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SECURITY POLICY ENFORCEMENT IN APPLICATION ENVIRONMENTS USING DISTRIBUTED SCRIPT-BASED CONTROL STRUCTURES

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**SECURITY POLICY ENFORCEMENT IN APPLICATION ENVIRONMENTS
USING DISTRIBUTED SCRIPT-BASED CONTROL STRUCTURES**

by

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Abstract

Security Policy Enforcement in Application Environments Using Distributed Script-Based Control Structures

Klaus-Peter Fischer-Hellmann

Dipl.-Math.

Business processes involving several partners in different organisations impose demanding requirements on procedures for specification, execution and maintenance. A framework referred to as business process management (BPM) has evolved for this purpose over the last ten years. Other approaches, such as service-oriented architecture (SOA) or the concept of virtual organisations (VOs), assist in the definition of architectures and procedures for modelling and execution of so-called collaborative business processes (CBPs).

Methods for the specification of business processes play a central role in this context, and, several standards have emerged for this purpose. Among these, Web Services Business Process Execution Language (WS-BPEL, usually abbreviated BPEL) has evolved to become the de facto standard for business process definition. As such, this language has been selected as the foundation for the research in this thesis.

Having a broadly accepted standard would principally allow the specification of business processes in a platform-independent manner, including the capability to specify them at one location and have them executed at others (possibly spread across different organisations). Though technically feasible, this approach has significant security implications, particularly on the side that is to execute a process.

The research project focused upon these security issues arising when business processes are specified and executed in a distributed manner. The central goal has been the development of methods to cope with the security issues arising when BPEL as a standard is deployed in such a way exploiting the significant aspect of a standard to be platform-independent

The research devised novel methods for specifying security policies in such a manner that the assessment of compliance with these policies is greatly facilitated such that the assessment becomes suited to be performed automatically. An analysis of the security-relevant semantics of BPEL as a specification language was conducted that resulted in the identification of so-called security-relevant semantic patterns. Based on these results, methods to specify security policy-implied restrictions in terms of such semantic patterns and to assess the compliance of BPEL scripts with these policies have been developed. These methods are particularly suited for assessment of remotely defined BPEL scripts since they allow for pre-execution enforcement of local security policies thereby mitigating or even removing the security implications involved in distributed definition and execution of business processes.

As initially envisaged, these methods are comparatively easy to apply, as they are based on technologies customary for practitioners in this field. The viability of the methods proposed for automatic compliance assessment has been proven via a prototypic implementation of the essential functionality required for proof-of-concept.

Contents

List of Figures	ix
List of Tables	xi
List of XML Snippets	xii
List of Abbreviations and Acronyms.....	xiii
Acknowledgements.....	xvii
Author's Declaration	xix
1 Introduction.....	1
1.1 Aims and Objectives	4
1.2 Thesis Structure	6
2 Cross-Organisational Deployment of Business Processes.....	9
2.1 Extended Use of Business Process Definition Languages in CBP Scenarios	11
2.2 Motivating Example of Cross-Organisational Business Process.....	13
2.2.1 Description of Business Process Example.....	14
2.2.2 Security Policy-Induced Restrictions in Cross-Organisational Business Process Execution.....	17
2.3 Security Issues Related to Cross-Organisational Deployment of CBP	19

2.4	Restriction of Research to WS-BPEL without Loss of Generality	22
2.5	Summary	25
3	Approaches to Specification and Enforcement of Security Policies	27
3.1	Specification of Security Aspects for Web Services	29
3.1.1	Web Service Security (WS-Security)	31
3.1.2	WS-SecurityPolicy	32
3.1.3	WS-Trust	32
3.1.4	Web Services Policy Framework (WS-Policy)	33
3.1.5	Security Assertion Markup Language (SAML)	33
3.1.6	eXtensible Access Control Markup Language (XACML)	34
3.2	Role-Based Access Control for Web Services and Business Processes	35
3.3	Relation of Programs and Programming Languages with Security Policies	38
3.4	Verification of Consistency between Program Code and Security Policies	43
3.5	Security Policy Enforcement via Code Instrumentation and Runtime Monitoring	45
3.6	Summary	48
4	Analysis of Security-Relevant Semantics of BPEL	52
4.1	Scope of Analysis	52
4.1.1	Search for Security-Relevant Building Blocks of BPEL Semantics	55

