pre- and post-conditions which ensure their correct application. Second, the *formal semantics* of access rule changes must be specified. Only this guarantees their unambiguous application and supports the precise analysis of change effects. To achieve this, we base the semantics of access rule changes on the effects they have on associated *valid actor sets*, i.e. the set of actors who qualify for the particular access rule. This also enables, for example, analysis of access rule change effects on user worklists in PAIS.

Note that this paper significantly extends the work presented in Rinderle-Ma and Reichert (2008). Besides giving more technical details and additional examples, we complement our results on the change of access rules by a comprehensive discussion on the controlled evolution of organisational models and their effects on access rules. Completely new conceptual results are provided with respect to the support of high-level change operations on access rules. Here, the interesting conclusion is that based on additional knowledge from the associated organisational model the semantics of such high-level operations can be determined without recalculating valid actor sets from scratch.

The remainder of this paper is organised as follows. Section 2 provides fundamentals on organisational models and corresponding access rules. Based on this, Section 3 deals with changes of organisational models and discusses how they might affect related access rules. Following this, we deal with direct access rule changes in EIS. Section 4 provides well-defined change operations for this and Section 5 defines their formal semantics. We extend this work in Section 6 by showing how to exploit organisational knowledge for enabling high-level access rule changes. Section 7 discusses our approach and Section 8 deals with related work. We close with a summary and outlook in Section 9.

2. Organizational models and access rules

In this section we provide information needed for the formal underpinning of our work.

2.1. Organizational models

An *organisational meta-model* defines entity and relation types based on which concrete organisational structures can be modelled, i.e. the meta-model can be seen as the schema which can be instantiated multiple times by concrete *organisational models*. The organisational meta-model OMM used in this paper is based on the *Role Based Access Control Model* (RBAC) as described by Ferraiolo *et al.* (2003). Basically, it consists of entity types `OrganizationalUnit`, `Actor`, and `Role` (cf. Figure 3). Concrete organisational units (e.g. `clinic`) can be hierarchically related to each other based on relation type `is_subordinated`. Similarly, concrete roles can be specialised by introducing corresponding sub-roles (relation type `specia-lises`). Thereby, a sub-role inherits all abilities of its superior role, but may have additional ones. Finally, actors may have roles (relation type has) and belong to organisational units (relation type `belongs_to`).

We use this well-established, but rather simple organisational meta-model OMM in this paper in order to focus on core issues related to access rule changes. However, subsequent considerations can be transferred to more complex organisational meta-models as well, e.g. capturing entities such as abilities or substitution relations – see Rinderle and Reichert (2007) for examples.

Based on OMM, concrete organisational models can be defined, i.e. a concrete organisational model OM constitutes an instance of OMM (cf. Definition 2.1). Consider the example shown in Figure 4. The depicted organisational model OM comprises the three organisational units (OU) `CallCenter, Accounting` and `Marketing`, which are hierarchically subordinated to organisational unit `WebBank`. `Role CAgent`, in turn, is specialised by roles `CAgent_p` and `CAgent_b`. Finally, actors are assigned to roles and belong to one organisational unit (e.g. actor `Black` has role `Secretary` and belongs to organisational unit `Accounting`).

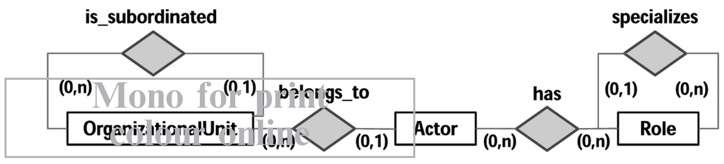


Figure 3. Organizational meta-model (in ER notation).

Definition 2.1: Organizational model. *An organisational model is a tuple OM = (Actors, Roles, OrgUnits, has, belongs_to, is_subordinated, specialises), where:*

- *Actors corresponds to the set of actors, i.e. the people performing activities or accessing data objects,*
- *Roles corresponds to the set of organisational roles,*
- *OrgUnits corresponds to the set of organisational units,*
- *has* $\subseteq$ *Roles* $\times$ *Actors captures the relations linking actors to roles,*
- *belongs_to* $\subseteq$ *OrgUnits* $\times$ *Actors captures the relations linking actors to organisational units,*
- *is_subordinated* $\subseteq$ *OrgUnits* $\times$ *OrgUnits defines the organisational hierarchy, and*
- *specialises* $\subseteq$ *Roles* $\times$ *Roles defines the role hierarchy.*

Furthermore, two notions on relations are needed in the following:
– $R(x) := \{y \in X \mid (x,y) \in R\}$ *for any relation* $R \in$ {*has, belongs_to, specialises, is_subordinated*}
– R^* *is the transitive closure of R*

Consider Figure 4. An example for generic relation R(x) is given by has(Secretary) = {Black, Moss} (with R = 'has'). The semantics of the two relations is_subordinated and specialises can be informally defined as follows: all actors belonging to an organisational unit also belong to its superordinated organisational units; e.g. actors Smith, Sharp and Moss, who all belong to organisational unit Marketing, also belong to superordinated organisational unit WebBank (cf. Figure 4). Furthermore, if an actor has a particular role she will possess all superior roles as well, e.g. actor Jones has role SeniorAcc and therefore also possesses role Accountant.

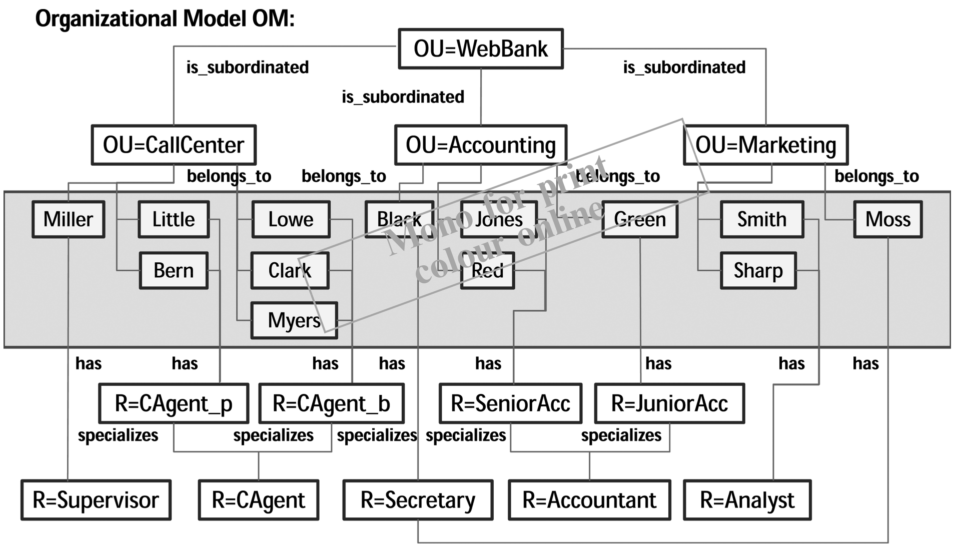


Figure 4. Organizational model for online banking scenario.

2.2. Access rules

We provide a notion for access rules and specify their formal semantics. We need this information later in order to be able to reason about access rule changes.

Definition 2.2: Elementary access rule. *Let OM = (Actors, ...) be an organisational model (cf. Definition 2.1). An elementary access rule EAR on OM is defined as follows:*

$$\begin{aligned} EAR \equiv\ & (EAR0 \longleftarrow \tau^*)^2 \mid \\ & (EAR1 \longleftarrow Role = r) \mid \\ & (EAR2 \longleftarrow OrgUnit = o) \mid \\ & (EAR3 \longleftarrow Role += r) \mid \\ & (EAR4 \longleftarrow OrgUnit += o). \end{aligned}$$

The set of all entities qualifying for an elementary access rule EAR on OM can be defined as follows:

$$QualEntities(OM, \mathrm{EAR}) = \begin{cases} r & : EAR = EAR1 \\ o & : EAR = EAR2 \\ specialises^*(r) & : EAR = EAR3 \\ is\_subordinated^*(o) & : EAR = EAR4 \\ \emptyset & : otherwise. \end{cases}$$

Formal semantics of elementary access rule EAR is defined over the set of valid actors qualifying for EAR based on OM. We denote this set as VAS(OM, EAR) $\subseteq$ Actors with

- *VAS(OM, EAR0) = $\emptyset$.*
- *VAS(OM, EAR1) = has(r), i.e. the set of actors having role r.*
- *VAS(OM, EAR2) = belongs_to(o), i.e. the set of actors belonging to unit o.*
- *VAS(OM, EAR3) = has(specialises *(r)), i.e. the set of actors having role r or a more specialised one.*
- *VAS(OM, EAR4) = has(is_subordinated *(o)), i.e. the set of actors belonging to organisational unit o or a subordinated one.*

Figure 5 gives an example for the use of access rules in a PAIS. It shows a simple business process model representing a direct marketing measurement in an online banking scenario. For each process activity, its associated access rule specifies which actors qualify for carrying out this activity based on organisational model OM (cf. Figure 4). First of all, a flyer on a new product is sent to private customers by the secretary of the marketing unit. Then, these customers are contacted by a call agent who is specialised on private customers. If a customer shows interest, an appointment for another consulting will be made by the secretary of the accounting unit. This consulting is subsequently done by a senior or junior accountant. Finally, the outcome of the marketing measurement is evaluated by an analyst.

Specifically, Figure 5 shows two elementary access rules AR2 and AR5 and the associated valid actor sets based on organisational model OM. Taking elementary access rules as basis, the general notion of access rule can be formally defined (see

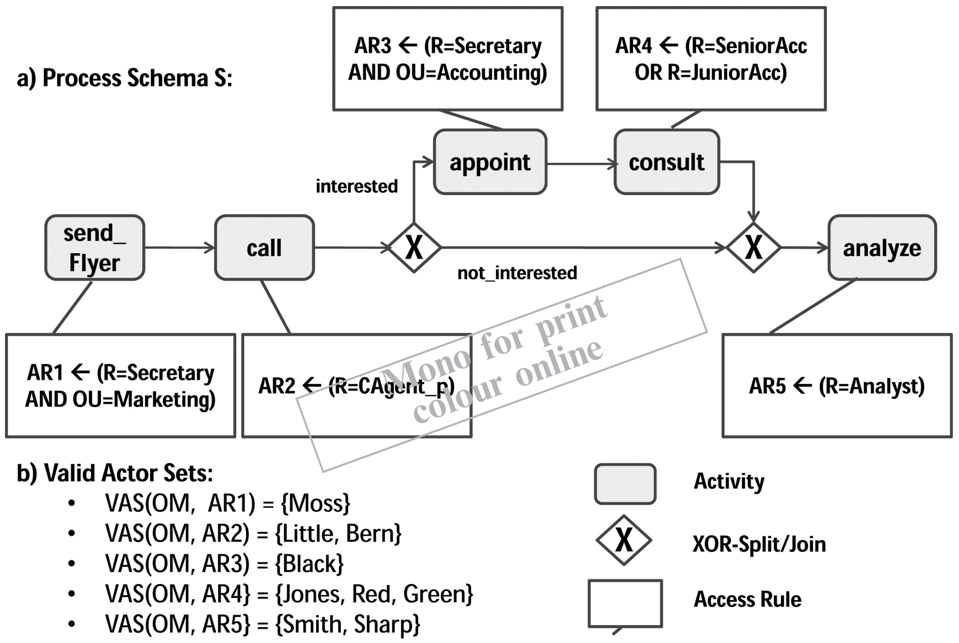


Figure 5. Direct marketing process (in BPMN notation).

below). Here, elementary access rules may be combined by logical operators AND, OR, and NOT. Note that we restrict the complexity of access rules by using negation only in the context of elementary access rules. However, this constitutes no restriction regarding the expressiveness of access rules since any negation contained within an access rule AR can be always pushed to the elementary access rules contained within AR.

