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as Architectural Reconfigurations<sup>1</sup>

Hyder Ali Nizamani and Emilio Tuosto

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# Patterns of Federated Identity Management Systems as Architectural Reconfigurations<sup>†</sup>

Hyder Ali Nizamani<sup>1</sup> and Emilio Tuosto<sup>2</sup>

<sup>1</sup> han3@le.ac.uk, <sup>2</sup> et52@mcs.le.ac.uk

Department of Computer Science  
University of Leicester, UK

**Abstract:** This paper proposes a formal model of Federated Identity Management systems (FIMs) in terms of architectural design rewriting. FIMs allow cross-domain user authentication to enable access control across the organisations under the concept known as Circle of Trust (CoT). Patterns of FIMs emerged as recurring CoT scenarios due to the fact that each of the pattern has different security and trust requirements. This paper proposes a formal model for FIMs to characterise their patterns as architectural styles. More precisely, an architectural style is given to precisely pinpoint all possible legal configurations of the CoT in terms of the patterns. The proposed model is specified through style-consistent (graphical) designs in terms of architectural design rewriting (ADR).

**Keywords:** Modelling, Federation, Identity Management, Circle of Trust, Patterns, Architectural Style, Reconfigurations.

## 1 Introduction

We give a definition of patterns emerging for *federated identity management systems* (FIMs) in a formal model of graph transformation. In particular, we show how patterns can be formally specified as architectural styles along with a representation of FIMs in a formal framework can suitably express transformations of their patterns.

The fundamental goal of FIMs is to share identity related information for cross-domain user authentication through some protocols and standards [15, 13, 11]. Typically, federations are created and managed by establishing legal (i.e., business, administrative, etc.) relationships by a set of contracts that specifies obligations and rights together with the policies each organisation has to follow [12]. These federated organisations form a Circle of Trust (CoT) that can be defined as a group of Service Providers (SPs) and Identity Providers (IDPs). Roughly upon requests to the services, the SP uses identity related information to enforce access control.

Nowadays, FIMs implementations may be found in various domains (i.e., finance, education, healthcare, etc.) and such systems are considered relatively static due to the nature of the CoT. However, a dynamic approach may be realised that enables organisations leaving or joining the CoTs to take some economic benefits in today's emerging dynamic and scalable systems (e.g., Clouds and Web 2.0). In this way, one can take advantages of service-oriented computing (SoC) that can provide not only functional but some non-functional requirements (i.e., security) as

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services. For instance, FIMs can be used to deal with access control in a cloud. Consequently, architectural modeling of these systems becomes necessary; for instance, in current distributed systems the possibility to tackle (dynamic) changes is paramount. Remarkably, this reflects at the architectural level and requires what is known as architectural *reconfiguration*. Architectural styles may provide a suitable mechanism for guiding the reconfigurations in a way that any change in the architecture does not violate the style. At the best of our knowledge, only informal FIMs models have been given; in [12, 7] some interesting FIMs patterns are presented in terms of security and trust requirements.

This paper focuses on modeling architectural aspects of FIMs that are validated against the patterns given in [12] and introduces an architectural style for the purpose. Architectural aspects of FIMs are formalised using *Architectural Design Rewriting* (ADR) that is a graphical formalism introduced in [4, 5] to formally specify architectural aspects of systems. The architectural styles corresponding to the patterns in [12] are formally characterised by a type graph and a few ADR productions. The type graph specifies the architectural elements of FIMs by describing components (edges) and their legal interconnections (nodes) while ADR productions formalise refinement. In fact, a selected FIMs pattern is generated by some design productions that guarantee a valid CoT by construction; for instance, as shown later, the constraint that a legal CoT configuration must have at least one IDP and one SP is formalised by suitable productions. In other words, architectural styles can model well-formedness conditions of FIMs as well as the patterns induced by the security and trust requirements studied in [4, 5].

The main motivations for using ADR are (i) that it is a mathematically precise framework, (ii) that ADR allows style-based design and, more importantly, (iii) that ADR features style-preserving reconfigurations of software architectures. Noteworthy, style-preserving reconfigurations are not naturally supported by other architectural description languages (cf. [6]). In ADR instead, style-preserving reconfigurations can be enforced by imposing simple conditions on the format of reconfiguration rules. More precisely, an ADR reconfiguration rule has the form

$$r : t \rightarrow t' \tag{1}$$

where  $t$  and  $t'$  are typed terms of an algebra induced by the graph rewriting mechanisms of ADR (i.e., productions); an ADR reconfiguration system is a set of rules where  $t$  and  $t'$  have the same type for each rule (1). Remarkably, style-preserving reconfigurations are paramount for FIMs as violations of well-formedness may hinder their correctness (security and trust requirements).

