Semantic Interoperability Middleware – Cases and Applications in Electronic Government

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Abstract

Information systems in different public agencies need to seamlessly collaborate to support the delivery of public services through a one-stop government portal. For such collaboration to be successful, the systems must be organizationally, semantically and technically interoperable. In this paper, we illustrate the need for semantic interoperability services in Electronic Government and present a solution – Semantic Interoperability Middleware (SIM) that provides such services. Three case studies are drawn from the context of the delivery of welfare benefits involving the collaboration of different public and private organizations. Each case presents a need that is addressed through a SIM service – Mediation, Validation and Discovery. The paper also presents the requirements and architecture of SIM and highlights how SIM services address generic semantic differences and associated conflicts.

1. Introduction

Customer centricity is a fundamental principle of modern public administration. It involves reflecting the needs of government stakeholders in the packaging, organization and delivery of public services, rather than the structure of government [1].

Seamless collaboration among government organizations and other service delivery participants such as intermediaries and suppliers are required to support customer-oriented services delivered through a one-stop government portal [2]. However, seamless collaboration is only possible when technical, semantic and organizational interoperability are guaranteed among supporting information systems.

In particular, semantic interoperability requires that precise meaning of exchanged information is understandable by recipient applications, even when these applications were not initially developed for this purpose [3]. While standardization can help, guaranteeing conceptual regularity in a service delivery ecosystem with overlapping functional areas and domains is difficult. For instance, the same citizen could be a patient, beneficiary or student to different organizations (e.g. government hospital, welfare office and institution respectively) involved in processing such citizen's information. Ontologies can be used to formally describe how semantic differences and related semantic conflicts that may arise in the context of information exchange in general and Electronic Government [4] in particular can be resolved [5]. For simplicity, information systems that wish to exchange information could rely on a set of semantic services to exploit these ontologies in different situations.

In this paper, we illustrate the need for semantic interoperability services when enabling collaboration in the delivery of electronic public services and present a solution that provides such services. This need is illustrated through three case studies in the context of the delivery of welfare benefits at a one-stop portal. Each case study presents a set of semantic challenges – in terms of semantic differences and conflicts to be resolved. We present the Semantic Interoperability Middleware (SIM) as a solution that provides three major functional services - *Mediation*, *Validation* and *Discovery* - to address the needs presented by the case studies. Each SIM service addresses a set of semantic conflicts arising from specific contexts during service delivery based on the definitions and rules in relevant ontologies.

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The rest of the paper is organized as follows: Section 2 describes the case studies, Section 3 presents the SIM, Section 4 applies SIM to resolve case studies, and Section 5 draws some conclusions.

2. Case Studies

This section describes three case studies related to the delivery of welfare benefits through a one-stop government portal. The case studies were selected based on the analysis of typical collaboration patterns in Electronic Government [6], and in previous studies [7][8]. The collaborations involved in the delivery of selected welfare services are shown in Figure 1.

Governments provide welfare benefits to bring relief to beneficiaries. For instance, alleviating poor living conditions of citizens and providing financial aids to students. However, the provision of welfare benefits is guided by well defined eligibility conditions. Our case studies include four welfare benefits – child benefit, social assistance, housing benefit and retirement pension. Example eligibility criteria for the benefits are indicated below:

- *Child Benefit* - The applicant must be a citizen with at least two non-adult children and all included dependants in the application must be immediate family members - spouse or children.
- *Social Assistance* - The applicant must be a citizen with income below a specified amount. The applicant's income is defined as the total income of all applicant's household members.
- *Housing Benefit* - The applicant must be a citizen that does not own any residence.
- *Retirement Pension* - The applicant must be a citizen who is over 65 years of age.