Definition 2.3: Access rule. *Let OM be an organisational model. An access rule AR is defined as concatenation of other access rules by using logical operators AND, OR, and NOT. Formally:*

$$AR \equiv EAR \mid NEAR \mid CAR \mid DAR$$

where

- *EAR constitutes an elementary access rule (cf. Definition 2.2),*
- *NEAR ⟵ (NOT (EAR)) where EAR is an elementary access rule,*
- *CAR ⟵ (AR1 AND AR2) where AR1 and AR2 are access rules, and*
- *DAR ⟵ (AR1 OR AR2) where AR1 and AR2 are access rules.*

Formal semantics of elementary access rule EAR has been already given in Definition 2.2, the one of NEAR, CAR and DAR can be defined as follows:

- *VAS(OM,NEAR) = Actors \ VAS(OM,AR) corresponds to the set of actors not qualifying for access rule AR,*
- *VAS(OM,CAR) = VAS(OM,AR1) ∩ VAS(OM,AR2) corresponds to the set of actors qualifying for access rules AR1 and AR2,*

- *VAS(OM,DAR) = VAS(OM,AR1) ∪ VAS(OM,AR2) corresponds to the set of actors qualifying for access rules AR1 or AR2*

$\mathcal{AR}^{OM}$*denotes the set of all access rules over OM.*

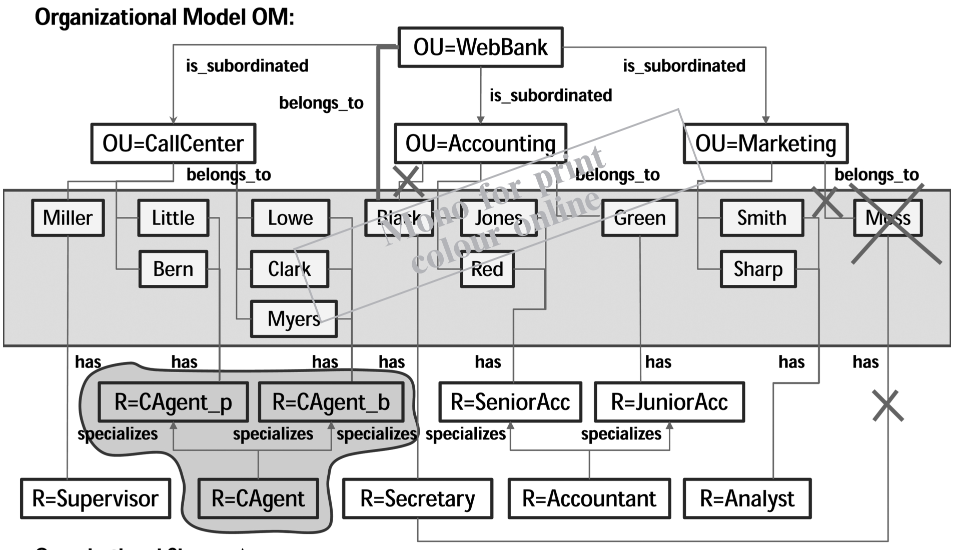
Figure 5 depicts non-elementary access rules `AR1`, `AR3`, and `AR4`. Regarding `AR1`, for example, valid actor set `VAS(OM, AR1)` corresponds to intersection of `VAS(OM, R = Secretary) ={ Black,Moss}` and `VAS(OM, OU = Marketing)= {Smith,Sharp,Moss}` .

3. Organizational changes and their effects on access rules

In this section we present a framework for modifying organisational models while controlling the effects on access rules at the same time.

3.1. On changing organisational models

Assume that our online bank has to streamline its organization due to a financial crisis (cf. Figures 4 and 5). Necessary actions are depicted in Figure 6. Due to the reorganization, there is no longer a distinction between call agents serving private customers and those dealing with business customers, i.e. these two roles are now merged into role `CAgent`. Furthermore, only one secretary for the whole `WebBank` remains, i.e. one secretary is laid off and role `Secretary` is reassigned to organisational unit `WebBank`. The challenge now is to realise these changes for the given organisational model, which is implemented and used by one or more EIS.



Organizational Change Δ =
(DeleteRelation(OM, (Secretary, Moss)), DeleteRelation(OM, Marketing, Moss)),
DeleteRelation(OM, (CAgent, CAgent_b),
ReAssignRelation(OM, (Accounting, Black), Black, WebBank) ,
DeleteRelation(OM, (CAgent, CAgent_p)), DeleteEntity(OM, Moss),
DeleteEntity(OM, CAgent), JoinEntities(OM, CAgent_p, CAgent_b, CAgent))

Figure 6. Changes after streamlining the organization.

In order to be able to express all relevant kinds of changes of an organisational model *OM*, CEOSIS provides a complete set of basic change operations[3] with well-defined semantics, e.g. for creating or deleting organisational entities as well as the relations between them. For each change operation there are formal pre- and postconditions, which enables preservation of the correctness properties of organisational model *OM* when applying the operation(s) to it (assuming that *OM* was a correct model before). In addition to these basic change operations, CEOSIS provides common high-level operations in order to facilitate change definition and to capture more semantics about model changes. As example of such a high-level operation consider the join of two entities (e.g. a fusion of two organisational units as depicted in Figure 6). Table 1 depicts selected basic as well as high-level operations for changing organisational models in CEOSIS.

At the bottom of Figure 6 the change operations needed to realise the desired streamlining actions (i.e. adaptations of the given organisational model of our running example) are depicted. For instance, there is one operation which reassigns actor `Black` from organisational unit `Accounting` to organisational unit `WebBank`. Merging the organisational roles `CAgent_p` and `CAgent_b`, in turn, is accomplished by first deleting superordinated role `CAgent` and subsequently joining roles `CAgent_p` and `CAgent_b` into new role `CAgent`. (There exist other options to realise this merger which are omitted here.) Figure 7 depicts the organisational model OM' that results after implementing the desired reorganization.

3.2. *Effects on access rules*

Using the change operations presented in Table 1, we are able to modify organisational models while preserving certain model properties. However, this does not guarantee any control of possible side-effects of such model changes on, for

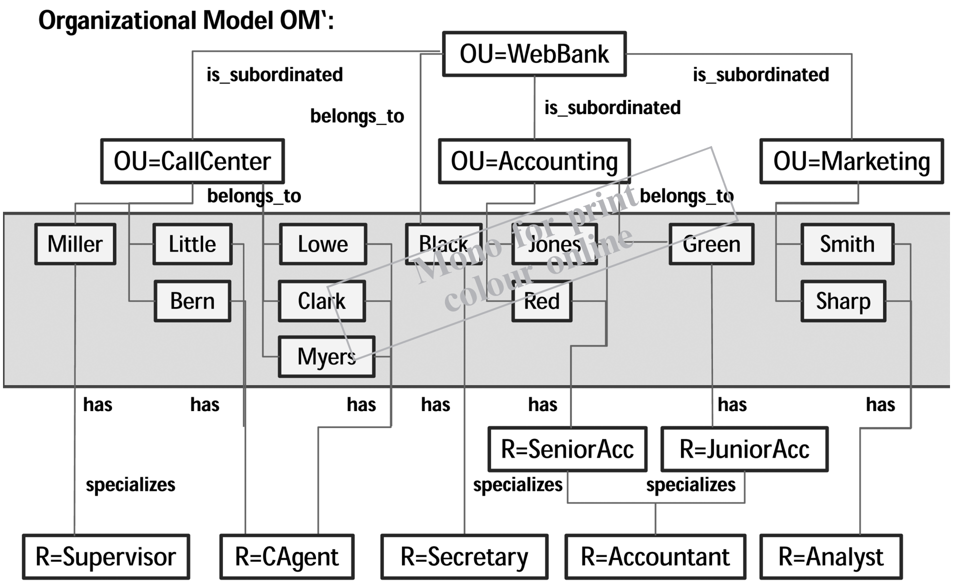


Figure 7. Modified organisational model.

Table 1. Selection of change operations on organizational models (Rinderle and Reichert 2007).

Let Entities := Actors ∪ Roles ∪ OrgUnits and Relations := $\{(e_1, e_2) \mid e_1, e_2 \in \textit{Entities} \wedge (e_1, e_2) \in \{\textit{has, belongs\_to, its\_subordinated, specialises}\}\}$	
`CreateEntity`: $\mathcal{OM} \times \textit{Identifier} \mapsto \mathcal{OM}$ with `CreateEntitiy(OM, eId)` $=$ `OM′`	
Preconditions:	• eId ∉ Entities
Postconditions:	• Entities′ = Entities ∪ {eId}
	• Relations′ = Relations
`DeleteEntity`: $\mathcal{OM} \times \mathcal{E} \mapsto \mathcal{OM}$ with `DeleteEntity(OM, e)` $=$ `OM′`	
Preconditions:	• e ∈ Entities
	• ∄ rel = (e1, e2) ∈ Relations with e1 = e ∨ e2 = e
Postconditions:	• Entities′ = Entities \ {e}
	• Relations′ = Relations
`CreateRelation`: $\mathcal{OM} \times \mathcal{E} \times \mathcal{E} \mapsto \mathcal{OM}$ with `CreateRelation(OM, e1, e2)` $=$ `OM′)`	
Preconditions:	• e1, e2 ∈ Entities
	• (e1, e2) ∉ Relations
	• e2 ∉ R^* $(e1)$ with R ∈ (specialises, is_subordinated}
Postconditions:	• Entities′ = Entities
	• Relations′ = Relations ∪ {(e1, e2)}
`DeleteRelation`: $\mathcal{OM} \times \mathcal{R}_{\mathcal{E}} \mapsto \mathcal{OM}$ with `DeleteRelation(OM, relation)` $=$ `OM′`	
Preconditions:	• relation ∈ Relations
Postconditions:	• Entities′ = Entities
	• Relations′ = Relations \ {relation}
`ReAssignRelaton`: $\mathcal{OM} \times \mathcal{R}_{\mathcal{E}} \times \mathcal{E} \times \mathcal{E} \mapsto \mathcal{OM}$ with `ReAssignRelation(OM, r, e, eNew)` $=$ `OM′`	
Preconditions:	• r = (e1, e2) ∈ Relations
	• e = e1 ∨ e = e2 (w.l.o.g., we assume e = e1 in the following)
	• eNew ∈ Entities
	• e ∈ Actors ⇒ e2 ∉ Actors
	• e ∈ Roels ⇒ e2 ∉ OrgUnits
	• e ∈ OrgUnits ⇒ e2 ∉ Roles
	• e2 ∉ R^* $(e1)$ with R ∈ {specialises, is_subordinated}
Postconditions:	• Relations′ = Relations ∪ {(e, eNew)} \ {(e1, e2))}
Postconditions:	• Entities′ = Entities
`JoinEntities`: $\mathcal{OM} \times \mathcal{E} \times \mathcal{E} \times \textit{Identifiers} \mapsto \mathcal{OM}$ with `JoinEntities(OM, e1, e2, nId)` $=$ `OM′`	
Preconditions:	• e1, e2 ∈ Entities
	• nId ∉ Entities
	• e1, e2 ∉ Actors
Postconditions:	• CreateEntity(OM, eNew) := eNew
	• ∀ (e1, e1) ∈ Relations: ReassignRelation(OM, (e, e1), e1, eNew)
	• ∀ (e1, e2) ∈ Relations: ReassignRelation(OM, (e, e2), e2, eNew)
	• ∀ (e1, e) ∈ Relations: ReassignRelation(OM, (e1, e), e1, eNew)
	• ∀ (e, e2) ∈ Relations: ReassignRelation(OM, (e, e1), e2, eNew)
	• DeleteEntity(OM, e1)
	• DeleteEntity(OM, e2)

example, access rules. Consider again our process example in Figure 8. After changing the underlying organisational model, for example, access rule `AR2` cannot be resolved anymore. The reason is that role `CAgent_p`, to which access rule `AR2` refers, is no longer present in OM′. We denote this problem as *dangling reference*.