**Structure of the paper** § 2 briefly describes the concept of FIMs, some of their patterns, and basic definitions of ADR. The ADR model of FIMs is in § 3. Architectural configurations of the selected FIM patterns are in § 4 and their reconfigurations are addressed in § 5. Related work is given in § 6. Finally, the summary and the future research directions are briefly described in § 7.

## 2 Background

This section gives an overview of FIMs and the basic definitions of ADR.

## 2.1 Federated Identity Management

FIMs forms an interesting class of distributed systems that allow group of organisations to “federate” to share services (or resources). Typically, sharing distributed resources requires an access control system to authenticate users. FIMs make users’ authentication information available in a global context so that organisations can be part of different federations and have more business relationships with different group of organisations.

The roles involved in FIMs are

- users (whose identity is to be federated),
- identity providers (IDP), and
- service providers (SP)

where IDP vouch authentication statements for users (e.g., by issuing certificate) and SP dispense services.

*Example 1* A university can be part of a federation of digital libraries, in which case the university is the IDP, each library is an SP, and students and staff are users. ◇

The notion of *Circle of Trust* (CoT) is key to FIMs and permits to establish complex contracts that describe common policies and obligations. In [1], a CoT is defined as a framework that specifies a common set of cooperation policies together with collaboration interfaces within a certain group of organisations having trusted relationships. Users provide verified identities in order to access resources shared by member organisations of the CoT. FIMs allow users from different organisations to be authenticated when accessing remote resources in their CoT [16]. In FIMs, a CoT can be described as a federation of identity and service provider organisations.

FIMs are becoming ubiquitous and can be found in many different application contexts, including eCommerce, education, eHealth, eGovernment.

*Example 2* (cf. [10]) A financial institution needs its users (employees, customers, etc.) to access services offered by a third party provider. The financial institution is the IDP managing the authentication information of its users to the third party SP. The financial institution (IDP) authenticates its users to grant them access to SP’s resources. ◇

In FIMs, an SP relies on the authentication information sent by the IDP when users request access to services so to support *Single Sign-on* (SSO), namely allowing users to authenticate only at their IDP without re-authenticating themselves to access services offered by SPs in the CoT. In [7], architectural (and behavioural) aspects of FIMs are informally represented as a pattern for a CoT where a single IDP is federated to multiple SPs. Other patterns are informally described in [12]: (i) *Bilateral Federation*, (ii) *Multiple IDPs Federation*, (iii) *Multiple SPs Federation*, and (iv) *Arbitrary Federation*. The differences among those patterns are described in [12] in connection with trust relationships; each pattern has implication on trust management and what security threats the corresponding FIMs are exposed to (e.g., privacy of user identities, business data, access control, authentication). More precisely, patterns (i-iv) are ordered according to the

security threats they are subject to, pattern (i) being the “most robust”. We now briefly comment on the security threats hindering each pattern (see [12] for details).

In (i), a single IDP is federated to a single SP and they agree to deal with the private data according to common policies. Since the access to services is mediated by the IDP, the latter is aware of users’ activities (e.g., how often users communicate with the SP). The IDP may exploit this kind of information to acquire knowledge on users’ behaviour and this is regarded as a threat to users’ privacy. Also, SP receives information related to users’ identity from the IDP hence the SP might disclose (i.e., to other SPs) such information without the consent of the IDP or the user.

In (ii), a single SP is federated to multiple IDPs; users may be registered at several IDPs and they notify the SP about which IDPs will be used for authentication. The additional threat with respect to pattern (i) is that some or all IDPs might decide to cross-check the information about the accesses to the SP.

In (iii), a single IDP is federated to multiple SPs; a typical situation in this case is that delegation of user authentication is necessary. For instance, a service in the federation may be delegated (by an IDP or by another SP) to provide users’ credentials if it needs to invoke other services in the federation. The additional threats with respect to pattern (ii) include unauthorised delegation of authentication and “collusion” of SPs to accumulate identity information. The first threat may happen when users invoke a complex service that needs to make further invocations to other SPs in the federation. The second threat is quite serious as it would allow SPs to correlate their information and accumulate data on users.

Pattern (iv) is the most vulnerable as it allows the free combination of patterns (i-iii) and is exposed to all their threats.

## 2.2 Architectural Design Rewriting

The *Architectural Design Rewriting* (ADR) approach [4, 5] permits to design hierarchical and reconfigurable software architectures. The main features of ADR include a rule-based approach, hierarchical design, and an algebraic presentation. We borrow the main definitions of ADR from [4] (where more details can be found).

Software architectures are modeled in ADR as hypergraphs whose edges represent components and nodes (vertices) represent interconnections between the components.

**Definition 1** ([4]) A *(hyper)graph* is a tuple  $G = \langle V, E, t \rangle$  where  $V$  is the set of nodes,  $E$  is the set of edges and  $t : E \rightarrow V^*$  is the tentacle function.