4.1.2 Trade-Off Between Policy Strictness and Functional Richness.....	56
4.1.3 Need for Information Flow Analysis in Policy Compliance Assessment	58
4.1.4 Approach to Dispensability of Security Classification System.....	59
4.1.5 Risks of Policy Violations of Remotely Defined Business Processes.....	62
4.2 Overview of BPEL Semantics	63
4.2.1 General Structure of BPEL Scripts.....	66
4.2.2 Primitive and Structured Activities in Normal Process Flow.....	68
4.2.3 Additional Flow Control and Structuring Elements.....	70
4.2.4 Special Activities for Fault Handling	72
4.2.5 Concept of Multiple Instantiation in BPEL.....	73
4.2.6 Extensibility of BPEL and Problems for Compliance Assessment Involved.....	73
4.3 Classification of Security Policy-Derived Restrictions for WS Invocation.....	75
4.4 Security Analysis of Semantic Patterns of BPEL	82
4.4.1 Definition of Semantic Patterns of BPEL.....	82
4.4.2 Results of Security Analysis of Semantic Patterns.....	83
4.5 Considerations with Respect to Separation of Duty Constraints	92
4.6 Summary	94

5	Specification of Security Policy for Compliance Assessment of CBPs	96
5.1	Redefinition of Security Policy in Terms of Security-Relevant Semantic Patterns.....	99
5.2	Security Policy Statement	100
5.2.1	Security Policy Statement Template.....	101
5.2.2	Internal Web Service Restriction Statement.....	105
5.2.3	External Web Service Restriction Statement.....	109
5.3	Approach to Reduce Complexity of Security Policy Statements	112
5.4	Coping with Dynamic Aspects in Static Compliance Analysis.....	114
5.5	Summary	118
6	Security Policy Compliance Assessment for BPEL Scripts	120
6.1	Procedure of Compliance Assessment.....	120
6.1.1	Prerequisites for Compliance Assessment.....	121
6.1.2	Analysis of Declaration Part in BPEL Script	122
6.1.3	Checking BPEL Script for Security-Relevant Semantic Patterns	123
6.1.4	Example of Covert Channel Establishment in BPEL Script	124
6.1.5	Information Flow Analysis in Parallel Flows.....	126
6.2	Workflows in Distributed Definition and Execution of CBPs.....	128
6.3	Delegation of Security Policy Compliance Assessment.....	132

6.3.1	Domain-Internal Delegation of Compliance Assessment	133
6.3.2	Domain-External Delegation of Compliance Assessment	134
6.4	Summary	137
7	Proof of Concept by Research Prototype	139
7.1	Scope of Research Prototype	139
7.2	Machine-Readable Format of Security Policy Statement	147
7.2.1	Rationale for Definition of XML Schema in Current Form	148
7.2.2	Annotated SPS Schema in Condensed Notation	149
7.3	Architecture of Research Prototype	154
7.4	Functionality of Research Prototype at a Glance	156
7.4.1	Conversion of SPS into Internal Representation	157
7.4.2	Conversion of Variable Declarations into Internal Representation	158
7.4.3	Combined Forward/Backward Information Flow Analysis	158
7.4.4	Handling of Parallel Flows in Information Flow Analysis	161
7.4.5	Implementation of Covert Channel Prevention	162
7.5	Evaluation of Research Prototype	163
7.6	Summary	167

8	Examining the Wider Applicability of the Results	170
8.1	Motivation for Remote Definition of Grid Processes	171
8.2	Approaches to Specification of Grid Service Security	177
8.3	Security-Relevant Semantic Patterns in BPEL-Based Grid Processes	179
8.4	Rewriting Security Policies to Support Pre-Execution Security Policy Assessment	184
8.5	Delegation of Security Assessment.....	189
8.6	Summary	192
9	Conclusions and Directions of Further Research.....	194
9.1	Achievements of the Research.....	194
9.2	Limitations of the Research	197
9.3	Directions of Further Research	201
	Appendices.....	203
A.1.	Published Papers	203
A.2.	XML Schema for Security Policy Statement.....	206
A.3.	Outline of Sophisticated Covert Channel Prevention for Activity validate	211
A.4.	Java Code of Research Prototype.....	213
A.5.	Examples of BPEL Scripts Used for Validation of Research Prototype	213