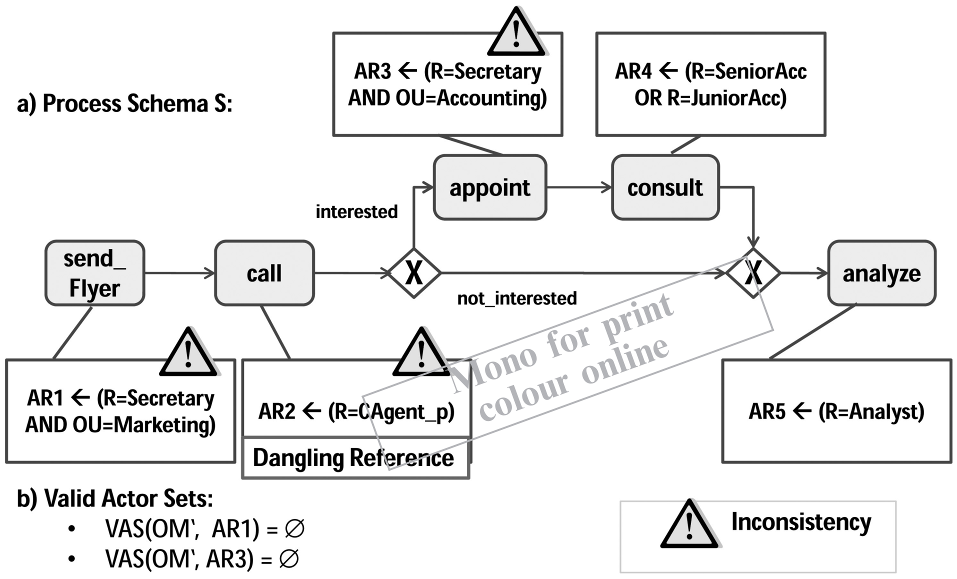


Figure 8. Effects on direct marketing process.

Another problem is present for access rules AR1 and AR3. Even though they do not contain dangling references (and thus are resolvable over OM′), their valid actor sets become empty on OM′. This might raise severe problems when access rules are resolved and the corresponding tasks shall be assigned to the worklists of qualifying actors.[4] If the valid actor set of an access rule becomes empty for a process activity, either the process will be blocked at this point or the PAIS will assign the corresponding work item to other, potentially non-authorised users (e.g. the system administrator). Particularly in the context of sensitive data such false task assignments constitute a severe security threat.

Consequently, the challenge is to control the side-effects of organisational changes on access rules. Specifically, access rules have to be checked for dangling references and empty valid actor sets. In the following we give formal notions for both problems. Based on these notions, we provide a criterion which allows us to decide whether or not an access rule AR is *valid* with respect to a given organisational model OM. We call an access rule valid on OM if the following two conditions hold:

(1) AR does not contain *dangling references*, i.e. it does not refer to entities not present in OM. Formally:

$$\mathit{DanglingRef}(OM, \mathrm{AR}) = \begin{cases} \mathrm{FALSE} & \mathit{if}\ \forall\, \mathrm{EAR} \in \mathrm{AR}: \\ & \mathit{QualEntities}(OM, \mathrm{EAR}) \neq \emptyset \\ \mathrm{TRUE} & \mathit{otherwise} \end{cases}$$

where the notion EAR ∈ AR expresses that elementary access rule EAR is contained within access rule AR.

(2) AR is resolvable, i.e. the set of valid actors VAS(OM, AR) does not become empty. We consider this second constraint as an important property of any

access control component in order to ensure that objects remain accessible or tasks remain doable. Formally:

$$Resolv(OM, \mathrm{AR}) = \begin{cases} \mathrm{TRUE} & \textit{if } VAS(\mathrm{OM}, \mathrm{AR}) \neq \emptyset \\ \mathrm{FALSE} & \textit{otherwise.} \end{cases}$$

Definition 3.1: Valid access rule. *Let OM = (Entities, Relations) be an organisational model and let AR be an access rule on OM. Then, AR is valid regarding OM if and only if there are no dangling references within the elementary access rules contained in AR and AR is resolvable over the set Entities. Formally:*

$$\begin{aligned} Valid(OM, \texttt{AR}) = \texttt{TRUE} :\Leftrightarrow (&DanglingRef(OM, \texttt{AR}) \\ &= \texttt{FALSE} \wedge Resolv(OM, \texttt{AR}) = \texttt{TRUE}). \end{aligned}$$

3.3. Adapting access rules after organisational changes

Determining potential problems in connection with organisational changes (e.g. empty valid actor sets) is a first important step. Another one is to cope with identified problems in an adequate and efficient way. CEOSIS offers a number of sophisticated adaptation policies in this context. In the following, we exemplarily provide one of these policies, which enables adaptations of access rules when applying the high-level change operation `JoinEntities` (cf. Table 1) to an organisational model. Note that adaptation policies are applied in a semi-automatic manner, i.e. the system only recommends adaptations of the access rules affected by an organisational change, but the final decision has to be made by the user.

Adaptation policy (avoiding dangling references). *Let OM = (Entities, Relations) be an organisational model and let* `AR` *be a valid access rule on OM. Let further* $\Delta_{\mathrm{op}} = \texttt{JoinEntities(OM, ...)}$ *be a high-level change operation which transforms OM into another organisational model OM'. Then, when applying adaptation rule δ_{AR} (see below) to* `AR` *this rule can be transformed into an access rule* `AR'`*on OM' which does not contain dangling references and which is semantically 'close' to* `AR`*. For Δ_{op} the corresponding adaptation rule δ_{AR} turns out as follows:*

$$\Delta_{\mathrm{op}} = \texttt{JoinEntities}(\texttt{OM}, e_1, e_2, newEnt) \Rightarrow$$

$$\delta_{AR} : \forall \texttt{EAR} \in \texttt{AR} \textit{ with } \texttt{EAR} \textit{ refers to } e_i \ (i = 1, 2) : \textit{substitute } e_i \textit{ by } newEnt.$$

Consider again access rule `AR2` in Figure 8, which contains a dangling reference to `CAgent_p` based on OM′. This situation has occurred after joining `CAgent_p` and `CAgent_b`. Thus, when applying the above adaptation policy, the reference to `CAgent_p` is substituted by a reference to the newly introduced entity `CAgent`. Figure 9 depicts the result.

Even if the problem of dangling references is satisfactorily solved we still might be confronted with non-resolvable access rules when changing an organisational model. This, in turn, could cause runtime errors or at least runtime delays (e.g. if activities cannot be processed immediately due to the absence of qualifying actors). Worst case severe security problems can result (e.g. in case a manual activity without

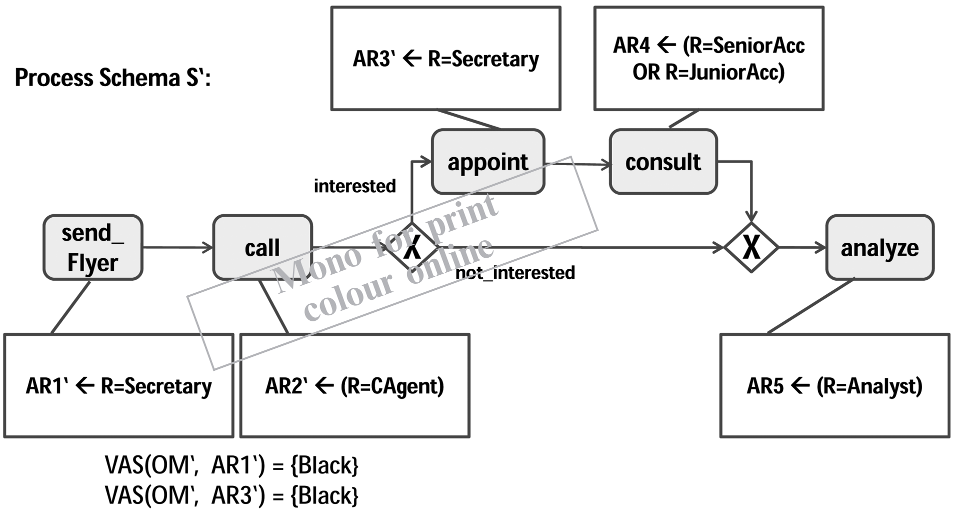


Figure 9. Adapted direct marketing process.

qualifying actors is offered to the system or process administrator as in some commercial workflow systems).

Let OM be an organisational model which is transformed into another organisational model OM' by change Δ. Furthermore, let AR be an access rule on OM. First of all, we illustrate, at an abstract level, how the valid actor set of an access rule AR based on OM may change when migrating this rule to the new model version OM'. Figure 10 depicts possible relations between the valid actor set of AR on OM (i.e. VAS(OM,AR)) and the valid actor set of AR on OM' (i.e. VAS(OM′,AR)): in Figure 10a the migration of AR from OM to OM' does not influence the valid actor set, i.e. the set of valid actors remains the same. Consequently, AR is still resolvable over OM' in this case, and does not require any adaptation of worklists or lists of qualified actors afterwards. Figure 10b depicts the scenario in which the valid actor set is expanded when migrating AR to OM'. In practice this might require, for example, an update of user worklists by additionally inserting the associated work items into the worklists of newly qualified actors from the difference set VAS(OM′, AR) \ VAS(OM, AR). By contrast, the valid actor set could be also reduced due to a model change as depicted in Figure 10c. Consequently, for all actors no longer qualified for accessing the associated object or task (i.e. VAS(OM, AR) \ VAS(OM′, AR)) the associated access privileges have to be adapted accordingly. Note that for the scenario depicted in Figure 10c, the valid actor set of AR on OM' might become empty; AR then would no longer resolvable on OM'.

Another scenario is depicted in Figure 10d. Here, neither VAS(OM,AR) is a subset of VAS(OM′,AR) nor vice versa. Generally, we can further distinguish between sub-cases d1 and d2. For sub-case d1 there still exist actors contained in both valid actor sets, i.e. intersection of VAS(OM,AR) and VAS(OM′,AR) is non-empty. For such a case, we first have to withdraw the privileges associated with AR for all actors contained in VAS(OM,AR) \ VAS(OM′,AR). Second, we have to newly assign these privileges to the actors contained in VAS(OM′,AR) \ VAS(OM,AR). Finally, if VAS(OM,AR) and VAS(OM′,AR) are disjoint as in the context of sub-case

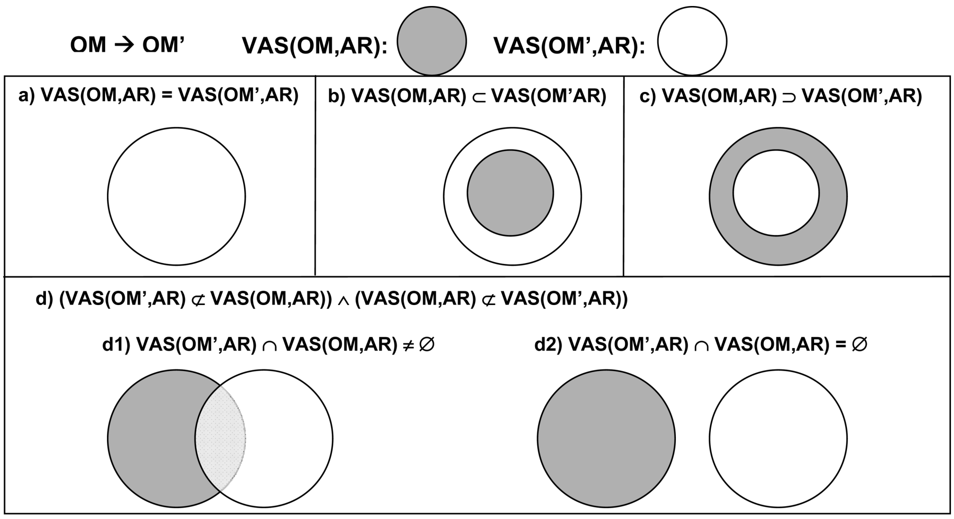

OM → OM'
VAS(OM,AR):
VAS(OM',AR):
a) VAS(OM,AR) = VAS(OM',AR)
b) VAS(OM,AR) ⊂ VAS(OM'AR)
c) VAS(OM,AR) ⊃ VAS(OM',AR)
d) (VAS(OM',AR) ⊄ VAS(OM,AR)) ∧ (VAS(OM,AR) ⊄ VAS(OM',AR))
d1) VAS(OM',AR) ∩ VAS(OM,AR) ≠ ∅
d2) VAS(OM',AR) ∩ VAS(OM,AR) = ∅

Figure 10. Changing organisational models and migrating access rules.

d2 the privileges associated with AR have to be removed for all actors from VAS(OM,AR) and be added for those belonging to VAS(OM′,AR).

