

Policy-based Authentication and Authorization based on the Layered Privacy Language

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Abstract: In 2018 the *General Data Protection Regulation (GDPR)* has been enforced providing a new legal framework with rules and regulations for processing *personal data*. The requirement for distinguishing between purposes has been introduced, leading to the necessity of adapting existing authentication and authorization processes. We introduce a detailed authentication and authorization extension, which is able to verify requests on personal data based on the *Layered Privacy Language (LPL)*. This extension is evaluated in the form of a benchmark, utilizing the *Policy-based De-identification*, to demonstrating its efficiency and suitability for data-warehouses.

Keywords: Access Control, GDPR, Privacy, Privacy Language

1 Introduction

The *General Data Protection Regulation (GDPR)* has been enforced in Europe since May 25th 2018 constituting *Privacy by Design* and *Privacy by Default* for all technical systems [Co16, Art. 25]. Hereby, processing of personal data, which also includes storage of personal data in databases and data-warehouses, requires either a legal basis or consent [Co16, Art. 6]. Furthermore, several conditions for consent have to be fulfilled, including the necessity of the *Controller* demonstrating that the *Data Subject* consented. Consent has to be given freely, or consent has to be differentiated according to the purposes of processing [Co16, Art. 7, Recital 32]. Therefore, common authentication and authorization processes have to be adapted and extended to allow a purpose-based processing of personal data to comply with the GDPR. The Layered Privacy Language (LPL) in combination with its overarching privacy framework intends to comply with the requirements of the GDPR to enforce privacy policies 'from consent to processing' [Ge18b].

The focus of this work lies in the detailing of the extension of authentication and authorization by introducing purpose- and data-based authorization based on LPL as well as its evaluation. The evaluation considers the scalability of this extension utilizing a benchmark.

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In the following, we will give an introduction of relevant elements of LPL in section 2. Section 3 details the authentication and authorization processes of LPL introducing purpose- and data-based authorization, which will be evaluated in section 4. Related work is presented in section 5. Lastly, the work is concluded and future work is outlined in section 6.

2 Layered Privacy Language (LPL)

The Layered Privacy Language (LPL) is a domain specific language, designed to model legal privacy policies [Ge18b]. In the following, we will detail only the relevant elements for the scope of this paper. We also want to point out, that we will not consider the *UI Extension* [Ge18a] or *Art. 12-14 GDPR Extension* [GP18].

The root element of LPL is the *LayeredPrivacyPolicy*-element *lpp*, which has a set of *Purpose*-elements *p*, a *DataSource*-element *ds*, as well as several attributes which are not relevant for the scope of this work. Hereby, the *DataSource*-element denotes either the *Data Subject* or another legal entity (e.g. a *Controller*) providing the data. A *Purpose*-element further describes a set of *DataRecipient*-elements *dr* as well as a set of *Data*-elements *d*, further elements and attributes are omitted for the sake of this work.

Based on LPL an overarching privacy framework is developed, which is intended to provide both a user interface to inform the user on the privacy policy as well as the enforcement of the policy. In general, the life-cycle of LPL consists of six steps. It starts with the *Creation* step, in which the responsible data protection officer creates the LPL privacy policy. This policy is then presented to the *Data Subject* during the *Negotiation* step, in which the *Data Subject* can personalize it and eventually decides to accept or give consent to the personalized privacy policy or not. If the privacy policy is accepted or consented to, then the privacy policy will be validated and information about the *Data Subject* and its personal data will be added during the *Pre-Processing* before it is stored along with the regular data during *Storage*. During the *Transfer* step, data may be transferred to third parties under a negotiated policy, to which then the original privacy policy will be added. Lastly, the stored data will be processed during the *Usage* step, which will be the main focus in this work.

Hereby, the *Policy-based De-identification* process will be applied on each request for data processing, whereas data will be de-identified as necessary, when the requesting entity is authenticated and authorized to process the data for the specified purposes. The processes for authentication and authorization are the focus of this work and will be detailed in the following in the context of the *Policy-based De-identification*.

3 Policy-based De-Identification

A request on the *Policy-based De-identification* generally takes the form of the following tuple:

$$request = (userIdentifier, credential, \widehat{P}, \widehat{D}, \widehat{DS})$$

Where *userIdentifier* is the unique identifier of the requesting user (e.g. username), *credential* the credential of the user for authentication (e.g. password), \widehat{P} the set of all requested *Purposes*, \widehat{D} the set of all requested *Data* and \widehat{DS} the set of all requested *DataSources*.