A.6. Copies of Web Pages Referred in Section References	213
References.....	214
Copies of Own Publications	224
Addendum	
CD-ROM	(inside back cover)

List of Figures

Figure 1: Layered Architecture in Business-to-Business Interaction	2
Figure 2: Collaborative Business Process Using Locally Defined Subprocesses	10
Figure 3: Cross-Organisational Deployment of Business Processes	12
Figure 4: Collaborative Business Process Example	13
Figure 5: Security Policy Statement Template with Exemplary Entries	102
Figure 6: Example of Internal Web Service Restriction Statement.....	107
Figure 7: Example of External Web Service Restriction Statement.....	110
Figure 8: Steps for Reduction of Complexity of Security Policy Statement (Part 1)...	112
Figure 9: Steps for Reduction of Complexity of Security Policy Statement (Part 2)...	113
Figure 10: Steps for Reduction of Complexity of Security Policy Statement (Part 3).	113
Figure 11: Covert Channel Example	125
Figure 12: Workflow for Specification of Security Policy Statements	129
Figure 13: Workflow for Compliance Assessment of BPEL Script.....	130
Figure 14: Workflow Deployment and Execution of BPEL Script.....	131
Figure 15: Domain-Internal Delegation of Security Assessment	133
Figure 16: Outsourcing of Security Assessment.....	135

Figure 17: Class Diagram of Research Prototype..... 155

Figure 18: Successful Assessment of BPEL Script in Research Prototype..... 156

Figure 19: Detection of SPS Violation in Research Prototype..... 157

Figure 20: Grid Process Execution Scenario 172

Figure 21: Reducing Maintenance Overhead by Remote Definition of
Grid Processes 174

List of Tables

Table 1: Classification of Access Restrictions to Web Services and WS Parameters....	77
Table 2: Security Relevance of Semantic Patterns with Primitive Activities.....	85
Table 3: Security Relevance of Semantic Patterns with Structured Activities.....	90
Table 4: Coverage of Checking Functionality by Prototype	143
Table 5: Comparison Between CBP Context and Grid Context.....	176
Table 6: Classification of Access Restrictions to Grid Services and GS Parameters...	180
Table 7: Security Relevance of Semantic Patterns with Primitive Activities (Grid)....	181
Table 8: Security Relevance of Semantic Patterns with Structured Activities (Grid)..	183

List of XML Snippets

Listing 1: Graph-Structured Modelling	71
Listing 2: Block-Structured Modelling.....	71
Listing 3: Overall XML Structure of SPS	149
Listing 4: Structure of Internal Web Service Restriction Statement	150
Listing 5: Structure of Restriction Indication for Input Parameters	151
Listing 6: Structure of Restriction Indication for Output Parameters.....	152
Listing 7: Extract from BPEL Script Invoking WS not Defined in SPS	165

List of Abbreviations and Acronyms

ACM	Association for Computing Machinery
BEA	BEA Systems, Inc.
BPDL	Business Process Definition Language
BPEL	Business Process Execution Language
BPEL4WS	Business Process Execution Language for Web Services (formerly for WS-BPEL)
BPMI.org	Business Process Management Initiative
CBP	Cooperative Business Process
CHR	Constraint Handling Rules
CTMF	Conformance Testing Methodology and Framework
DAAD	Deutscher Akademischer Austauschdienst
DAC	Discretionary Access Control
EFSA	Extended Finite State Automaton (aka Extended Finite State Machine, EFSM)
EWSRS	External Web Service Restriction Statement
FQ	Frequency Check of Invocation