Knowing which of these cases applies in a given change scenario is helpful in order to conduct the necessary adaptations of qualified actor lists or work lists when migrating an access rule to the changed organisational model. For this, Rinderle and Reichert (2007) provided a comprehensive framework for basic as well as high-level change operations on organisational models. Regarding our online banking scenario (cf. Figure 9), users would be supported by making them aware of possibly empty valid actor sets for AR1 and AR3 on the new organisational model. Adequate transformations could be as shown in Figure 9.

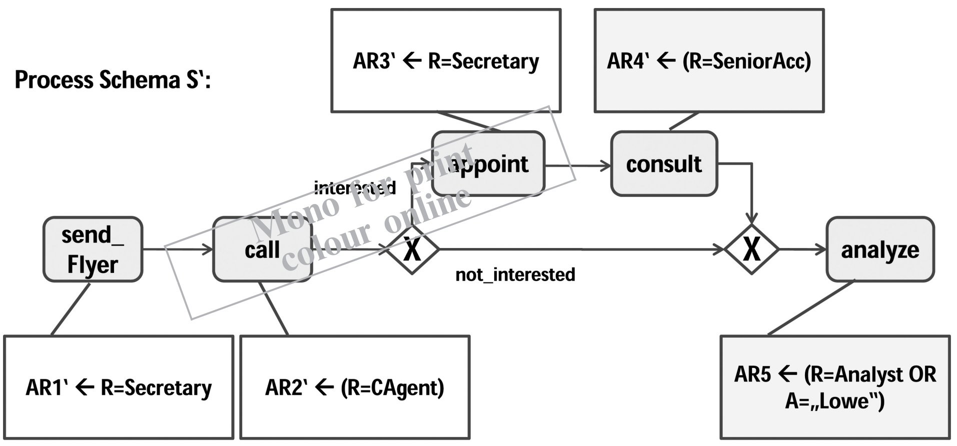
4. Direct access rule changes

The adaptation of access rules in conjunction with changes of organisational models constitutes only one use case. As discussed in Section 1 it must be also possible to directly change access rules. Consider the scenario depicted in Figure 11. As additional streamlining action, is has been decided to let the consultancy only be done by senior accountants in order to save time. Furthermore, actor Lowe is now supposed to assist the analyst since it has turned out that Lowe has practical experiences with data mining. Both considerations are reflected in changed access rules AR4 and AR5 (cf. Figure 11).

In order to be able to apply direct access rule changes within the EIS, first of all, we have to define respective operations (e.g. for deleting AND-terms within an access rule). The formal semantics of these change operations is presented in Section 5. It is based on the valid actor sets of the access rules before and after the changes.

4.1. An operator-tree-based representation for access rules

In order to precisely define access rule changes, it is necessary to base their definition on a representation other than the intuitive one presented in Definition 2.3. Using



b) Access rule change Δ = (deleteTerm(OP_{AR4}, (R=JuniorAcc)), addTerm(OP_{AR5}, (A=„Lowe"), OR)

c) Valid Actor Sets:

- VAS(OM', AR4') = {Jones, Red}
- VAS(OM', AR5') = {Smith, Sharp, Lowe}

Figure 11. Changing access rules AR4 and AR5.

the notion given in Definition 2.3 it would be difficult to express at which substructure level of nested access rule structures a new AND-term shall be added. Thus we have to find a representation which enables convenient access to any substructure level of an access rule. For an access rule AR, a suitable representation for this is provided by operator tree $\mathcal{OP}_{AR} = (\mathrm{O}, \mathrm{L})$. Here O denotes the set of all operator nodes and L denotes the set of all elementary access rules AR is built of. $\mathcal{OP}_{AR}$ can be determined similarly to building the operator-tree for a complex expression or SQL-statement. An example of an access rule with corresponding operator-tree is depicted in Figure 12. Generally, an operator tree does not necessarily need to be balanced.

$\mathcal{OP}_{AR} = (\mathrm{O}, \mathrm{L})$ has the following characteristics:

- $\mathcal{OP}_{AR}$ is a binary tree.
- O corresponds to the set of non-leaf nodes (including the tree root) and L corresponds to leaf nodes.
- The tree has to be traversed in Inorder to build the associated access rule term.
- NOT is only used as direct predecessor node of a leaf (remember that NOT can be only used in the context of elementary access rules in CEOSIS, cf. Definition 2.3).

How to build the operator tree for a given access rule is shown in the next section.

4.2. *Basic access rule changes*

We introduce a complete set of basic change operations on access rules[5] and on their operator-tree representation respectively. Before, we define basic notions on operator trees:

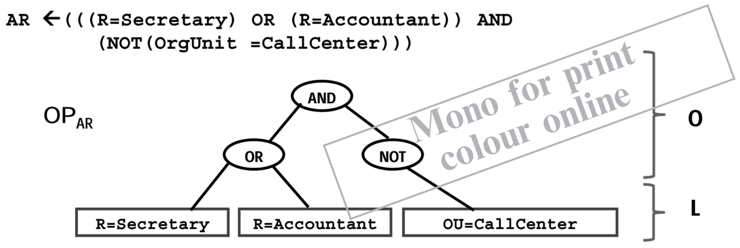

AR ←(((R=Secretary) OR (R=Accountant)) AND
(NOT(OrgUnit =CallCenter)))
OP_AR
AND
OR
NOT
R=Secretary
R=Accountant
OU=CallCenter
O
L
Mono for print colour online

Figure 12. Access rule and operator tree.

Definition 4.1: Functions on op trees. *Let* AR $\in \mathcal{AR}^{OM}$ *be an access rule and let* $\mathcal{OP}_{AR}$ *be its operator tree. Then:*

- *The empty tree* τ *consists of one void node, i.e. it reflects empty access rule* $EAR0 \longleftarrow \tau^*$.
- *Let* $\mathcal{OP}^{OM}$ *denote the set of all operator trees for access rules over an organisational model* OM. *Let further* $\mathcal{N}$ *denote the total set of nodes belonging to any operator tree from* $\mathcal{OP}^{OM}$. *Then:*
  - *pred:* $\mathcal{OP}^{OM} \times \mathcal{N} \mapsto \mathcal{N}$ *with pred(*$\mathcal{OP}_{AR}$, n*)* $= p$ *determines direct predecessor node p of node n in* $\mathcal{OP}_{AR}$
  - *root:* $\mathcal{OP}^{OM} \times \mathcal{N} \mapsto \mathcal{N}$ *determines the root node of operator tree* $\mathcal{OP}_{AR}$.
- *Merge:* $\mathcal{OP}^{OM} \times \mathcal{OP}^{OM} \times \{AND, OR, VOID^6\} \mapsto \mathcal{OP}^{OM}$
  Merge(S,T,op $= [AND|OR|V\ OID]$*)* $= S'$ *merges two operator trees S and T using op, where* $T = \mathcal{OP}_{EAR}$ *with EAR being an elementary access rule. Root of* S' *is op, left child tree is S, right child tree is* $\mathcal{OP}_{EAR}$
- *Substitute:* $\mathcal{OP}^{OM} \times \mathcal{OP}^{OM} \times \mathcal{OP}^{OM} \mapsto \mathcal{OP}^{OM}$
  Substitute(T,S,S') $= T'$ *substitutes sub-tree S in T by sub-tree* S' *resulting in* T' *(cf. Figure 13, Step 1)*
- *Optimise:* $\mathcal{OP}_{AR} \mapsto \mathcal{OP}_{AR}$
  Optimise(T) $= T'$ *works as follows: if operator tree T contains empty tree* τ *then T can be optimised by merging* τ *and its sibling tree S resulting in optimised tree* T'. *More precisely, let O be the predecessor of* τ *and S. Then O,* τ*, and S can be merged to S (cf. Figure 13, Step 2).*

CEOSIS provides a set of basic change operations that allow for adding, deleting, and negating terms within operator trees. We claim that these change operations can only be applied to correct access rules resulting in correct access rules again (i.e. access rules belonging to $\mathcal{AR}^{OM}$). Structural correctness is preserved by formal pre- and postconditions defined for each change operation. In the context of our ADEPT2 process management technology (Rinderle *et al.* 2004a,b), for example, we additionally ensure compliance with the underlying organisational model OM by forbidding access rule changes which refer to entities not being present in *OM*.

Definition 4.2: Basic change operations on access rules. *Let* $AR \in \mathcal{AR}^{OM}$ *be an access rule with operator tree*$\mathcal{OP}_{AR}$. *Let further EAR be an elementary access rule with operator tree* $\mathcal{OP}_{EAR}$. *Assume that AR is transformed into another access rule* $AR' \in \mathcal{AR}^{OM}$ *(represented by* $\mathcal{OP}_{AR'}$*) by applying change op* $\in$ *{addTerm, deleteTerm, negateTerm} with*

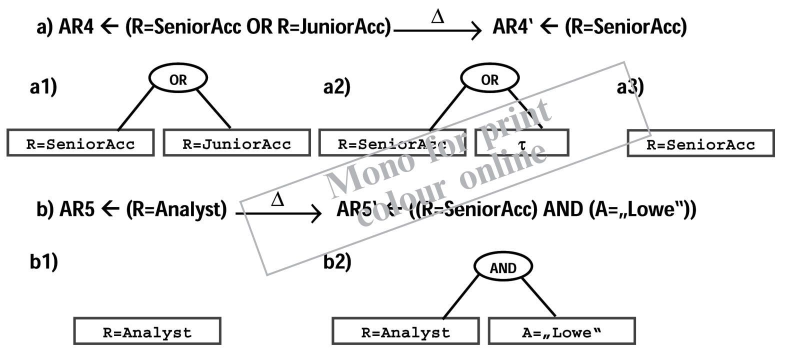

a) AR4 ← (R=SeniorAcc OR R=JuniorAcc) Δ AR4' ← (R=SeniorAcc)
a1)
OR
R=SeniorAcc
R=JuniorAcc
a2)
OR
R=SeniorAcc
τ
a3)
R=SeniorAcc
b) AR5 ← (R=Analyst) Δ AR5' ← ((R=SeniorAcc) AND (A=„Lowe"))
b1)
R=Analyst
b2)
AND
R=Analyst
A=„Lowe"

Figure 13. Delete operation with subsequent optimization.

- *addTerm* $(\mathcal{OP}_{AR}, S, [AND|OR|VOID], EAR) = \mathcal{OP}_{AR'}$
  Precond.: S is sub-tree of $\mathcal{OP}_{AR}$
  Postcond.: $\mathcal{OP}_{AR'} = Optimise(Substitute(\mathcal{OP}_{AR}, S, Merge(S, \mathcal{OP}_{EAR})))$
- *deleteTerm* $(\mathcal{OP}_{AR}, S) = \mathcal{OP}_{AR'}$
  Precond.: S is sub-tree of $\mathcal{OP}_{AR}$ *and S does not contain the root node (the root node is deleted by tree merging if a direct sub-tree of the root node is deleted)*
  Postcond.: $OP_{AR'} = Optimise(Substitute(OP_{AR}, S, \tau))$
- *negateTerm* $(\mathcal{OP}_{AR}, S) = \mathcal{OP}_{AR'}$
  Precond.: S is leaf node, i.e. $S = \mathcal{OP}_{EAR}$ *and pred* $(\mathcal{OP}_{AR}, EAR) \neq NOT$ *(the second condition is necessary to achieve operator trees where NOT is only used in connection with leaf nodes according to the definition of access rules.).*
  Postcond.: $\mathcal{OP}_{AR'} = Substitute(\mathcal{OP}_{AR}, S, \mathcal{OP}_{NOT(EAR)})$

Figure 13 depicts an example for applying the delete operation. First, the sub-tree reflecting elementary access rule `EAR` $\longleftarrow$ `R = Secretary` (cf. Figure 12) is substituted by empty tree τ. Then the optimization function is run on the resulting tree which eliminates τ by lifting up remaining elementary access rule `EAR'`$\longleftarrow$ `R = SeniorAcc` to the next level within the operator tree.