*Example 3* An ADR graph on the sets  $\{\odot, \bullet\}$  (of nodes) and  $\{N, T\}$  (of edges) can be graphically represented as



The tentacle function is represented by the lines connecting edges ordered clockwise starting from the arrow-headed tentacle; the tentacle function of (2) maps  $N$  to  $[\odot, \odot, \bullet]$  and  $T$  to  $[\bullet]$ .  $\diamond$

The vocabulary of an architecture is given by a distinguished graph, the *type graph*, over which graphs are typed; edges are partitioned in *terminal* (not refinable) and *non-terminal* ones (refinable). In Example 3 the doubly-lined box  $N$  is non-terminal while  $T$  is a terminal.

**Definition 2** ([4]) A graph  $G$  is *typed* over a graph  $H$  when  $G$  is homomorphic to  $H$ , namely when there are  $f_V : V_G \rightarrow V_H$  and  $f_E : E_G \rightarrow E_H$  preserving the tentacle functions, i.e.  $f_V^* \circ t_G = t_H \circ f_E$ , where  $f_V^*$  is the homomorphic extension of  $f_V$  to  $V_G^*$ .

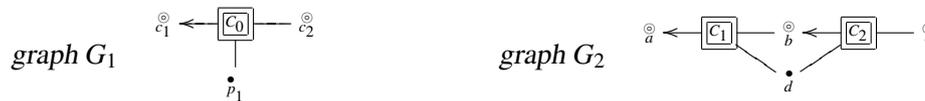
Architectures are modeled using designs which represent architectural components with their interconnections. Architectures can be composed using *design productions*.

**Definition 3** ([4]) A *design* is a graph with interface, i.e. a triple  $d = \langle L_d, R_d, i_d \rangle$ , where  $L_d$  is a (typed) graph consisting only of a nonterminal and by distinct nodes attached to its tentacles;  $R_d$  is a (typed) graph without nonterminal edges; and  $i_d : V_{L_d} \rightarrow V_{R_d}$  is a total function.

A (*design*) *production*  $p$  is a tuple  $\langle L_p, R_p, i_p, l \rangle$  where  $L_p$  is a (typed) graph consisting only of a nonterminal labeled by say  $A_p$  and by distinct nodes attached to its tentacles;  $R_p$  is a (typed) graph with both terminal and non-terminal edges;  $i_p : V_{L_p} \rightarrow V_{R_p}$  is a type preserving function; and  $l$  is a bijection mapping the non-terminal edges of  $R_p$  on an initial segment  $[1, 2, \dots, n_p]$  of positive numbers. Given a production  $p$  as above, call  $L_p$  the left-hand-side (LHS) of  $p$  and  $R_p$  the right-hand-side (RHS) of  $p$ .

Productions allow top-down design by refinement, bottom-up typing of the actual architecture and well-formed composition of the architectures. The set of design productions together with the type graph represent the architectural style.

*Example 4* Productions have a convenient graphical representation which we illustrate with an example. The graphs  $G_1$  and  $G_2$  below can be typed over the graph (2) in the obvious way



Ignoring the labelling function, the production with LHS  $G_1$  and RHS  $G_2$  (together with the homomorphisms) can be drawn as



where the outermost dotted box corresponds to  $G_1$ , the inner graph is  $G_2$  (with the explicit typing given by the homomorphism), and the dotted lines map the nodes of  $G_1$  to those of  $G_2$ .  $\diamond$

If non-terminal edges are considered as 'types' (of architectures), ADR productions have a convenient "functional" reading illustrated continuing Example 4.

*Example 5* Production (3) can be thought of as a function  $\mathbf{p} : N \times N \rightarrow N$  taking two architectures of 'type'  $N$  and returning a new architecture of type  $N$  so that productions become constructors of a sorted algebra of architectures whose terms yield configurations. For instance, if  $x$  and  $y$  are architecture of type  $N$ , the term  $\mathbf{p}(\mathbf{p}(x, y), x)$  is an architecture of type  $N$ .  $\diamond$

In ADR, the design rules can be given an algebraic formulation where a term describes a particular style-proof (as  $\mathbf{p}(\mathbf{p}(x,y),x)$  in Example 5). Style-preserving reconfigurations are operated at the level of style-proofs by exploiting term rewriting over style-proof terms. A graph transformation rule can be represented as a rewrite rule  $L \rightarrow R$ ; if  $L$  and  $R$  are terms of the same type the rule is style-preserving [5].