GGF	Global Grid Forum
GS	Grid Service
HTTP	Hypertext Transfer Protocol
IBM	International Business Machines Corp.
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IFA	Information Flow Analysis
INESC	Instituto de Engenharia de Sistema e Computadores, Lisbon, Portugal
ISO	International Organisation for Standardization
ITU	International Telecommunication Union
IWSRS	Internal Web Service Restriction Statement
MAC	Mandatory Access Control
NIST	National Institute of Standards and Technology
NRG	Network Research Group (University of Plymouth)
OASIS	Organization for the Advancement of Structured Information Standards
OGSA	Open Grid Services Architecture
OGSI	Open Grid Services Infrastructure
PCC	Proof Carrying Code
PDP	Policy Decision Point
PEP	Policy Enforcement Point

RBAC	Role-Based Access Control
RFC	Request for Comment
SAC	Security Assessment Centre
SAML	Security Assertion Markup Language
SAP	SAP AG
SLA	Service Level Agreement
SOA	Service-Oriented Architecture
SOAP	Simple Object Access Protocol
SOC	Service-Oriented Computing
SoD	Separation of Duty
SPS	Security Policy Statement
UDDI	Universal Description, Discovery, and Integration
UN	United Nations
UN/CEFACT	United Nations Centre for Trade Facilitation and Electronic Business
URI	Universal Resource Identifier
VO	Virtual Organisation
W3C	World Wide Web Consortium
WFMS	Workflow Management System
WS	Web Service
WSCI	Web Services Choreography Interface
WSDL	Web Services Description Language
WS-BPEL	Web Services Business Process Execution Language (abbr. BPEL)

XACML	eXtensible Access Control Markup Language
XML	eXtensible Markup Language
XPath	XML Path Language
XPDL	XML Process Definition Language

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Author's Declaration

At no time during the registration for the degree of Doctor of Philosophy has the author been registered for any other University award without prior agreement of the Graduate Committee.

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- 1st NRG Collaborative Research Symposium, Darmstadt, Germany, October 2005
- 6th International Network Conference, INC'2006, Samos, Greece, July 2006
- 2nd NRG Collaborative Research Symposium, Darmstadt, Germany, October 2006
- 1st International Workshop on Security Technologies for Next Generation Collaborative Business Applications (SECOBAP'07), Istanbul, Turkey, April 2007
- 3rd Collaborative Research Symposium on Security, E-learning, Internet and Networking (SEIN 2007), Plymouth, UK, June 2007
- 4th International Conference on Trust, Privacy & Security in Digital Business (TrustBus'07), Regensburg, Germany, September 2007

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1 INTRODUCTION

Service-oriented computing (SOC) is currently considered to be one of the most promising new paradigms for distributed computing (Curbera *et al.*, 2003; Foster and Tuecke, 2005; Papazoglou and Georgakopoulos, 2003). Though comparatively new, a significant amount of research has already been dedicated to this field (*e.g.*, Deubler *et al.*, 2004; Papazoglou and van den Heuvel, 2007). Web services, and the composition or choreography and orchestration of them, play a central role in current approaches to service oriented computing (Berardi *et al.*, 2003). Service orientation is also expected to have an important influence in the field of Grid computing, where the provisioning of computing resources within a conceptual huge network of collaborating computers and devices can also be fostered by services (so-called Grid services in this context) provided by different nodes (Tuecke *et al.*, 2003).

In service-oriented approaches using Web services, a layered architecture for composing new services from existing services or for executing processes based on existing services has emerged (Medjahed *et al.*, 2003), as shown in Figure 1 (adapted from *ibid.*, p.56). The communication aspects reside in the bottom layer. Messages between Web services and other communication partners are exchanged using standardised protocols such as SOAP (Box *et al.*, 2000) and HTTP (Fielding *et al.*, 1999). The layer above, the content layer, contains the definition of Web services, thereby providing a service-oriented architecture (SOA) in order to allow for service-oriented computing. Web Services Description Language (WSDL) (Christensen *et al.*, 2001) is used for the definition of Web services in this layer while Universal

Description, Discovery and Integration (UDDI) (Clement *et al.*, 2004) is intended for publication and discovery of Web services provided by an organisation in order to be used by others.