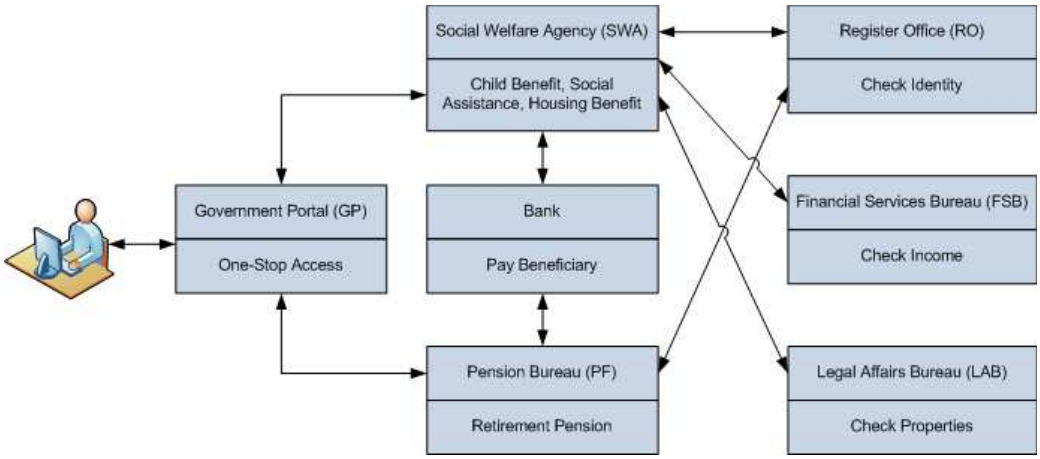

Figure 1. Collaborative Delivery of Welfare Benefits

The delivery of these benefits involves a variety of organizations. In our service ecosystem, the child, social assistance and housing benefits are provided by the Social Welfare Agency (SWA), while the retirement pension service is provided by Pensions Bureau (PB). From Figure 1, SWA and PB collaborate with other organizations such as: i) Register Office (RO) for verifying the identity of applicants; ii) Financial Bureau (FSB) for obtaining information on the applicants' income; iii) Legal Affairs Bureau (LAB) for checking the records of the properties owned by applicants; iv) and Bank (B) for disbursing the benefits. In addition, the benefits are accessed through a one-stop government portal (GP) that is maintained by a private-sector organization.

Each time a citizen applies for a benefit through GP, the following procedure is executed: (s1) Citizen logs into GP; (s2) Citizen looks for services suiting his needs; (s3) Citizen finds the service and selects it; (s4) GP displays a partially filled application form; (s5) Citizen completes the form with personal data and other information and submits; (s6) GP forwards the application form to the issuing agency - SWA or PB; and (s7) The agency (SWA or PB) processes the application in collaboration with other organizations, like RO, FSB, LAB, and Bank.

The steps above may involve addressing various semantic differences. Details of semantic differences and conflicts are discussed in [4][12], particularly in the context of public service delivery.

2.1. Case 1 - Recommending Benefits

This case illustrates the need for a service to overcome semantic difference that may arise between how a citizen conceives his/her necessity and the conceptual organization of services on the government portal (steps s2 and s3 of the process). Without guidance - recommender or discovery service at the portal, the citizen may fail to locate the required service due to semantic conflicts that are associated with the interpretation of evidence and

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precondition or eligibility rules for required service [12]. A possible way to assist a citizen is for GP to proactively suggest benefits suited to citizen's situation, based on his profile and eligibility criteria.

2.2. Case 2 - Checking Application Validity

Case 2 shows the need for a service to validate the contents of forms submitted by citizens through GP (for instance in step s5). When a citizen applies for a child benefit, say, GP validates the form based on some set of rules (checklist) for benefits applications. If the information supplied is valid, GP sends the form to SWA using a standard schema. SWA receives the information and checks for the eligibility of the applicant. If the applicant is not eligible, the application is rejected and the applicant is notified through GP. It would be desirable to check eligibility at the point of submission and to provide immediate feedback to applicants. In validating this application, semantic differences in the interpretation of evidence, evidence placeholders and preconditions may also arise. Traditionally, eligibility rules are embedded in software code. The maintenance of these rules necessitates code modification.

2.3. Case 3 - Mediating Information Requests

This case illustrates the need for a service to mediate semantic conflicts and to enable the collaboration required for processing valid submitted applications (step s7). SWA as the responsible agency for social assistance needs to request RO for the identity of the persons living with the applicant in order to calculate the applicant's income.