Generally, a sequence of basic change operations $<op_1, \ldots, op_n>$ can be used to built up the operator tree for an access rule starting with the empty tree. Consider access rule AR as given in Figure 12. Starting from empty tree τ, the following basic change operations build $\mathcal{OP}_{AR}$:

$op_1 : \mathcal{OP}_1 =$ addTerm(τ, τ, VOID, R = Secretary)
$op_2 : \mathcal{OP}_2 =$ addTerm($\mathcal{OP}_1, \mathcal{OP}_1$, OR, R = Accountant)
$op_3 : \mathcal{OP}_3 =$ addTerm(OP_2, OP_2, AND, OU = CallCenter)
$op_4 : \mathcal{OP}_{AR} =$ negateTerm($\mathcal{OP}_3, \mathcal{OP}_{OU=CallCenter}$)

Formal semantics of these change operations is presented in Section 5.

4.3. High-level access rule changes

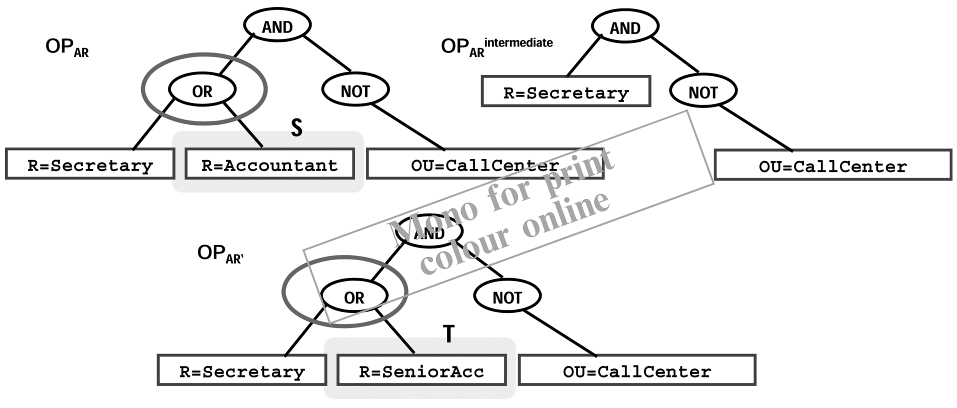
For more sophisticated user support CEOSIS additionally provides *high-level change operations*. Their definition is based on the elementary change operations introduced in Definition 4.2. As example consider high-level change `substitute`

AccessRules($\mathcal{OP}_{AR}$, S, T). Here sub-tree S of operator tree $\mathcal{OP}_{AR}$ is substituted by another sub-tree T. At access rule level this means to substitute a part of the access rule by another access rule. In Figure 14, for example, sub-tree S (representing the elementary access rule R = Accountant) is substituted by sub-tree T (representing the elementary access rule R = SeniorAcc).

Basically, the substitution of access rules can be realised by applying operation deleteTerm ($\mathcal{OP}_{AR}$, S) first, followed by a sequence of addTerm operations. They build up T within $\mathcal{OP}_{AR}$ by inserting the elementary access rules out of which T consists (cf. Figure 14). The pre- and postconditions of high-level change operations can then be derived by aggregating the pre- and postconditions of the constituting basic change operations. One important benefit regarding the ease-of-use of high-level change operations is that all 'details' of applying the basic change operations are encapsulated within the high-level operation. For example, if we want to be able to add the new terms in the right way afterwards, it will become necessary to 'memorise' some operator nodes before deleting the terms to be substituted. In Figure 14, for example, it has to be memorised that S was connected to $\mathcal{OP}_{\mathrm{R=Secretary}}$ by an OR-operator. Without memorising this information explicitly, it will be lost after deleting S as it can bee seen from $\mathcal{OP}_{AR}^{\mathrm{intermediate}}$.

Another high-level change operation is swapAccessRules($\mathcal{OP}_{AR}$, S, T) which swaps sub-trees S and T within $\mathcal{OP}$. An example is depicted in Figure 15. Again swapAccessRules($\mathcal{OP}_{AR}$, S, T) can be expressed by basic change operations; i.e.

$$\begin{aligned}
&\mathtt{swapAcessRules}(\mathcal{OP}_{AR}, \mathtt{S}, \mathtt{T}) = \\
&\quad (\mathtt{deleteTerm}(\mathcal{OP}_{AR}, \mathtt{S})), \mathtt{deleteTerm}(\mathcal{OP}_{AR'}, \mathtt{T}), \\
&\quad \mathtt{addTerm}(\mathcal{OP}_{AR}^{\mathrm{delete}}, \mathcal{OP}_{AR}^{\mathrm{delete}}, \mathrm{AND}, \mathtt{T}), \\
&\quad \mathtt{addTerm}(\mathcal{OP}_{AR}^{\mathrm{intermediate}}, \mathcal{OP}_{AR}^{\mathrm{intermediate}}, \mathrm{AND}, \mathtt{S}))
\end{aligned}$$



Applied change operation:

```
op = substituteAccessRule(OP_AR, R=Accountant, R=SeniorAcc) =
        (deleteTerm(OP_AR, S),
                addTerm(OP_AR^intermediate, OP_R=Secretary, OR, T))
with S = OP_R=Accountant and T = OP_R=SeniorAcc
```

Figure 14. Example for substituting access rules.

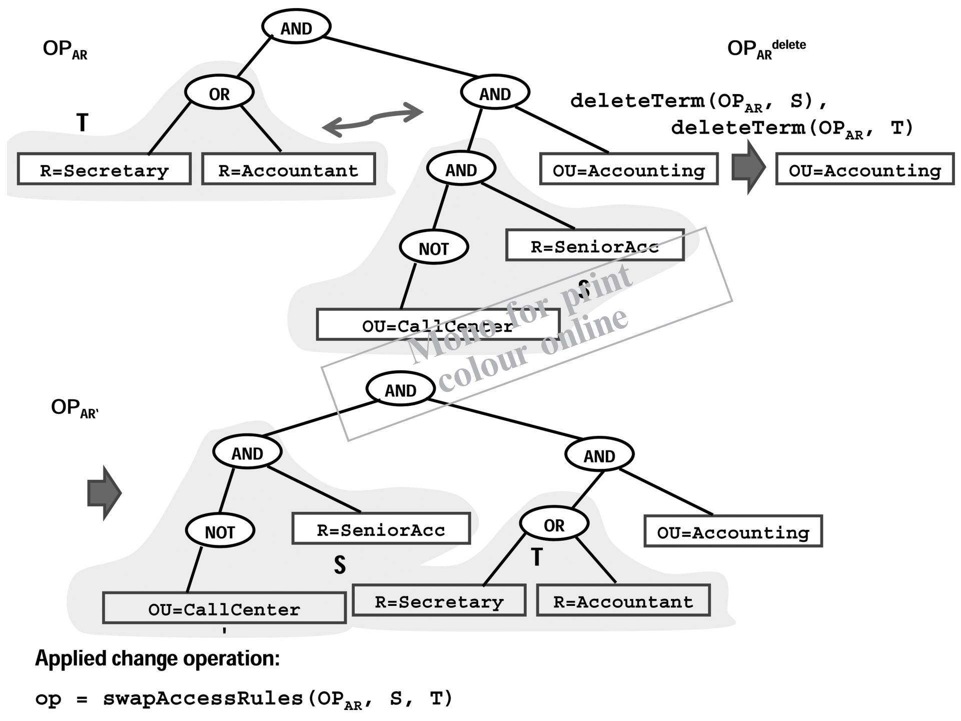


Figure 15. Example for swapping operator trees.

Again it has to be memorised which operator nodes were used to fix the sub-trees to be swapped within the operator tree (in Figure 15, for example, S and T are fixed by an AND-operator). The semantics of high-level change operations is discussed in Section 6.

5. Semantics of access rule changes

Formal semantics of access rule changes can be expressed based on the effects the changes have on valid actor sets (cf. Section 2.2). In particular, we are interested in statements such as ‘valid actor set of access rule AR is reduced, expanded, or not affected by the change’. Note that for the following considerations on change semantics we assume direct access rule changes, i.e. the underlying organisational model has not been modified.

Definition 5.1: Reduction/expansion of actor sets. *Let $AR \in \mathcal{AR}^{OM}$ be an access rule (over organisational model OM) and let Δ_{AR} be a change which transforms AR into another access rule $AR' \in \mathcal{AR}^{OM}$. Then, the effect of Δ_{AR} on AR is called*

- *reduction iff $VAS(OM,AR') \subset VAS(OM,AR)$*
- *expansion iff $VAS(OM,AR') \supset VAS(OM,AR)$*
- *zero_effect iff $VAS(OM,AR') = VAS(OM,AR)$*

5.1. Root level and substructure level changes

For elementary access rules the analysis of change effects is easy to accomplish. For example, let EAR $\longleftarrow$ (R = Secretary) and EAR$'$ $\longleftarrow$ (R = Accountant) be two elementary access rules with operator trees $\mathcal{OP}_{EAR}$ and $\mathcal{OP}_{EAR'}$ respectively. Let further change *op* = *addTerm* ($\mathcal{OP}_{EAR}, \mathcal{OP}_{EAR}$, *AND*, EAR$'$) = AR transform EAR into AR. Then the effect on the actor set of EAR is a *reduction*, more precisely, the actor sets of AR can be determined as intersection of the actor sets of EAR and EAR$'$.

Things will become more complicated if the access rules to be changed are more complex. Consider, for example, access rule AR in Figure 12 and elementary rule EAR$'$ $\longleftarrow$ (OU = Accounting). If we apply change operation op^a = addTerm($\mathcal{OP}_{AR}, \mathcal{OP}_{AR}$, AND, EAR$'$) (cf. Figure 16b) the effect can be determined as intersection of the actor sets of AR and EAR$'$ again. However, when applying change operation op^b = addTerm($\mathcal{OP}_{AR}, \mathcal{OP}_{NOT(OrgUnit='administration')}$, AND, EAR$'$) (cf. Figure 16c), effects on the valid actors sets of AR cannot be determined straightforward. Note that op^a operates at the *root level* of AR (the formal meaning is described in the following), whereas op^b operates at a substructure level of AR. The notions of root level and substructure level changes of access rules are presented in Definition 5.2.