Let us define a reconfiguration rule to add components (at abstract level) to the architectures of type  $N$  given by the production in Example 5 and a production  $\mathbf{q} : N \rightarrow N$  that takes a configuration of type  $N$  and returns another configuration of type  $N$ . To illustrate this, assume  $x$  and  $y$  are architectures of type  $N$  and consider the reconfiguration rule

$$add(y) : \mathbf{q}(x) \rightarrow \mathbf{p}(\mathbf{q}(x),y)$$

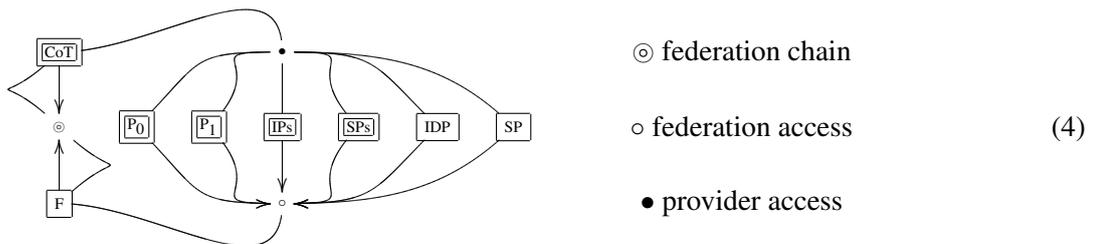
where a sub-term  $\mathbf{q}(x)$  of type  $N$  on the LHS of the rule is replaced by term  $\mathbf{p}(\mathbf{q}(x),y)$  of the same type on the RHS. Now, we demonstrate how to apply such a rule to reconfigure an architecture of type  $N$ . For instance, the reconfiguration

$$\mathbf{p}(\mathbf{q}(x_1),y_1) \rightarrow \mathbf{p}(\mathbf{p}(\mathbf{q}(x_1),y_2),y_1)$$

is obtained by applying the rule  $add$  to the subterm  $\mathbf{q}(x_1)$  on the LHS so to yield the term on the RHS where  $y_2$  is attached in the new configuration by means of the constructor  $\mathbf{p}$ .

### 3 Modeling FIM systems in ADR

We define FIMs architectures in terms of ADR productions on the type graph depicted in (4) which yields the vocabulary for the architectural elements of FIMs



The graph (4) yields the types of components and nodes represent the kind of ports used to connect them. More precisely, federation chain nodes  $\odot$  are used to form chains of edges of type  $F$  or  $CoT$ ; federation access nodes  $\circ$  connect  $IDP$  and  $SP$  providers with a federation  $F$ ; provider access nodes  $\bullet$  connect providers. Formally, the type graph (4) and is defined as

$$V_H = \{\odot, \circ, \bullet\} \quad E_H = \{CoT, F, P_0, P_1, IP_s, SP_s, IDP, SP\} \quad t_H : \begin{cases} CoT \mapsto [\odot, \odot, \bullet] \\ F \mapsto [\odot, \odot, \circ] \\ P_0, P_1, IP_s, SP_s, IDP, SP \mapsto [\circ, \bullet] \end{cases}$$

The non-terminal edges in (4) can be refined into complex graphs using the corresponding design productions (described later) that define legal configurations of FIMs. The non-terminal edge  $CoT$  will be refined into providers (i.e.,  $IDP$  and  $SP$ ) connected to each other and to their

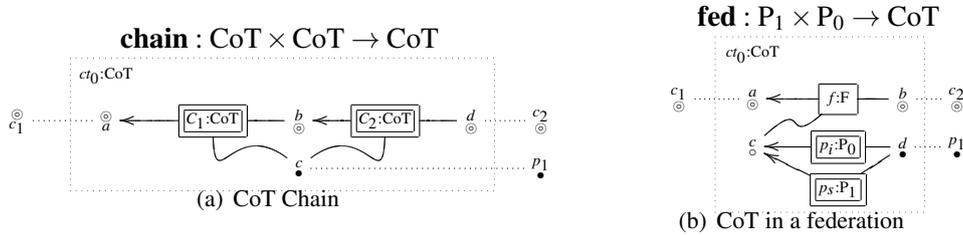


Figure 1: A CoT and a chain of CoT

federation in FIMs. These providers can be obtained by refining non-terminal edges; for example, by refining non-terminal edges of type  $P_0$  and IPs configurations with identity providers can be obtained, while configurations with service providers are obtained by refining non-terminal edges of type  $P_1$  and SPs. The terminal edges  $F$ ,  $IDP$ , and  $SP$  are the types for a federation, an identity provider, and a service provider respectively.