LPL now defines four steps for this process of inspecting which *Data* the *Data Recipient* is allowed to request:

1. **Entity-Authentication.** Verify the authenticity of the requesting entity.
2. **Purpose-Authorization.** Get all *Child-Purposes* \widehat{P}_{child} of the requested *Purposes* $\widehat{P}_{requested}$ and consider which *Purposes* are relevant.
3. **Entity-Authorization.** Verify if the requesting entity (*Data Recipient*) is authorized to request the *Purposes* $\widehat{P}_{requested}$ (or \widehat{P}_{child}).
4. **Data-Authorization.** Verify whether it is allowed to request the requested *Data* \widehat{D} of the requested *Data Sources* \widehat{DS} with the authorized *Purposes* $\widehat{P}_{authorized}$.

The result of the de-identification process can be described as follows:

$$resultset = (\widehat{SD}); \quad SD = (dataSource, \widehat{DP}); \quad DP = (data, \widehat{P}_{result})$$

Where *dataSource* is a *DataSource*-element, *data* a requested and authorized *Data*-element, and \widehat{P}_{result} is the set of all relevant *Purposes* for a specific *Data*-element for a specific *Data Source*-element which are authorized. *DP* maps all relevant *Purposes* to a *Data*-element and *SD* maps this *Data-Purpose Maps* to a specific *Data Source*-element. The four steps of the *Policy-based De-identification* will be detailed in the following.

3.1 Entity-Authentication

The *Entity-Authentication* process has the task of verifying the identity of a *Data Recipient*. It will be inspected if the requesting entity is known³. Then the entity authentication will be conducted, based on the configured authentication method. A request on the *Entity-Authentication* has generally the form of the following tuple:

$$request = (userIdentifier, credential)$$

The module verifies if the handed *userIdentifier* and the *credential* belongs together. Some different authentication methods are possible (e.g. hashed passwords or OAuth). The result of *Entity-Authentication* is the authenticated *DataRecipient*-element dr_{auth} .

³ Basically, an entity is stored in the data-storage (e.g. database). But there can be some special cases when entities are known but not stored in the data-storage (e.g. for some API-keys)

3.2 Purpose-Authorization

The *Purpose-Authorization* process has the task of gathering all authorized *Purposes* for a specific request. Each *Purpose* p can have *Child-Purposes* \widehat{P}_{child} . Contrary to the original definition in [Ge18b], it will be allowed that a *Child-Purpose* inherits from two (or more) *Parent-Purposes*. This change in definition should provide the framework with more flexibility. It is important, that no cycles in the definition of the *Purposes* exists.

A *Purpose* p is relevant for a *DataSource*-element ds if it (or one of its *Parent-Purposes*) is part of the privacy policy of the *Data Source*. If a *Purpose* is mentioned in at least one of the requested *DataSource*-elements DS , it is relevant for the current request. A request on *Purpose-Authorization* has generally the form of the following tuple:

$$request = (\widehat{P}_{requested}, \widehat{DS}_{requested})$$

Where $\widehat{P}_{requested}$ is the set of all requested *Purpose*-elements and $\widehat{DS}_{requested}$ is the set of all requested *DataSource*-elements. The module initially receives all inherited child *Purpose*-elements \widehat{P}_{child} of the requested *Purpose*-elements $\widehat{P}_{requested}$ and then maps to each of the inherited child *Purpose*-elements P_{child} all *DataSource*-elements for which this specific *Purpose*-element is relevant. Finally, all elements from \widehat{P}_{child} , which do not have mapped any *DataSource*-elements, will be removed. The result of the *Purpose-Authorization* can be described as follows:

$$resultset = (\widehat{PD}); \quad PD = (p, \widehat{E})$$

Where p is the *Purpose*-element and \widehat{E} is the set of *DataSource*-elements for which the corresponding *Purpose*-element is relevant.

3.3 Entity-Authorization

The *Entity-Authorization* process verifies whether a *DataRecipient* dr is authorized for requesting a set of *Purposes* \widehat{P} . Each *Entity* e can have *Child-Entities* \widehat{E}_{child} . So, the *Entity* e can inherit the rights for requesting *Purposes* from its *Child-Entities* \widehat{E}_{child} . It is important, that no cycles in the definition of the *Entities* exists.