Business Process Layer	Vendor-Specific or Standardized Business Process Definition Technology
Content Layer	Web Services, WSDL → SOA, SOC
Communication Layer	SOAP, HTTP

Figure 1: Layered Architecture in Business-to-Business Interaction

While Web services are stateless by their definition, stateful processes reside in the top layer of this architecture, defining potentially long running business processes based on the invocation of Web services. Business process definition languages (BPDs) are used for the purpose of defining the orchestration and choreography of Web services in order to establish a business process. It should be noted that a business process defined using one of these languages can itself be considered a Web service from the point of view of external communication parties.

The request for fast adaptation of enhanced services and business processes to changing requirements led to a framework denoted as business process management. Methods for the specification of business process in the top-most layer of Figure 1 play a central

role. For this purpose, a high-level definition language is used abstracting from as many aspects as possible covered in the layers below. After an initial period where vendor-specific definition languages have been used coming with platforms for specification and execution of business processes, the need of standardisation to avoid dependency on certain platforms (vendor lock-in) has grown leading to a variety of business process definition languages (BPDs) for the specification of enhanced Web services or business processes in the top layer of Figure 1. These BPDs were initiated by different standardisation organisations or vendor groups. Of course, having competing standards aiming the same purpose detracts from the very function of seeking for standardisation in a particular field. Fortunately, one among these standard propositions, namely Web Services Business Process Execution Language (WS-BPEL or BPEL for short) propagated by the Organization for the Advancement of Structured Information Standards (OASIS) backed by many prominent vendors of business application platforms, evolved the de facto standard in this field even prior to its official acceptance as an OASIS standard in April 2007 (OASIS, 2007).

Based on methods for platform-independent definition of business processes offered by such standardisation, the growing demand for specification of cross-organisational business processes was fostered. Collaborative business processes (CBPs) came to the centre of interest of some research (*e.g.*, Lippe *et al.* 2005; Coetzee and Eloff, 2003). With CBPs, the specification of the interoperability aspects between different organisations are important while the organisation-specific aspects how a functionality or a service is provided could remain opaque. However, specifying a CBP at one location and distributing the specifications to the partner organisations involved in such

a CBP for execution could be another approach. This approach is essentially fostered by the use of standardised specification languages for business processes.

1.1 Aims and Objectives

Since security already is an important issue in distributed applications in general, this topic is also of significant importance for CBPs and, in particular, for the application of BPDs. Security of Web services is well studied and several approaches for access control to Web services exist (*e.g.*, Abendroth and Jensen, 2003; Dimmock *et al.*, 2004). Role-based access control (RBAC) (Ferraiolo *et al.*, 2001; Peng and Chen, 2004) is the widely used concept for dealing with security aspects in this field. However, novel security aspects not covered in the aforementioned approaches arise from the distributed definition and execution of CBPs. The following questions have to be answered in this context:

- Are the semantics of a remotely defined business process compatible with the security policy effective at the node where it is to be executed?
- Which classification, with respect to access control, is required for the Web service offered by the remotely defined business process in order to be compliant with the security policy in the domain where it will be executed?

It is anticipated that becoming able to cope with security issues arising from distributed definition and execution of business processes using standardised BPDs such as BPEL

(Alves *et al.*, 2007) will foster the acceptance of cross-organisational development of business processes (*i.e.*, specification of BPDL scripts remotely from the site of execution). This may allow additional capabilities provided by these standards to be deployed in practical applications such as supply chain management. Since the second of the above questions is already in the scope of other related work, this research project aimed to address the first question.

To this extent, the research project has been dedicated to fulfilling the following objectives:

1. Analysis of the security-relevant semantics of BPDL-defined business processes, in particular in environments where the BPDL scripts specifying a business process are being defined remotely from the location of execution.
2. Based on the results of this analysis, development of a framework for assessing compliance of remotely defined business processes with security policies effective at the location of their execution. This includes a method for defining security policies in terms of security-relevant semantics of BPDLS in order to facilitate the assessment process.
3. Development of methods for compliance assessment preferably based on technologies customary in the context of SOA established on Web services and business processes. The reason for this objective is to aim at ease of applicability for practitioners accustomed to the specification of Web services and business

processes. In order to apply the methods proposed in this research project, potential users should not be forced to acquire additional skills in addition to those already acquainted in the field of application.