Figure 1 shows productions **chain** and **fed** that refine non-terminal edge  $CoT$  into a federation of providers and chain of  $CoT$ s. Notice that LHS and RHS of productions are typed over the graph (4). Production **chain** catenates  $CoT$ s  $C_1$  and  $C_2$  by connecting them on node  $b$  as illustrated in Figure 1(a). Also, node  $c$  is used to connect  $C_1$  and  $C_2$  to providers and exported together with  $a$  and  $d$  to possibly extend the chain. Production **fed** generates configurations of  $CoT$  by connecting several providers (obtained by refining  $p_i$  and  $p_s$ ) to each other and to a federation  $f$  as illustrated in Figure 1(b). Providers  $p_i$  and  $p_s$  interact with federation  $f$  through node  $c$  of type  $\circ$ ; nodes  $c_1$  and  $c_2$  allow  $f$  to connect to other  $CoT$  and node  $p_1$  to connect to other providers. Observe that  $c_1$ ,  $c_2$ , and  $p_1$  are the nodes of the LHS of **fed** corresponding to the nodes of the RHS as specified by the dotted lines and 'exported' in the interface of **fed**; also,  $p_1$  allows providers generated by  $p_s$  and  $p_i$  to connect to providers in other  $CoT$ s.

Figure 2 shows the productions to generate configurations of identity providers for  $P_0$  in production **fed**. Production **pips** generates a configuration consisting of an IPs and an  $IDP$ . Production **ips** generates configuration with many IPs (obtained by refining  $ip_1$  and  $ip_2$ ). Finally, productions **ip** and **noip** yield non refinable configurations; **ip** generates a single identity provider  $i$  while **noip** generates an empty configuration. The productions for generating service providers are similar to those in Figure 2 and they are reported in Appendix A.

We illustrate how the legal configurations of FIMs in (5) can be derived using the productions given above, by refining  $G_1$  into  $G_2$

$$G_1 = \begin{array}{c} \circ \leftarrow [C_1:CoT] \rightarrow \circ \\ \downarrow \\ \bullet \end{array} \quad G_2 = \begin{array}{c} \circ \leftarrow [f:F] \rightarrow \circ \\ \downarrow \\ \bullet \end{array} \begin{array}{c} [p_s:P_1] \\ \downarrow \\ \bullet \end{array} \quad (5)$$

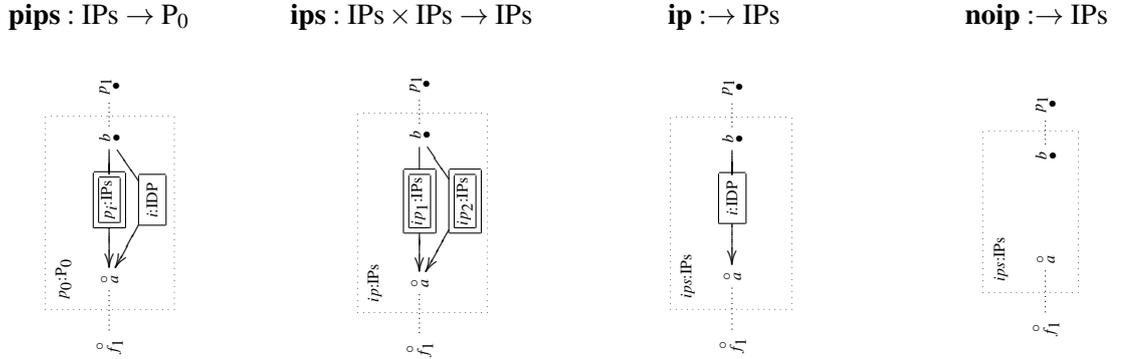
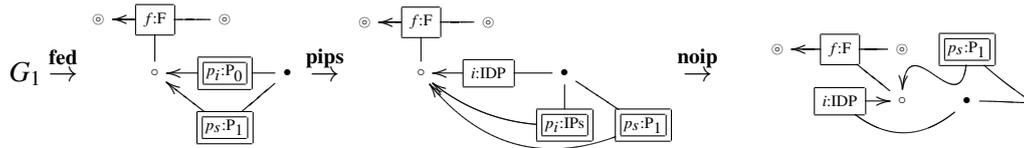


Figure 2: The Productions for Identity Providers

( $G_1$  and  $G_2$  are typed over (4) in the obvious way). The initial sequence of reductions is



Namely, in the first step, **fed** is applied to generate the federation  $f$ ; then the edge  $p_i$  is refined by applying **pips** yielding a provider  $p_i$  of type IPs and a provider  $i$  of type IDP. Finally, configuration  $G_2$  is obtained by applying **noip** which cancels the non-terminal  $p_i$ . Any configuration  $x$  refining  $P_1$  yields a term-like representation of  $G_2$  as **fed(pips(noip),  $x$ )** which highlights the hierarchical structure of the FIMs configuration  $G_2$ . In this way, the FIMs patterns can be generated and are illustrated in the next section.