A *DataRecipient* dr is allowed to request a specific *Purpose* p if the *DataRecipient* dr or at least one of its children \widehat{DR}_{child} is authorized for using the *Purpose* p . A request on *Entity-Authorization* has generally the form of the following tuple:

$$request = (dr, \widehat{P}_{relevant}, \widehat{P}_{requested})$$

Where dr is the *DataRecipient*, $\widehat{P_{relevant}}$ is the set of all relevant *Purposes* and $\widehat{P_{requested}}$ ⁴ is the set of all requested *Purposes*. The result of *Entity-Authorization* is a set of all relevant *Purposes* for which the *Data Recipient* is authorized.

3.4 Data-Authorization

Data-Authorization verifies whether it is allowed to request the *Data* \widehat{D} of the *DataSource*-elements \widehat{DS} with the authorized *Purposes* $\widehat{P_{aut}}$. For each *Purpose* p it is defined which *Data* elements \widehat{D} are allowed to be requested for the *Purpose* p and for each *Data Source* ds *Purposes* are defined to be used. The result of *Purpose-Authorization* has already mapped each requested *DataSource*-element \widehat{DS} to its relevant *Purposes*. The *Data-Authorization* now has to reorder the map and get for each requested *DataSource* ds and each requested *Data* element d a set of possible *Purposes*. A request on *Data-Authorization* has generally the form of the following tuple:

$$request = (\widehat{D}, \widehat{DS}, \widehat{P_{aut}})$$

Where \widehat{D} is the set of all requested *Data*, \widehat{DS} is the set of all requested *DataSources* and $\widehat{P_{aut}}$ is the set of all authorized *Purposes*. Basically, the module reorder the data \widehat{D} , \widehat{DS} and $\widehat{P_{aut}}$ so that they are in the form of the resultset. Some different configurations of *Data-Authorization* are possible (e.g. return only data which are permitted for all requested *Data Source* elements). The result of the *Data-Authorization* can be described as follows:

$$resultset = (\widehat{SDP}); \quad SDP = (ds, \widehat{DP}); \quad DP = (d, \widehat{P})$$

Where p is the *Purpose*-element, ds the *DataSource*-element, d the *Data*-element and \widehat{E} the set of entities for which the corresponding *Purpose*-element is relevant.

4 Benchmark-Evaluation

We implemented the steps *Entity-Authentication*, *Purpose-Authorization*, *Entity-Authorization* and *Data-Authorization* on the basis of *section 3* in *JAVA* and verified the functionality with unit tests, to measure the execution times of the individual steps depending on the input variables (e.g. number of purposes) to determine the efficiency of the *Policy-based De-identification*. It is not the goal to be able to calculate the detailed execution times of specific requests on a dataset with specific parameters rather it is important for using the *Layered Privacy Language* on data-warehouses to ensure that the concept is scalable. In this section, execution times are analyzed, time intensive processes and method are to be found and if necessary and possible, improved or possible improvements found.

⁴ $\widehat{P_{requested}}$ will be needed for a specific system configuration where will be considered if the permission on at least on of the requested *Purposes* $\widehat{P_{requested}}$ is missing.

The execution time of a request basically depends on the *system-configuration* (e.g. type of entity authentication), the amount and dependencies of the *data in the data-storage* (e.g. number of possible Data Subjects) and the amount of the requested *Data Sources*, *Data* and *Purposes*. The goal is now to measure and compare the execution times of the individual steps while varying the individual parameters. For this purpose, it is necessary to implement a *Benchmark Test Suite* which tests all possible system configurations by entering the parameters for the data store and the requested data and then saves the individual execution times. For this the *Mockito* framework is used, to mock the interface to the persistence layer. Specifically, we determine the parameters in *Tab. 1*.