Definition 5.2: Root vs substructure level changes. *Let $\mathcal{OP}_{AR}$ be the operator tree representation of access rule $AR \in \mathcal{AR}^{OM}$ and let* op *be a basic change operation which transforms AR into another access rule $AR' \in \mathcal{AR}^{\mathrm{OM}}$. Then we denote* op *as*

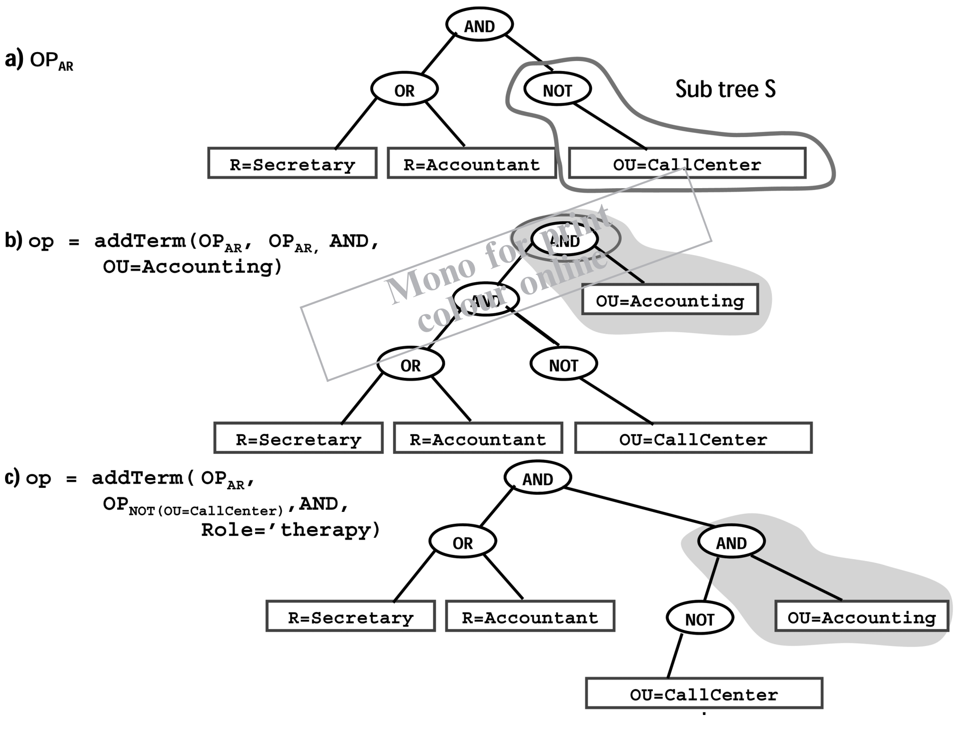


Figure 16. Access rule changes.

- *root level change if either a new root is added to operator tree $\mathcal{OP}_{AR}$ or the root of $\mathcal{OP}_{AR}$ is deleted (e.g. by tree merging after applying the delete operation). This holds for*
  - *op = addTerm($\mathcal{OP}_{AR}, \mathcal{OP}_{AR}$, [AND|OR|VOID], EAR)*
  - *op = deleteTerm($\mathcal{OP}_{AR}$, S) with pred(root(S)) = root($\mathcal{OP}_{AR}$)*
  - *op = negateTerm($\mathcal{OP}_{EAR}, \mathcal{OP}_{EAR}$) with EAR being an elementary access rule;*
- *substructure level change otherwise.*

The root level change depicted in Figure 16b shows that operator tree $\mathcal{OP}_{\mathrm{AR}}$ grows when adding a new root node, whereas the substructure level change (cf. Figure 16c) is conducted by substituting sub-tree $S = \mathcal{OP}_{NOT(OrgUnit='administration')}$ by the sub-tree $S' = \mathcal{OP}_{(NOT(OrgUnit='administration'))AND(Role='therapist')}$. As can be seen new root AND has been added to S.

5.2. Basic access rule changes

The basic idea of our approach for determining the effects of access rule changes on valid actor sets (in terms of reduction, expansion, or *zero_effect*) is as follows. First, it must be checked how root level changes affect valid actor sets of respective access rules. Second, for substructure level changes the following observation can be made: a substructure level change is a root change regarding the affected sub-tree (cf. Figure 18), i.e. we can determine effect $e \in$ {*reduction, expansion, or zero_effect*} on the affected sub-tree. Effect *e* can then be 'propagated' upwards to the root of the new operator tree. Then, a fundamental question is, for example, whether a reduction on the affected sub-tree remains a reduction when being propagated to the root level.

Thus, for determining the effects of basic access rule changes on valid actor sets a first step is to present the effects of root level changes on operator trees.

Proposition 5.3: Effects of root level changes. *Consider the following elements:*

- *$\mathcal{OP}_{AR}$: Operator tree of access rule AR over organisational model OM with S and T being sub-trees of $\mathcal{OP}_{AR}$ with pred($\mathcal{OP}_{AR}$,root(S)) = pred($\mathcal{OP}_{AR}$, root(T)) root($\mathcal{OP}_{AR}$). S corresponds to access rule AR_S and T to access rule AR_T.*
- *EAR: Elementary access rule with operator tree $\mathcal{OP}_{EAR}$.*
- *op: root level change which transforms* AR *into another access rule AR' with operator tree$\mathcal{OP}_{AR'}$.*

Then, the effect (i.e. formal semantics) of operation op on $\mathcal{OP}_{AR}$ can be determined according to the following table (see Figure 17 *for a graphical illustration):*

op: addTerm($\mathcal{OP}_{AR}$, $\mathcal{OP}_{AR}$, [AND | OR],EAR) = $\mathcal{OP}_{AR'}$
- *op: addTerm($\mathcal{OP}_{AR}$, $\mathcal{OP}_{AR}$, AND, EAR) = $\mathcal{OP}_{AR'}$:*
  VAS(OM,AR') = VAS(OM,AR') ∩ VAS(OM, EAR)
  ⇒ **Reduction**
- *op: addTerm($\mathcal{OP}_{AR}$, $\mathcal{OP}_{AR}$, OR, EAR) = $\mathcal{OP}_{AR'}$:*
  VAS(OM,AR') = VAS(OM,AR) ∪ VAS(OM,EAR)
  ⇒ **Expansion**

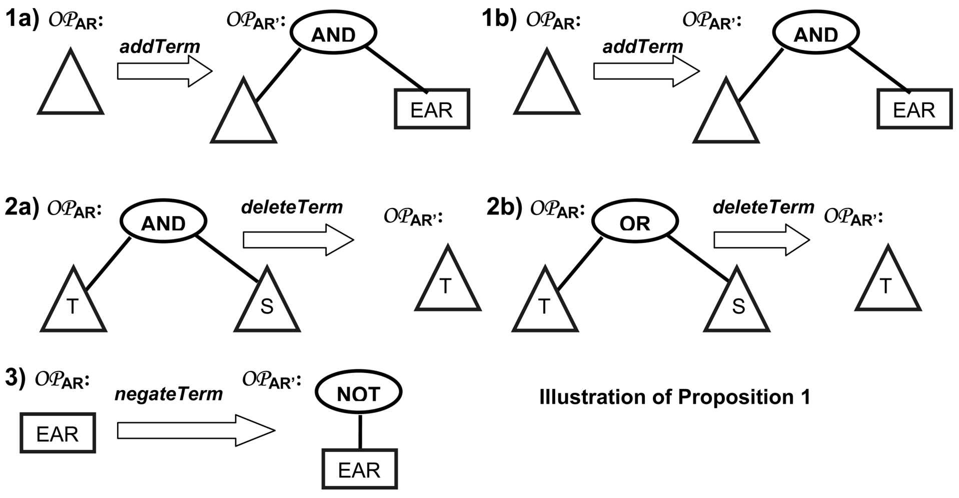


Figure 17. Effects of root level changes.

op: deleteTerm$(\mathcal{OP}_{AR}, \mathrm{S}) = \mathcal{OP}_{AR'}$

- $root(\mathcal{OP}_{AR}) = AND$:
  $VAS(OM,AR) = VAS(OM,AR_T) \cap VAS(OM,AR_S)$
  $\subseteq VAS(OM,AR_T) = VAS(OM,AR')$
  $\Rightarrow$ **Expansion**
- $root(\mathcal{OP}_{AR}) = OR$:
  $VAS(OM,AR) = VAS(OM,T) \cup VAS(OM,S)$
  $\supseteq VAS(OM,T) = VAS(OM,AR')$
  $\Rightarrow$ **Reduction**

---

op: negateTerm$(\mathcal{OP}_{EAR}, \mathcal{OP}_{EAR}) = \mathcal{OP}_{AR'}$:
$VAS(OM,AR') = Actors \setminus VAS(OM,EAR)$
$\Rightarrow$ *effect cannot be determined in terms of expansion, reduction, or zero effect*

Figure 17 illustrates the different cases covered by Proposition 5.3.

So far, we have only considered root level changes. For substructure level changes, we first determine the (minimal) sub-tree which is affected by the respective change (*affected sub-tree*). The effects of the substructure change on the affected sub-tree can be determined using Proposition 5.3 for root level changes and are reflected by the *resulting sub-tree* (cf. Proposition 5.4). According to Proposition 5.3, it is not possible to derive the effects of negation in terms of *reduction, expansion*, or *zero_effect*. When applying a negation operation, however, at least we know that VAS(OM,AR) and VAS(OM,AR′) are *disjoint*, which can be used to describe the semantics of the negation operation. To provide the semantics of substructure level changes, the effects on the affected sub-tree are propagated to the root. In this paper, we show how this can be done for effects *reduction, expansion*, and *zero_effect*. Obviously, for other effects (such as *disjoint*) other techniques have to be applied in order to analyze the effects of substructure level changes. Thus, in the following, we

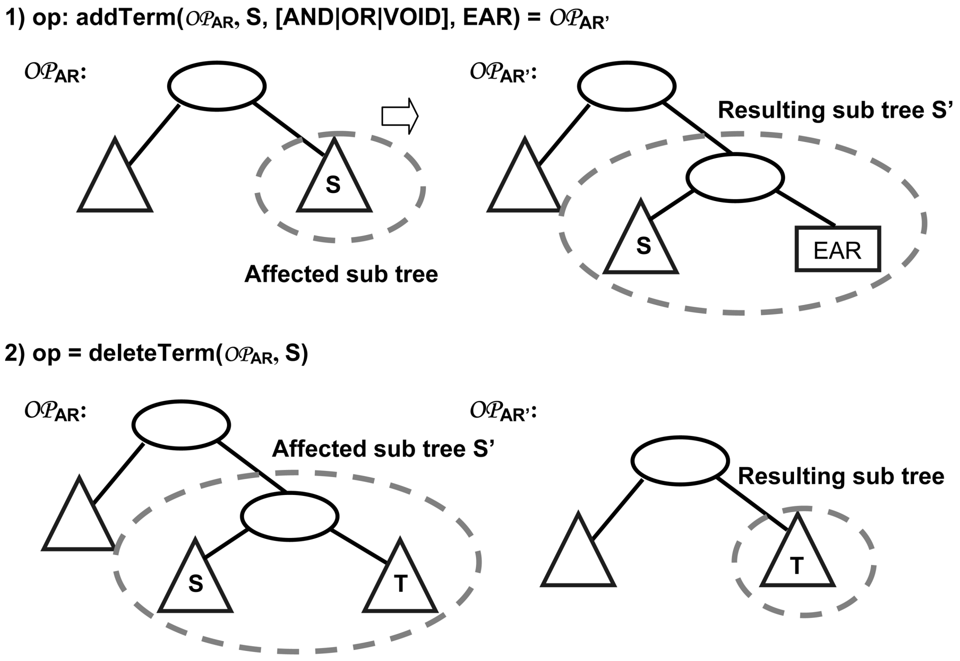


Figure 18. Affected and resulting sub-trees.

focus on operations *addTerm* and *deleteTerm* and leave *negateTerm* to future publications.