## 4 Architectural configurations of the FIM patterns

We show how to generate the architectural configurations of the FIM patterns described in § 2.1. It is worth remarking that a configuration in ADR is generated by applying productions. Moreover, ADR configurations can be given a representation as a term of a suitable algebra. Such terms formalise FIMs patterns whose configuration is specified in the graphs corresponding to terms. To illustrate this, we apply the productions for FIMs and the approach given in § 3 to some simple examples.

Let us begin with the pattern (i). The configuration with a single IDP and a single SP is generated by applying production **fed** first then followed by a refinement of the non-terminal edges  $P_0$  and  $P_1$  (introduced by **fed**). In the second step indeed, productions **pips** generates the configuration for  $P_0$  consisting of a terminal IDP and a non-terminal IPs (and, similarly, productions **psps** generates the configuration for  $P_1$  that consists of a terminal SP and a non-terminal SPs). Observe that the obtained graph contains non-terminal edges IPs and SPs (introduced by applying **pips** and **psps**, respectively); these (spurious) non-terminal edges are cancelled using the productions **noip** and **nosp**. As a result, we obtain the configuration of the pattern (i) which is graphically

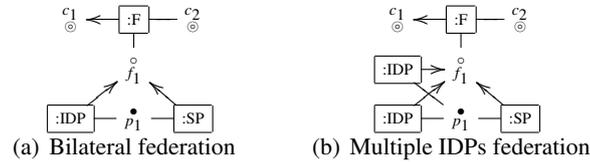


Figure 3: Some architectural configurations of the CoT in FIMs

represented in Figure 3(a) (where edge names are omitted as immaterial). In ADR, such configurations can be given an algebraic formulation; for instance, the configuration in Figure 3(a) is given by the term  $\mathbf{fed}(\mathbf{pips}(\mathbf{noip}), \mathbf{psps}(\mathbf{nosp}))$ .

An example of bilateral federation can be given by a scenario where an airline is federated to a hotel to allow a traveler to book a room after booking a flight; the traveler may use his/her airline account to access the hotel and book a room without need to be re-authenticated (in this case, the airline would act as IDP and the hotel as SP).

A configuration of pattern (ii) can be generated in a similar way as done for the configuration of pattern (i). For instance, consider the case where two IDPs are federated to a single SP. Initially, the same sequence of productions can be followed that is used above for generating configuration of pattern (i) where a single IDP is federated to a single SP, with the difference that before applying the  $\mathbf{noip}$  production, the non-terminal  $p_i$  in the production  $\mathbf{pips}$  is further refined using the production  $\mathbf{ips}$ . This introduces an additional IDP where either  $ip_1$  or  $ip_2$  in the production  $\mathbf{ips}$  is on turn refined by applying production  $\mathbf{ip}$ , while the other non-terminal is canceled using productions  $\mathbf{noip}$ . In this way, a configuration for pattern (ii) is obtained; its term representation is

$$\mathbf{fed}(\mathbf{pips}(\mathbf{ips}(\mathbf{ip}, \mathbf{noip})), \mathbf{psps}(\mathbf{nosp}))$$

and its graphical representation is in Figure 3(b). Example 6 illustrates a scenario where this pattern may be useful.

*Example 6* Suppose that the scenario described above has to be modified so that travellers are authenticated either by the airline company or via another account on train company. In other words the airline and the train companies act as IDPs while the hotel is the SP. According to pattern (ii), a traveler can book a room after booking a flight or a train.  $\diamond$

Configurations for the other patterns can be obtained in a similar way and examples are omitted for space limits.

For pattern conformance, one has to check whether a configuration belongs to a FIM pattern or not. In order to do so, one has to parse the corresponding term representation of the configuration and consider the occurrences of the productions that represent terminal edges. For instance, whenever productions  $\mathbf{pips}$  and  $\mathbf{ip}$  are applied each of them generate a single IDP; similarly, productions  $\mathbf{psps}$  and  $\mathbf{ip}$  generate an SP. Noteworthy, productions  $\mathbf{pips}$  and  $\mathbf{psps}$  can be applied only once to generate/part all the terms belonging to FIMs patterns. Such kind of conditions

enforce the creation of a legal CoT having at least one IDP and SP i.e., pattern (i). For conformance of rest of FIMs patterns i.e., patterns (ii-iv), one has to take into account the occurrences of productions **ip** and **sp** in the terms to enumerate IDPs and SPs respectively.

In the next section we show how reconfigurations can be described.

## 5 Architectural reconfigurations of the FIM patterns

Architectural styles may offer a suitable modelling mechanism to guide the changes at the architectural level; in fact, patterns for FIMs can be given in terms of ADR architectural style as illustrated in §4.