<i>PurposeAmount:</i>	Amount of different <i>Purposes</i> , which are predetermined.
<i>PurposeBranching:</i>	Degree of branching of the <i>Purposes</i> with each other.
<i>DataSourceNumber:</i>	Amount of different entities to which <i>Data</i> are stored.
<i>PurposePerLpp:</i>	Amount of <i>Purposes</i> for which a single entity has consented to.
<i>DataNumber:</i>	Value determining the amount of <i>Data</i> elements.
<i>DataPerPurpose:</i>	Value determining the amount of <i>Data</i> elements which can be requested with a single, specific <i>Purpose</i> .
<i>DataRecipientAmount:</i>	Amount of entities which are authorized to request data.
<i>RecipientBranching:</i>	Degree of branching of the <i>Data Recipients</i> .
<i>PurposePerRecipient:</i>	Amount of <i>Purposes</i> for which a single <i>Data Recipient</i> is authorized.
<i>RequestedPurposes:</i>	Amount of requested <i>Purposes</i> .
<i>RequestedData:</i>	Amount of different requested <i>Data</i> elements.
<i>RequestedDataSource:</i>	Amount of requested <i>Data Sources</i> .

Tab. 1: Configuration parameters for benchmark evaluation.

The *Benchmark Test Suite* first mocks the complete data store⁵ of the system depending on the configuration parameters. From this mocked objects, data (*Purposes*, *Data*, *Data Sources*) are determined, again depending on the configuration parameters, which should be used for a request to the system. This request then will be executed for every possible system configuration, measuring how much time each step will take. Finally, all measurements are stored in a separate, external database. All tests were executed on a *MacBook Pro (13 inch, Mid 2012)* with the operating system *macOS High Sierra (10.13.3)*, a *2,5 GHz Intel Core i5* processor and *16 GB 1600 MHz DDR3* random access memory.

The measurements were analyzed by comparing the change of the execution times by varying one single configuration parameter at a time. *Tab. 2* shows an example of such values. With this (and further) measurements it was possible to approximate algorithms to determine a dependency on the varied configuration parameter.

It can be observed that *Entity-Authentication* is affected by *DataRecipientAmount*, *Purpose-Authorization* is affected by *PurposeAmount*, *DataSourceNumber*, *PurposePerLPP*, *RequestedPurposes* and *RequestedDataSource*, *Entity-Authorization* is affected by *PurposeAmount*, *DataSourceNumber*, *PurposePerLPP* and *DataRecipientAmount*, *Data-Authorization* is af-

⁵ The persistence-layer of the system, holding the relevant user and meta data for the *Layered Privacy Language*.

RequestedDataSource	1	100	250	500	1000
Entity Authentication	0.38	0.38	0.5	0.41	0.37
Purpose Authorization	110.76	251.21	494.89	878.67	1675.47
Entity Authorization	1,59	1.84	1.82	1.89	1.88
Data Authorization	0.77	0.72	0.85	0.73	0.68
Total	113.6	254.25	498.16	881.84	1678.51

Tab. 2: Measured execution time in *ms* of the individual steps on varying the *RequestedDataSource*.

	Entity- Authentication	Purpose- Authorization	Entity- Authorization	Data- Authorization
<i>PurposeAmount</i>		✓	✓	
<i>PurposeBranching</i>				
<i>DataSourceNumber</i>		✓	✓	
<i>PurposePerLpp</i>		✓	✓	
<i>DataNumber</i>				✓
<i>DataPerPurpose</i>				✓
<i>DataRecipientAmount</i>	✓		✓	
<i>RecipientBranching</i>				
<i>RequestedPurposes</i>		✓		✓
<i>RequestedData</i>				✓
<i>RequestedDataSource</i>		✓		

Tab. 3: Relevance of the individual benchmark test parameters to the different steps.

ected by *DataNumber*, *DataPerPurpose*, *RequestedPurposes* and *RequestedData* (see Tab. 3). In summary, it could be observed that each of the benchmark parameters has at a maximum a linear effect on the execution time of the steps. This ensures scalability.

However, the parameters *DataSourceNumber*, *RequestedPurposes* and *RequestedDataSources* are noteworthy since they already have an execution time $>100ms$ in some tested scenarios. Which is unacceptable for a system that is intended to work in real-time, therefore further investigation research was executed.

In the following, the parameter *RequestedDataSources* is exemplary further analyzed. The measured values of the benchmark evaluation indicate the *RequestedDataSource* parameter has a direct, linear effect on the execution time of *Purpose Authorization*.

$$t_{purposeAuthorization} = 1,5708ms * RequestedDataSources + 100.69ms$$

The value *RequestedDataSources* determines the number of *DataSource*-elements from which data should be queried. A request of *10.000* elements and even bigger numbers are normal in data-warehouse scenario (e.g. for generating a statistic). With the given formula, we already get the execution times for a *RequestedDataSource* of *10.000*.

$$t_{purposeAuthorization} = 15808.69ms$$

These execution times for the step of *PurposeAuthorization* is not acceptable for a real-time system. In order to optimize the software design, additional measurements were taken and analyzed.