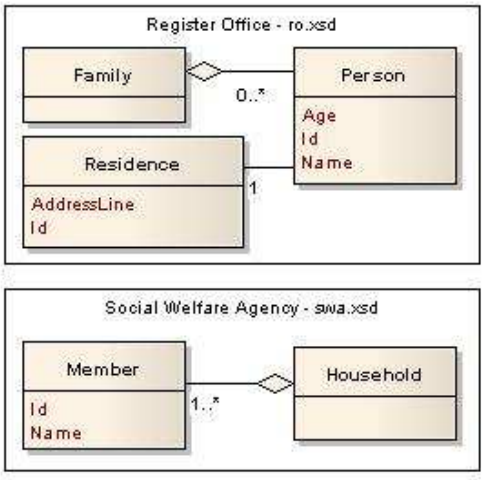

Figure 2. Household and Family – Heterogeneous Data Models

The exchange of data between SWA and RO is not automated since the two agencies arrange their records around different concepts. While SWA uses the concept of *Household* to describe a group of people sharing a Residence, RO uses the concept of *Family* to represent a group of people related through family bonds that may or may not share a Residence. This situation is depicted in Figure 2, which shows both SWA's schema (swa.xsd) and RO's schema (ro.xsd). There is a semantic difference between the concepts of Household and Family since the members of a household may not belong to the same family, and conversely persons constituting a family may not live together as part of a single household. Moreover, the two structures hold information about citizens but using different terms: Person and Member. There is a need to resolve these differences and automate the exchange of information between SWA and RO. The traditional solution to this problem relies on schema-based transformations. Developers usually implement such transformations based on their understanding of how meanings and terms in the two schemas are related.

3. Semantic Interoperability Middleware

The Semantic Interoperability Middleware (SIM) exploits ontologies to resolve semantic difference when enabling and maintaining collaborations among public- and private-sector organizations. It provides three domain-independent functional services (*Mediation*, *Validation* and *Discovery)* to address needs as the ones characterized in Section 2.

In contrast to other efforts like [9][10], SIM does not assume a specific technical architecture or environment such as Service Oriented Architecture (SOA), web services or any other communication middleware. It only assumes that collaborations are realized through the exchange of messages. This allows the use of SIM in the environments where the exchange of information is not supported by web services or SOA. The next sub-sections present the requirements and architecture of SIM.

3.1. Requirements

Three functional requirements F1, F2 and F3, and three non-functional requirements – NF1, NF2 and NF3 are specified. Each functional requirement addresses one of the needs presented in the cases:

F1) *Discovery* – SIM shall discover which resources are related to a given need. Given the descriptions of a need, the description of a set of resources, and particular criteria relating them, SIM shall provide a discovery service that infers a set of resources related to the need.

F2) *Validation* – SIM shall check that the data contained in a message is consistent with respect to some specified description.

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F3) *Mediation* – SIM shall resolve semantic differences in messages. It shall translate the contents of a sent message according to the receiver's terms and meaning.

Non-functional requirements describe design and architecture constraints for SIM:

NF1) *Explicit Semantics* – SIM shall use ontologies to describe the meaning of information and base its execution on it.
NF2) *Semantic Platform Transparency* – Client applications shall be independent of the underlying Knowledge Representation (KR) language and Reasoner used by SIM.
NF3) *Reusability* – SIM shall not depend on any particular communication middleware.

3.2. Architecture

The architecture depicted in Figure 3 shows the main components and their dependences. The behavior implementing each functional requirement (Discovery, Validation and Mediation) can be accessed through three methods defined in the `SIM Interface` component. This interface depends only on two components - one for resource identification and the other for handling XML documents.

The component SIM Implementation provides an implementation for SIM Interface. It depends on two components - one for ontology handling and another for reasoning. When a service is requested, the information is transformed from an XML format to an ontological format and loaded into the reasoner. Then, the reasoner is used to infer a response for the service. In the case of the Mediation service, the response is transformed back to XML format.

Non-functional requirements are realized as follows: NF1 - through the use of an ontology language and a reasoner; NF2 - not including in SIM Interface any class or interface specific to the ontology handler or reasoner; and NF3 - by making SIM completely independent of any particular communication middleware.

4. SIM Application

The following sections describe the application of SIM to resolve the case studies presented in Section 2. The implementation of the case studies using the SIM prototype is available at [11].