At run time, systems may need to be reconfigured; for instance, adding one or more components. Noticeably, such changes may need to be reflected at the architectural level, namely they may induce *architectural reconfiguration*. FIMs are no exception. The architectures of FIMs patterns may evolve during the life of their CoTs where IDPs and SPs can be added to the federations. For instance, the configuration of the pattern (i) consists of an airline (i.e., the IDP) and a hotel (i.e., the SP) can be reconfigured by introducing a train service (i.e., a new IDP). Such a change (adding an additional IDP) in the architecture reshapes the systems from pattern (i) to pattern (ii) so to allow users to book a room after booking a flight *or* a train.

This change of pattern can be defined at *basic* level (namely, one IDP, or one SP, or one instance of both is added) as well as at *abstract* level (namely, arbitrary collections of IDPs or SPs are added at once).

ADR offers a graphical support and a formal mechanism to deal with *style-preserving* architectural reconfigurations, namely architectural reconfigurations that do not modify the style. We remark that is crucial for FIMs as style preserving reconfigurations correspond to modifying configurations by changing their pattern while preserving a valid (legal) architecture. ADR can also express reconfigurations that violate styles. For instance, it is easy to define reconfiguration rules that cancel components so to obtain configurations without e.g., IDPs that are not considered valid FIMs. It is also worth remarking that the condition to preserve style is very simple; it is just necessary to ensure that LHS and RHS of the reconfiguration rule have the same type.

As we have seen in § 3, the design rules can be given an algebraic formulation where a term in ADR describes a particular style-proof.

In order to illustrate how ADR reconfiguration rules can describe variations of FIMs we consider the following rules.

$$addIDP : \mathbf{noip} \longrightarrow \mathbf{ips(ip, noip)} \quad (6)$$

$$addIDPs(X) : \mathbf{noip} \longrightarrow \mathbf{ips(X, noip)} \quad (7)$$

Intuitively, such rules allow us to add components; more precisely, they respectively introduce a new IDP and a set of many IDPs. Rule (6) is defined at basic level (terms without variables) to add a single IDP and rule (7) is defined at abstract level (terms with variables) to add a collection of IDPs to the configurations of FIMs patterns. Notice that in both rules the LHS and the RHS terms have the same type; this is central to preserve the style. In other words, ADR guarantees, by construction that when all reconfiguration rules preserve the types, then any derivation will

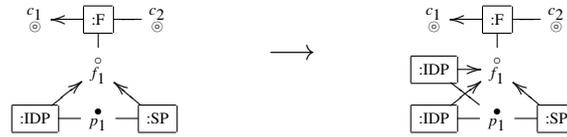


Figure 4: Rule to add an identity provider (from left to right)

not change the architectural style. Similarly, rules can be defined that add one or more SPs to the configurations of FIM patterns.

Table 1: Effects of basic reconfiguration rules on FIMs patterns

Rules	(i) to (ii)	(i) to (iii)	(ii) to (iv)	(iii) to (iv)	(i) to (iv)
Add a single IDP	✓			✓	✓
Add a single SP		✓	✓		✓

Table 1 shows the effects of basic reconfiguration rules that add a single IDP and a single SP on FIMs patterns (i-iv). Figure 4 (for simplicity, names of the edges are omitted) illustrates the reconfiguration of pattern (i) into pattern (ii) architecture by applying rule (6). The LHS graph shows configuration of pattern (i) consisting of an IDP (i.e., an airline) and an SP (i.e., a hotel). This architecture, is reconfigured by introducing an additional IDP (i.e., a train service) that yields a new configuration (RHS graph) that confirms to pattern (ii) with multiple IDPs federation. To illustrate such a change in the configuration obtained by applying rule (6), transition

$$\text{fed}(\text{pips}(\text{noip}), \text{psps}(\text{nosp})) \longrightarrow \text{fed}(\text{pips}(\text{ips}(\text{ip}, \text{noip})), \text{psps}(\text{nosp}))$$

describes the reconfiguration where the LHS term defines configuration of pattern (i) while the RHS term defines the new configuration that represent pattern (ii). In this reconfiguration, sub-term **noip** of type IPs on the LHS replaced with a new term **ips(ip, noip)** of same type on the RHS. Such a transition preserve the FIMs style. Similarly, the effects of applying the rule that adds an *SP* reconfigures the architecture of pattern (i) to pattern (iii). Moreover, rule (6) and the rule that add an *SP* can be applied together to reconfigure the architecture of pattern (i) to pattern (iv). Furthermore, these rules can be applied separately while moving from patterns (ii-iii) to pattern (iv), for instance; rule (6) can be used to move from pattern (iii) to pattern (iv) and the rule that add an *SP* to move from pattern (ii) to pattern (iv).

## 6 Related Work

Delessy et al. [7] describe a CoT that is informally represented as a pattern where a single IDP is federated to multiple SPs. They considered structural and behavioural aspects of FIMs. We give formal representation of various patterns of FIMs in terms of their structural and dynamic (i.e.,

reconfiguration) aspects. In [12], various federation patterns are described in terms of security and trust requirements. We formalise the patterns that are based on direct trust relationships, namely relationships not relying on third parties (cf. [12]).