Proposition 5.4: Effects of substructure level changes. *Let $\mathcal{OP}_{AR}$ be the operator tree of access rule* AR *over organisational model OM. Let further* op *be a change operation which transforms* AR *into another access rule* AR′ *with operator tree $\mathcal{OP}_{AR'}$. Then, the affected and resulting sub-trees of op on $\mathcal{OP}_{AR}$ can be determined as follows (cf.* Figure 18*):*

(1) op: addTerm($\mathcal{OP}_{AR}$,S,[AND | OR | VOID], EAR) = $\mathcal{OP}_{AR'}$ ⇒
- *affected sub-tree of op on $\mathcal{OP}_{AR}$ is S*
- *resulting sub-tree of op on $\mathcal{OP}_{AR}$ is S′ with root(S′) = pred($\mathcal{OP}_{AR'}$, root(S)) having sub-trees S and $\mathcal{OP}_{EAR}$.*

(2) op: deleteTerm($\mathcal{OP}_{AR}$, S) = $\mathcal{OP}_{AR'}$ ⇒
- *affected sub-tree of op on $\mathcal{OP}_{AR}$ is S′ with root(S′) = pred($\mathcal{OP}_{AR}$, root(S))*
- *resulting sub-tree of op on $\mathcal{OP}_{AR}$ is T with T being a sibling tree of S based on S′ in $\mathcal{OP}_{AR}$.*

To determine overall effect of a substructure level change on access rule AR, the effect on the affected sub-tree has to be *pushed* towards the root node of the operator tree of AR′ . Pushing means that we climb up the tree over the different operators and check the impact on the effects. We start with pushing the effect over the predecessor node of the root of the affected sub-tree (*one step push*) and extend this to a *multi step push* towards the root afterwards. To specify the one step push we introduce notion

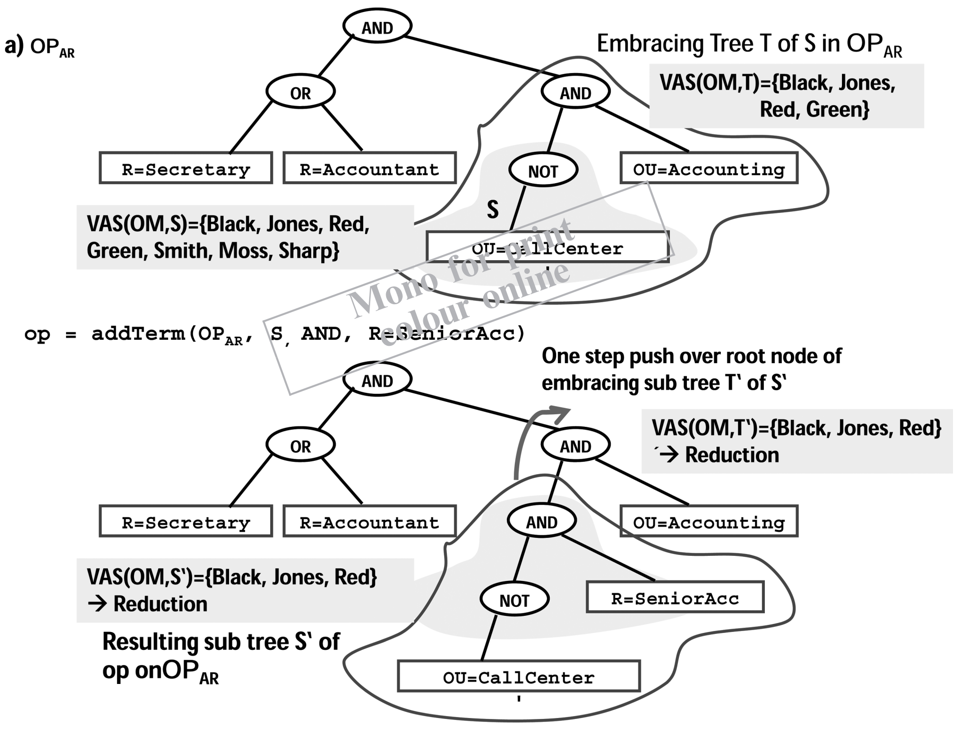

a) OP_{AR}
AND
OR
AND
R=Secretary
R=Accountant
NOT
OU=Accounting
OU=CallCenter
Embracing Tree T of S in OP_{AR}
VAS(OM,T)={Black, Jones, Red, Green}
S
VAS(OM,S)={Black, Jones, Red, Green, Smith, Moss, Sharp}
op = addTerm(OP_{AR}, S, AND, R=SeniorAcc)
One step push over root node of embracing sub tree T' of S'
VAS(OM,T')={Black, Jones, Red} → Reduction
AND
OR
AND
R=Secretary
R=Accountant
AND
OU=Accounting
NOT
R=SeniorAcc
OU=CallCenter
VAS(OM,S')={Black, Jones, Red} → Reduction
Resulting sub tree S' of op onOP_{AR}

Figure 19. Effects of one step push (example).

embracing tree of the affected sub-tree. An example for an embracing tree is shown in Figure 19.

Definition 5.5: Embracing tree. *Let $\mathcal{OP}_{AR}$ be an operator tree and let S be a sub-tree of $\mathcal{OP}_{AR}$. Then we denote T as the embracing tree of S in $\mathcal{OP}_{AR}$ iff*

- *T is sub-tree of $\mathcal{OP}_{AR}$ or $T = \mathcal{OP}_{AR}$;*
- *$root(T) = pred(\mathcal{OP}_{AR}, root(S))$.*

Based on Definition 5.5, the one step push can be formalised.

Proposition 5.6: One step push. *Let $\mathcal{OP}_{AR}$ be the operator tree of access rule* AR *over organisational model OM. Let further* op *be a change operating at substructure level with affected sub-tree S. Assume that the effect of* op *on S corresponds to $e \in$ {Reduction, Expansion, Zero_effect}. Then, one step push of e towards root ($\mathcal{OP}_{AR}$) means to lift up e over root(T) where T denotes the embracing tree of S′, i.e. we analyze how e is affected by lifting it over the next operator node on the way to the root. The effect of the one step push remains e, i.e. e is not affected by a one step push.*

For example, if the effect on the affected sub-tree is a reduction, intuitively the effect remains a reduction if we ‘climb over’ an OR node. The effects of a one step push over an AND node is illustrated by Figure 19. Valid actor set of affected sub-tree S is reduced according to Proposition 5.3, i.e. $\texttt{VAS(OM,S')} \subseteq \texttt{VAS(OM,S)}$. Lifting this effect over the root node of the embracing sub-tree T′, which is an AND node, keeps the effect of reduction.

Finally, it has to be analyzed how a *multiple step push* towards the root affects the effects of substructure level changes. As stated in Proposition 5.6, a one step push does not affect them. A multi step push can be seen as a one step push which is applied several times. Each time the initial effect of the substructure level change remains the same. Thus, overall, the multi step push does not affect the effect of the substructure level change. This means that the semantics of a substructure level change can be determined as easily as for a root level change. Thus, for any complex access rule and any basic change operation, the effect can be determined quickly. This is essential, for example, when adapting user worklists in PAIS as discussed in Section 7.

Proposition 5.7: Multi step push. *Let $\mathcal{OP}_{AR}$ be the operator tree of access rule* AR *over organisational model OM. Let further op be a substructure level change operation with affected sub-tree S and resulting sub-tree S′. Assume that the effect of op on S is e ∈ {Reduction, Expansion, Zero_effect}. Then, multi step pushing e towards root ($\mathcal{OP}_{AR}$) means to lift up e over all nodes on the path to root ($\mathcal{OP}_{AR}$) starting from root(T) where T denotes the embracing tree of S′. The effect of a multi step push towards the root remains e, i.e. e is not affected by the multi step push.*

6. Exploiting organisational knowledge for high-level access rule changes

As discussed in Section 4.3, a high-level access rule change Δ can be understood as an ordered sequence of basic access rule changes $op_1, \ldots, op_n$. Thus, it can be tried to aggregate the effects of $op_1, \ldots, op_n$ in order to determine semantics of Δ. However, such aggregation might be impossible, e.g. in case the effect of op_i is a reduction and the effect of op_j is an *expansion* ($i \neq j$). In this case, the actor sets being valid before and after the high-level change have to be re-calculated and explicitly compared. Generally, re-calculation could be used for determining the effects of basic change operations as well. However, as we discuss in Section 7, in many applications it is beneficiary to have a 'quick check' on the effects of access rule changes. For example, if we know that a change has effect *expansion* or *zero_effect*, we can delay the adaptation of user worklists in PAIS until the system is offline. Contrary, it can be expensive to always recalculate the new valid actor sets immediately. However, since high-level change operations consist of the consecutive application of basic change operations, their effects cannot be determined as easily as for basic operations. As example consider change $\texttt{substituteAccessRules}(\mathcal{OP}_{AR}\texttt{,S,T}) = \texttt{deleteTerm}(\mathcal{OP}_{AR}\texttt{, S)}, \texttt{addTerm}(\mathcal{OP}_{AR}^{\text{intermediate}}, \mathcal{OP}_{\text{R=Secretary}}, \texttt{OR, T)}$ as depicted in Figure 14. According to Proposition 5.3, for the `deleteTerm` operation we obtain a reduction effect, whereas for the `addTerm` operations an expansion results. Thus the overall effect cannot be determined.

However, for this scenario, one can think about some optimizations regarding high-level access rule changes. For high-level change `substituteAccessRules` ($\mathcal{OP}_{AR}$`,S,T)`, for example, additional information from the underlying organisational model can be used to determine the effects on the valid actor sets of the changed access rules. Assume, for example, that for access rule `AR` $\longleftarrow$ `Role` = 'R1', we substitute role `R1` by role `R2` resulting in `AR'`$\longleftarrow$ `Role` = ' `R2'`. Then, if we know from the underlying organisational model that `R2` is a sub-role of `R1`, it can be concluded that the effect on the valid actor set of `AR` is either *zero_effect* or *reduction*. The reason is that the same set of actors or less actors are assigned to a sub-role when compared to the superior one. Vice versa, if a role is substituted by a superior one within an access rule, the effect on the valid actor set will be *zero_effect* or expansion. One big advantage of determining the effects of access rule changes as described above is the following. If access rules are changed, the effects on the valid actor sets have to be propagated to user worklists at some point in time. This point in time can be chosen depending on the particular change effect. If, for example, the valid actor set is reduced, this poses a potential security threat on the system. Either work items might be offered to users who are no longer qualified or, if the valid actor set becomes empty, no actor will be qualified anymore. Hence, user worklists should be adapted *immediately*. Contrary, if the valid actor set is expanded, the only consequence might be that work items are not offered to all qualified users. Since this poses no security threat on the PAIS, the propagation of the access rule change to user worklists may be *delayed*, e.g. done offline when no user is working on the PAIS. Finally, in case of zero_effect no action is required at all. Same considerations hold for the hierarchial relations between organisational units. Proposition 6.1 summarises these considerations:

Proposition 6.1: Valid actor set relations for specialisation and subordination. *Let OM = (Actors, Roles, OrgUnits, has, belongs_to, is_subordinated, specialises) be an organisational model. Let further r1, r2 ∈ Roles be two roles and o1, o2 ∈ OrgUnits be to organisational units. Then:*

$$r1 \in specialises^*(r2) \Rightarrow VAS(OM,\ R = r1) \subseteq VAS(OM,\ R = r2)$$

$$o1 \in is\_subordinated^*(o2) \Rightarrow VAS(OM,\ OU = o1) \subseteq VAS(OM,\ OU = o2)$$

For the scenario depicted in Figure 14, for example, we know from OM that `SeniorAcc` is a sub-role of role `Accountant`. Thus, according to Proposition 6.1 `VAS(OM, R = SeniorAcc)` ⊆ `VAS(OM, R = Accountant)` holds. Consequently, the overall effect of the `substituteAccessRule`(...) operation can be determined as reduction (or zero_effect). Obviously that holds true since:

$$\mathtt{VAS}(\mathtt{OM}',\mathtt{AR}) = \{\mathtt{Black},\mathtt{Jones},\mathtt{Red},\mathtt{Green}\} \supseteq \mathtt{VAS}(\mathtt{OM}',\mathtt{AR}') = \{\mathtt{Black},\mathtt{Jones},\mathtt{Red}\}.$$

7. Discussion

In order to elaborate the requirements for a generic component enabling full life cycle support in respect to organisational entities as well as access rules we conducted an in-depth analysis of organisational structures and their evolution in several case studies. Corresponding results have been reported by Konyen (1996), Konyen (1996a,b), Reichert *et al.* (2004), Wiedemuth-Catrinescu (2002). Besides an in-depth analysis of healthcare processes and relevant access control requirements during these case studies, we identified typical organisational patterns in the medical environment (including organisational relations and complex substitution as well as delegation rules) as well as frequently occurring organisational changes. Examples of characteristic changes we identified over a period of two years include, for example, the relinking of organisational units and actors within the organisational chart, the definition of completely new organisational units, the merging of existing departments, or the outsourcing of organisational units. The latter took place, for example, when a certain medical lab services were outsourced to an external lab. All these observations from our case study have confirmed the high practical need for better supporting the evolution of organisational models at the IT level. In addition, we made similar observations in the context of our projects in other industry including the automotive domain and the financial sector. Finally, from discussions with an IT service centre from the University Hospital in Ulm we know that it takes about 10% of the IT staff's working time to implement access control policies and to cope with evolving organisational structures at the IT level. The reason is that most of the access control mechanisms in existing systems are hard-coded within the application programs. Thus, adaptations of organisational structures result in high efforts for code adaptations or – even more – inconsistencies and security holes.