4.1. Solution - Recommending Benefits

SIM Discovery can be used to resolve Case 1 presented in Section 2.1. The service requires an ontology describing the personal data of citizens (needs), public services (resources), and eligibility criteria that relate both. For the purpose of this example, the following public services are considered: housing benefit, child benefit, and retirement pension. A fragment of the ontology describing eligibility criteria is shown in Table 1 using Manchester Syntax for OWL 1.1. When a citizen logs into GP, he can request the portal to suggest benefits suited to his/her personal situation. SIM Discovery responds with the benefits that the citizen is eligible for.

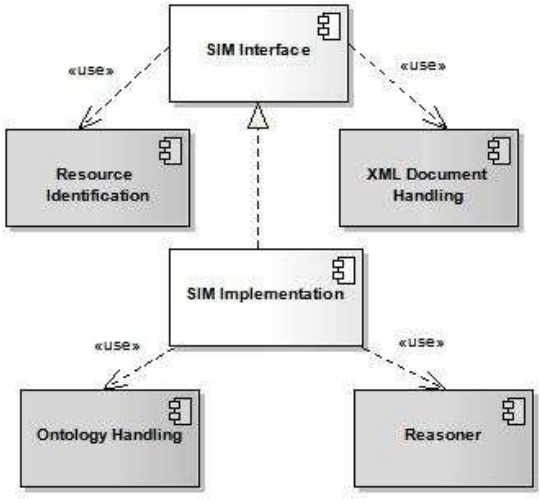

Figure 3. Architecture

Table 1. Ontology for Discovering Benefits

Child Benefit

`Class: EligibleForChildBenefit`
`  EquivalentTo: Person that`
`  hasChild min 2 Person`

Housing Benefit

`Class EligibleForHousingBenefit`
`  EquivalentTo: Person that`
`  owns exactly 0 Residence`

Retirement Pension

`Class: EligibleForRetirementPension`
`  EquivalentTo: Person that`
`  hasAge >=65`

In this function, SIM addresses semantic conflicts related to evidences and evidence placeholders (objects of eligibility rules) supplied by citizens. These conflicts include labeling, data value and precision conflicts.

4.2. Solution – Checking Application Validity

SIM Validation service can be used to resolve Case 2 described in Section 2.2. An ontology that specifies validity criteria for a child benefit application form is required. The message containing an application form is transformed into ontology individuals. If an individual of a valid application form can be inferred from the message, then the

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application form is considered valid. See Row 1 – ValidApplicationForm – in Table 2.

Table 2. Ontology for Detecting Ineligible Application Forms

1	`Class: ValidApplicationForm`
	`  EquivalentTo: ApplicationForm that`
	`  hasApplicant only EligibleApplicant`
	`  and hasDependant only ValidDependant`

	A valid application form is any application form having an applicant who is eligible and has only dependants who are valid.

2	`Class: EligibleApplicant`
	`  EquivalentTo: Applicant that`
	`  hasChild min 2 NotAdult`

	Eligible applicant is any applicant who has at least 2 children, and each of these children is not an adult.

3	`Class: ValidDependant`
	`  EquivalentTo: Dependant that`
	`  hasValidRelationWith min 1 Applicant`

	Specifies that a valid dependent is any dependant who has a valid relation with at least one applicant.

4	`Class: Applicant`
	`  EquivalentTo: Person that`
	`  appliesAsBeneficiary min 1`
	`  ApplicationForm`

	An applicant is any person who applies for a benefit by submitting at least one application form as a beneficiary.
5	`Class: NotAdult` `  EquivalentTo: Person that hasAge < 21`
	A non-adult is any person who has less than 21 years.