In [17] two new types of representation models are introduced; such models are called *dimension graph* (DG) and *pattern graph* (PG). The former shows the relationship (pattern-to-dimension) of a pattern with respect to various “dimensions” (i.e., life cycle stage, architectural level<sup>1</sup>, security concern, business domain, type of pattern, and regulations/policies) of classification of security patterns. Instead, PG shows the relationship (pattern-to-pattern) of a pattern to other patterns. In [17], the focus is on representing properties (e.g., what pattern can be used for certain purposes) of the security patterns and relationships (e.g., what kind of patterns can be used at the next stage to realise a given pattern) between the security patterns using a metamodel in UML class diagram. The metamodel is then used to create DG and PG as its instances represented in UML object diagrams so to introduce an improved classification of security patterns that helps the designers in analysing, finding, and understanding security patterns at each level of the development process. We propose a generic architectural model that represents a class of FIMs patterns using a formal and a graphical approach. Our goal is the modelling of (direct security and trust) relationships between the collaborating organisations at an abstract architectural level. We represent FIMs patterns as instances (typed graphs) of the model whose corresponding terms precisely show their construction. Moreover, reconfiguration rules and their relationships have been defined in terms of their effects on the architectures of given FIMs patterns.

An informal pattern system for authentication and authorisation infrastructures (AAIs) has been described in [8] by showing the possible interactions between the patterns given in [7, 14]. In [8], the focus is on security aspects at implementation level and can be used directly in the software development process such as to deal with security in web services. The purpose of our work is twofold, one to formally model FIMs as an architectural style and other to deal with changes in their architectures while respecting the FIMs style. We provide a mechanism to formally model FIM at an abstract level that may be used for concrete implementation for detailed analysis of the FIMs properties (i.e., privacy) while allowing reconfiguration in the FIMs.

Finally, in [3] ADR has been promoted to model some aspects of SOA by proposing an architectural style for a modelling language featuring module composition. FIMs patterns could be modelled following the approach described in [2] where ADR has been used as a formal support of style-based designs and reconfiguration of a UML profile for SOA. However, such approach would require OCL constraints to represent FIMs which are complex to deal with in the FIMs context.

## 7 Summary and Future Work

In this paper, an architectural style for modeling the FIMs patterns is given in terms of ADR productions. More precisely, an architectural style is used to formally generate the architectures of the selected FIMs patterns that conform to the valid CoT configurations. Also, reconfigurations of these patterns are addressed in a way that any application of the reconfiguration preserves the style.

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<sup>1</sup> In [17] typical architectural layers are application, DBMS, operating system, distribution, and network.

Currently, we are working on some inductively defined reconfiguration rules for FIMs. Moreover, we also intend to investigate the possibility of modeling behavioural aspects using [9] in order to support the execution of FIMs architectures.

Finally, one or more architectural styles for FIMs may be designed in the future to support more complex patterns such as to model indirect trust relationships (i.e., through trusted third parties) between the collaborating organisations.

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## A Productions for Generating Service Provider Configurations

Figure 5 shows the productions namely **psps**, **sps**, **sp**, and **nosp** that can be used to generate the configurations of service providers in the FIMs patterns.

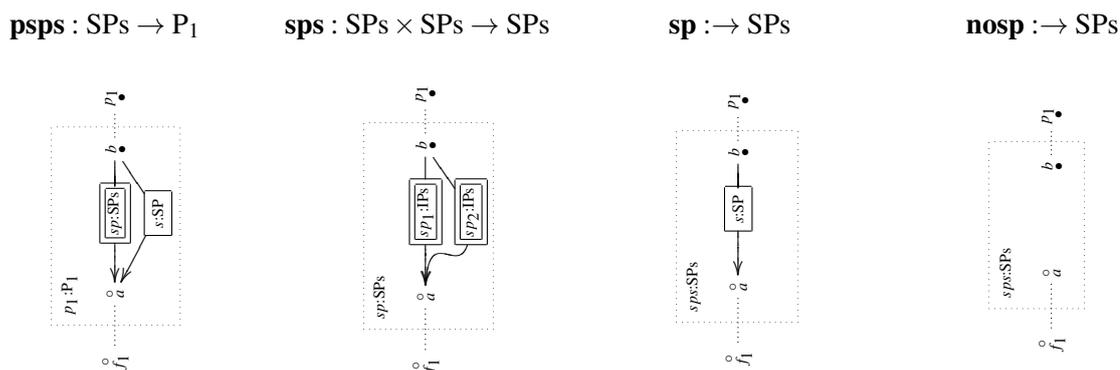


Figure 5: The Productions for Service Providers