Put all requested and inherited <i>Purposes</i> to the key-set of which executing <i>getInheritedPurposes</i>	7 ms 7 ms
Put the <i>Data Sources</i> to the relevant <i>Purposes</i> of which executing <i>getLppRelevantPurposes</i>	1289 ms 1278 ms
Getting all not relevant <i>Purposes</i> of the key-set	<1 ms
Remove all not relevant <i>Purposes</i> from the result map	<1 ms
Total execution time	1296 ms

Tab. 4: Detailed measured execution times of *Purpose-Authorization* for the benchmark test parameter *RequestedDataSource*.

From the *1296 ms* execution time of the step *Purpose-Authorization*, are *1286 ms* waiting for methods of other modules (*PurposeRequestManager* - the mocked persistence layer). The pure computing time required by this step is approximately *10 ms*.

Thus, we note that the high measured execution times of the *RequestedDataSource* parameter are due only to the time Mockito takes to process the *getInheritedPurposes* and *getLppRelevantPurposes* methods. Further optimization of *Purpose-Authorization* does not seem necessary to solve the original problem of long execution times for a high amount of *RequestedDataSource*. By connecting the implementation to a high-performance persistence layer, the execution time of the steps promise to be within an acceptable range. This

determination can analogously be transferred to the parameters *DataSourceNumber* and *RequestedPurposes*.

In summary, it can thus be stated that the measured execution times are very much influenced *Mockito*, and that queries can be processed even faster by a high-performance persistence layer. The aim of this *section 4*, however, was merely to show that the implementation can also be used in large systems and is scalable. This could be demonstrated.

5 Related Work

Data protection and purpose-based storage and processing of personal data is not a new field of research. Thereby, some privacy languages were already proposed, each with their own distinct application [Ge18b]. In the context of authentication and authorization amongst other the privacy languages *AIR* [Kh10], *DORIS* [BB88], *E-P3P* [As02], *P2U* [IV14], *P3P* [Cr06], *Ponder* [SLL01], *Primelife policy language* [Ar09], *Rei* [Ka02], *SecPAL* [BFG10], *SPECIAL* [Ki18], *XACL* [BCF04], are worth mentioning.

But also in the context of database systems, purpose-based authorization has been introduced in *Hippocratic Databases* [Ag02], which we will detail in the following. In contrast to the *Layered Privacy Language*, the *Hippocratic Database* design is not to be considered as fixed technology or framework [vTJ11], but as a vision of a database system that implements the principles of *Purpose Specification, Consent, Limited Collection, Limited Use, Limited Disclosure, Limited Retention, Accuracy, Safety, Openness and Compliance*. In the concept of *Hippocratic Databases*, analogues to the *Layered Privacy Language*, *Purposes* are the central component. For the stored data, the *Purposes* is attached, which is relevant for this record, for example we look at the schema of *Tab. 5*. In contrast to the *Layered Privacy*

purpose	customer id	name	email
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Tab. 5: Database Schema for *Hippocratic Database*.

Language, the *Entity-Authentication* is not part of the *Hippocratic Database* concept. Furthermore, the *Layered Privacy Language* promises a more flexible *Data-Authorization* with different configuration parameters (e.g. return only consented data from *Data Subjects*) and so a more flexible usage of the framework.

6 Conclusion

The *Layered Privacy Language* defines six steps to privacy-preserving process data - *Entity-Authentication, Purpose-Authorization, Entity-Authorization, Data-Authorization, Minimum Anonymization and Application of Privacy Model*. The first four steps are detailed and evaluated in this work. The benchmark evaluation shows that the implemented modules

are scalable and capable of processing complex requests (many requested data, extensive data storage) efficient, which depends on an efficient backend.

For future works the remaining steps of the *Policy-based De-identification* process will be evaluated, showing the introduced overhead of the policy processing against the de-identification solely. Furthermore, we plan to introduce pseudonymization capabilities utilizing tokenization methodology in both LPL as well as the *Policy-based De-identification* process. Another concern is the possibility of privacy inference that has to be detected and prevented due to consecutive requests. Lastly, different scenarii, concerning relevant privacy use cases, will be defined and used to evaluate the complete *Policy-based De-identification* process based on LPL.

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