Altogether our case studies have proven that any approach enabling the quick and correct adaptation of organisational models, including the control of their effects on running information systems, is crucial in practice. Our findings are supported by other studies. One example is the study on the dynamics of rules in an organization conducted by Stanford University (March *et al.* 2000).

In summary, contributions and benefits of the CEOSIS approach are as follows:

- *Explicit representation of organisational models*. In CEOSIS the representation of organisational structures is separated from the code of the application systems. This enables quick and correct adaptation of organisational models. Furthermore, due to the explicit definition of organisational models, the communication with domain experts and operating departments is facilitated.
- *Model quality and consistency*. The central management of organisational structures leads to a decrease of model inconsistencies and thus reduced maintenance costs.
- *Expressive organisational meta-model*. The meta-model chosen in CEOSIS enables coverage of organisational structures (according to the analyzed use cases) being relevant in practice. In order to capture additional kinds of organisational entities, we have extended the organisational meta-model as presented in this paper in several respects. Berroth (2005) and Reichert *et al.* (2004) describe these extensions in detail.
- *Explicit Management of Access Rules*. In CEOSIS organisational models as well as access rules can be explicitly modelled and maintained. Particularly, the references between access rules and the underlying organisational model can be specified and thus monitored and controlled by the information system. This means that potential conflicts in the course of organisational changes (e.g. orphaned or dangling references) can be resolved based on an adequate user assistance as well as intelligent adaptation strategies.

- *Exploiting the semantics of organisational changes.* In order to find intelligent adaptation strategies to overcome possible conflicts in connection with organisational changes, the CEOSIS approach exploits the maximum available information. Particularly, by analyzing the semantics of the applied changes (at organisational model as well as access rule level) provides the basis for adequate adaptation strategies. This leads to a new quality of determining and handling the effects of organisational changes. As a consequence, conflict detection and resolution is significantly quicker and more effective in CEOSIS than manual adaptation of hard-coded organisational structures within application software.
- *Support of access rule changes.* To our best knowledge, CEOSIS is the first formally rigorous approach to not only support organisational changes, but also direct adaptations of access rules as well. The latter often become necessary in practice as consequence of imprecise analysis or mistakes when modelling the access rules (e.g. a specific role is defined to narrow and thus does not reflect the real situation). The CEOSIS approach enables the specification of such access rule changes and the precise analysis of their effects.

In summary, CEOSIS enables the representation of organisational structures as well as organisational changes that occur frequently in practice. This is based on a formal underpinning. Specifically, organisational changes including modification of organisational models and access rules are formally defined. Furthermore their formal semantics is provided. In addition, the set of offered change operations is complete,[7] i.e. any organisational model OM can be transformed to any other organisational model OM' by applying a set of change operations to OM as offered by CEOSIS. As proof sketch we assume that by applying respective delete operations OM can be first transformed into the empty organisational model OM_{empty}, which can then be transformed into OM' by applying create entity/relation operations afterwards. The same holds for access rule operations. However, note that CEOSIS additionally supports several high-level change operations in order to enable changes as a high level of abstraction as well, i.e. the offered set of change operations is not minimal.

The modelling of organisational entities and relations as well as of access rules has been implemented within the AristaFlow System process management system, which supports an even more expressive organisational meta-model as introduced in this paper (Reichert *et al.* 2009, Berroth 2005). Currently, the described functionality of organisational evolution is prototypically realised.

8. Related work

Issues related to change management and life cycle management have been addressed in many disciplines including software engineering (Kramer and Magee 1990), rule maintenance (March *et al.* 2000), and business process management (Rinderle *et al.* 2004b). Similarities to the CEOSIS approach can be observed, for example, in the context of business rule maintenance (Herbst and Myrach 1996, Herbst 1997). Business rules typically reference application data (e.g. the age of a patient in a medical setting) and thus, if the rule or the referenced data is changed, orphaned references might result. Existing solutions apply repository technology to deal with such problems (Herbst and Myrach 1996). However, in addition to maintaining the references of rules, CEOSIS exploits the semantics of the applied change operations on organisational structures in order to proactively propose strategies to deal with such orphaned references. Furthermore, when evolving organisational structures other fundamental problems such as empty actor sets of non-resolvable worklists can occur which require new strategies to handle them properly.

The provision of an adequate access control framework is indispensable for any EIS. In the literature numerous approaches have been presented dealing with challenging issues related to access control, e.g. Klarmann (2001a), Bertino (1998), zur Muehlen (2004), Weber *et al.* (2005). These approaches range from traditional privilege management techniques such as *Access Control Lists* (ACLs) and *Capability Lists* (CPs) (Bishop 2002, Miller *et al.* 2003) to *Role-Based Access Control (RBAC)*. ACLs and CLs constitute a certain partitioning of the complete *privilege matrix*. In an EIS, for each subject S (e.g. a user) and each object O (e.g. a document) the privilege matrix maintains an entry on the privileges of S on O. ACLs maintain a list of authorised users for each object. CLs, in turn, manage a set of capabilities for each user for accessing certain objects. ACLs and CLs are well suited for privilege management in more static systems, i.e. systems for which users and objects remain quite stable over time. However, as many examples show, the set of users as well as the set of objects are frequently subject to change in EIS (Ferraiolo and Kuhn 1992). ACLs and CLs are not well suited for such flexible systems due to the enormous reorganization effort after changes.

Thus, many approaches use RBAC for defining and managing user access privileges (Bertino 1998, Ferraiolo and Kuhn 1992, Ferraiolo *et al.* 2003, NIST 2004), in EIS, e.g. to control the access to business documents and database objects, or to resolve the set of actors that qualify for a newly activated task in a *workflow system* (Botha and Eloff 2001, Bertino *et al.* 1999, Wainer *et al.* 2003, zur Muehlen 2004, Pfeiffer 2005, Weber *et al.* 2005).

Usually, corresponding models provide core RBAC features as well as role hierarchies. Regarding workflow-based applications, in addition, dynamic constraints (e.g. separation of duties) were extensively investigated in the past (Bertino *et al.* 1999, Wainer *et al.* 2003, Kuhn 1997). Practical issues related to RBAC (e.g. NIST's proposed RBAC standard, integration of RBAC with enterprise IT infrastructures, RBAC in commercial products) are summarised by Ferraiolo and Kuhn (1992).

In the workflow literature several proposals have been made aiming at adaptive process management, e.g. van der Aalst (2001), Rinderle *et al.* (2004a), Joeris and Herzog (1998), Weske (1999), Sadiq *et al.* (2000), Fent *et al.* (2002), Kochut *et al.* (2003), Edmond and ter Hofstede (2000). The ADEPT technology, for example, enables controlled changes at the process type as well as the process instance level; for details see Reichert and Dadam (1998), Rinderle *et al.* (2004b). Thereby, correctness and consistency constraints of a workflow are preserved when dynamically changing its structure, its state, or its attributes during runtime. In Weber *et al.* (2005) an extension to RBAC is proposed in order to accomplish such process changes is a safe way, i.e. to restrict changes to selected user groups or processes if required. Though all these approaches stress the need for adaptive information systems and define notions of correctness (for an overview see Rinderle *et al.* (2004a)), so far, focus has been on process changes. Hence the CEOSIS approach for the evolution of organisational structures is complementary to these approaches and therefore constitutes an important step towards a comprehensive support for adaptive information systems.

There are only few approaches (Klarmann 2001b,a, Domingos *et al.* 2003) which address the problem of organisational change and its handling in EIS. In Klarmann (2001b, a), eight categories of structural changes on organisational models are identified. Examples include the splitting of organisational units, the creation of new organisational entities, and the reassignment of an actor to a new organisational unit. In principle, all these cases can be captured by our change framework as well. As opposed to Klarmann (2001a), however, we additionally follow a rigorous formal approach in order to be able to derive the effects of organisational changes on related access rules as well. Corresponding issues are factored out by Klarmann (2001a). In Rinderle and Reichert (2005, 2007), we have ourselves introduced a first approach for evolving organisational models and for propagating corresponding changes to access rules. However, this previous work did not consider direct changes of access rules, i.e. changes which are independent of whether or not the underlying organisational model has been adapted.

The approach introduced by Domingos *et al.* (2003) deals with the evolution of access rules in workflow systems. However, only very simple scenarios are described without any formal foundation. Furthermore, the compact definition of access rules is aggravated by the lack of adequate abstraction mechanisms (e.g. hierarchical structures). Issues related to the modelling of organisational structures have been considered by different groups (Jablonski *et al.* 2001, zur Muehlen 2004, Berroth 2005). Most of them suggest a particular meta-model for capturing organisational entities and the relationships between them. Model changes and the adaptation of access rules, however, have not been studied by these approaches in sufficient detail. Particularly, no formal considerations exist and no proof-of-concept prototypes have been provided.

Ly *et al.* (2005) introduced *access rule mining* as first approach for the (semi-) automatic discovery of access rule optimizations (cf. Figure 2). This work has been extended by Rinderle-Ma and van der Aalst (2007). Using special mining techniques, it can be detected whether and – if yes – how users deviate from pre-specified access rules within daily business life, e.g. in case a task within a PAIS is always passed to a substitute. As another example consider a scenario where two users A and B qualify for a particular task, but always user A selects the corresponding work item. In both cases, the associated access rules should be optimised by directly adapting them.

In van der Aalst and Jablonski (2000) important issues related to changes of processes and organisational structures are discussed. In this work the authors also motivate the need for the controlled change of organisational models. In particular, they discuss different kinds of adaptations that have to be supported by respective components (e.g. to extend, reduce, replace, and re-link model elements). However, no concrete solution approach is provided (like, for example, formal change operators with well-defined semantics or mechanisms for adapting access rules after model changes).

9. Summary and outlook

In this paper, we have introduced an approach for managing the life cycle of access rules. First, we have shown how changes of an organisational model may affect related access rules. Second, we have presented issues emerging in the context of direct access rule changes (e.g. due to optimizations or access rule mining). In order to be able to directly change access rules, a complete set of change operations has been presented. Furthermore, we have precisely defined the formal semantics of these change operations in order to avoid any ambiguity when applying them. Finally, the correct definition of change operations required the introduction of a tree-based representation of access rules with associated tree operations.

In future work, we will elaborate the effects of access rule changes (direct or due to organisational changes) on user worklists in process-aware information systems. For this we plan to build up cost models to measure the efficiency of different adaptation strategies. Furthermore, we will dig deeper into the area of access rule mining.

Notes

1. CEOSIS: Controlled Evolution of Organizational Structures in Information Systems
2. τ^* denotes an empty term.
3. Completeness means that a given organisational model OM can be applied to an arbitrary other organisational model OM' using the given set of change operations.
4. In Process-Aware Information Systems, generally, actors access activities via their worklists.
5. Complete means that any access rule $AR \in \mathcal{AR}^{OM}$ can be transformed into any other access rule $AR' \in \mathcal{AR}^{OM}$ by applying a sequence of change operations $<op_1, \ldots, op_n>$.
6. VOID represents the empty operator.
7. But not minimal due to the definition of high-level change operations based on basic change operations.

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