6	`Class: Dependant`
	`  EquivalentTo: Person that`
	`  appliesAsDependant min 1`
	`  ApplicationForm`

	A dependant is any person who applies as dependant in at least one application form
7	`ObjectProperty: hasParent` `  SubPropertyOf: hasValidRelationWith`
	The property hasParent is a valid relation to apply as dependant
8	`ObjectProperty: hasSpouse SubPropertyOf: hasValidRelationWith`
	The property hasSpouse is a valid relation to apply as dependant

In a similar way as in Section 4.1, applying SIM Validation service to resolve this case study allows to exploit ontologies (explicit semantics). The main benefit is that the specification of meaning is detached from software code and changing how information is interpreted may only require modifying this specification. In this way, propagating the changes in laws and regulations requires less effort. As an example, suppose the eligibility criteria for the child benefit changes to include applicant's parents as dependants in the application form. The change in semantics can be simply realized by adding the axiom below to the underlying ontology.

```
ObjectProperty: hasChild
  SubPropertyOf: hasValidRelationWith
```

The validation service resolves semantic conflicts related to rules, evidences and evidence placeholders.

4.3. Solution – Mediating Information Requests

SIM Mediation can be used to resolve the case described in Section 2.3. The service can translate messages before they are received by SWA. The necessary artifacts to resolve the problem are depicted in Figure 4.

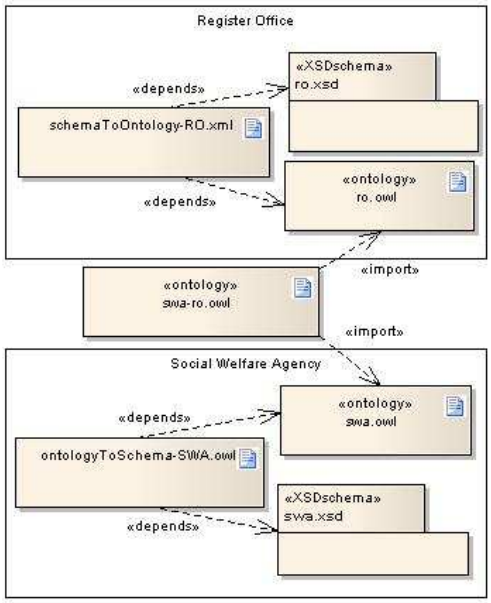

Figure 4. Artefacts to Resolve Semantic Differences

The message originated at RO is transformed into individuals of the `ro.owl` ontology according to the `schemaToOntology-RO.xml` transformation. The `swa-ro.owl` ontology specifies how the terms and meanings in RO (`ro.owl`) are related to the terms and meanings in SWA (`swa.owl`). Then the `ontologyToSchema-SWA.xml` specification is used to populate a new message according to the `swa.xsd` schema, inferring individuals of the concepts defined in the `swa.owl` ontology. The ontologies used by SIM to resolve the differences are shown in Table 3.

Through the mediation service, SIM also resolves schema-isomorphism conflicts due to difference in information structure as well as labeling conflicts

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due to the use of different labels for the same concept.

Table 3. Ontology Fragments for SWA-RO Mediation

swa-ro.owl	`Class: Household EquivalentTo:`
	`  Residence that`
	`  hasResident min 1 Person`
	`Class: Member EquivalentTo:`
	`  Person that`
	`  hasResidence min 1 Residence`
	`ObjectProperty:`
	`  hasResidence`
	`  Inverses: hasMember`

swa.owl	`ObjectProperty: hasMember`
	`  Domain: Household Range: Member`
	`Class: Household`
	`  SubClassOf: hasMember min 1 Member`

ro.owl	`ObjectProperty: hasFamilyMember`
	`  Domain: Family Range: Person`
	`ObjectProperty: hasResidence`
	`  Domain: Person Range: Residence`
	`ObjectProperty: hasResident`
	`  Domain: Residence Range: Person`
	`  Inverses: hasResidence`

5. Conclusions

We illustrated semantic interoperability problems in Electronic Government through case studies, and presented SIM as a solution to address them. Three advantages of applying SIM for resolving the cases were demonstrated: (i) SIM supports explicit semantics for the exchanged information; (ii) SIM enables participation of domain experts in the specification of the semantics of information, later used to execute SIM services; and (iii) SIM enables easy propagation of the effects of changes in regulations to system functionality.

Future work includes the development of services to address organizational interoperability issues; the formalization of SIM services; and the development of ontologies for welfare benefits and other types of public services. In addition, we intend to see how the output of other successful projects such as the SemanticGov and Access-eGov can be integrated with our solution to address semantic interoperability problems in e-government.

6. Acknowledgements

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