4. Investigation of the methods proposed with respect to their suitability for automatic performance of compliance assessment. Being able to perform compliance assessment with as little as possible human interference was deemed to support acceptance of such methods.
5. Evaluation of the feasibility of the framework for practical applications by implementing parts of it in a research prototype and evaluating this prototype in a test bed environment.

1.2 Thesis Structure

In Chapter 2, the current use of business process definition languages and conceivable extensions of its application, in particular in the context of CBPs, are discussed. Using a comprehensive example of a distributed business process taken from the context of supply chain management, security issues arising in the field of Web services and business processes are considered, in particular in situations where definition and execution of business processes are distributed across security domain boundaries.

The state of the art of specifying and enforcing security policies in general, as well as in SOA-based applications and in application environments using mobile code, in

particular with respect to access control and information flow control, is discussed in Chapter 3. In addition, restricting the research on a particular representative of BPDs, namely WS-BPEL, is justified in this section.

Chapter 4 contains an overview of WS-BPEL as a specification language and presents the results from an analysis of the security-relevant semantics of WS-BPEL performed as part of the research project. To this extent, security policy-induced restrictions for Web service invocations have been classified and so-called semantic patterns have been derived from this classification.

In Chapter 5, the results of this analysis are applied to propose a method for the specification of security policies that helps to facilitate the process of security policy assessment for cross-organisationally defined business processes. In addition, approaches to reduce the complexity of security policy specifications and to cope with dynamic aspects in pre-execution security policy assessment are discussed.

Chapter 6 takes a deeper look into the process of assessing the security-relevant behaviour by inspecting WS-BPEL scripts in order to determine the compliance to security policies and introduces an architecture that allows for separation of the security analysis and assessment of WS-BPEL scripts and the displacement of these tasks to special nodes in an application environment.

In Chapter 7, the research prototype specified and implemented during the research project as proof of concept will be presented. After introducing the scope of the research

prototype, the method of specifying security policy statements introduced in Chapter 5 in a machine-processible manner will be explained. Furthermore, the architecture of the prototype, the hierarchy of Java classes and the algorithms used for assessment of compliance with security policies and, in particular, for information flow analysis will be discussed. The chapter sums up the results of the proof of concept by presenting the evaluation of the prototype.

Chapter 8 considers the wider applicability of the results achieved in this research project. In particular, the transfer of the results to the field of Grid computing is discussed. The extent to which such transfer is possible is demonstrated, and issues for further research instigated by this approach are identified.

Finally, Chapter 9 contains a summary of and conclusions drawn from the results achieved, and discusses limitations and directions for further research based on these results.

2 CROSS-ORGANISATIONAL DEPLOYMENT OF BUSINESS PROCESSES

Collaborative business processes (CBPs) as defined, for instance, by Coetzee and Eloff (2003) denote business processes that span organisational boundaries in order to support business interactions involving cross-organisational workflows. Modelling of such CBPs has been discussed, for instance, by Lippe *et. al.* (2006). The definition of workflow views that provide as much information as required to allow for specification of CBPs assuring cross-organisational interoperability, but at the same time as less information as possible about the internal aspects of a workflow as implemented by a particular partner in a CBP is considered essential (Dickson *et al.*, 2004). Approaches to provide the required functionality for cross-organisational workflows based on SOA are considered particularly beneficial (Papazoglou and van den Heuvel, 2007). SOC established by those approaches facilitates the definition of CBPs. Standardized BPDs play a central role in the definition of CBPs due to their ability to specify business processes on top of Web services and their platform-independency (Sayaha and Zhang, 2005). Though currently the definition of executable business processes across organisational boundaries seems not yet to have found much interest in research, using standardised BPDs particularly for this purpose would exploit the capability offered by a standard more than is done currently. This consideration will be explained in more detail below.

In an SOC environment, first the situation is considered where the task of defining CBPs and related enhanced Web services using a BPD is distributed between several

nodes in different organisations. This state-of-the-art employment of a BPD, where each organisation engaged in a particular CBP defines on its own the respective business processes or enhanced Web services executed within their system, is depicted in Figure 2. Of course, agreement on the overall task of the CBP has to be achieved between the organisations involved.

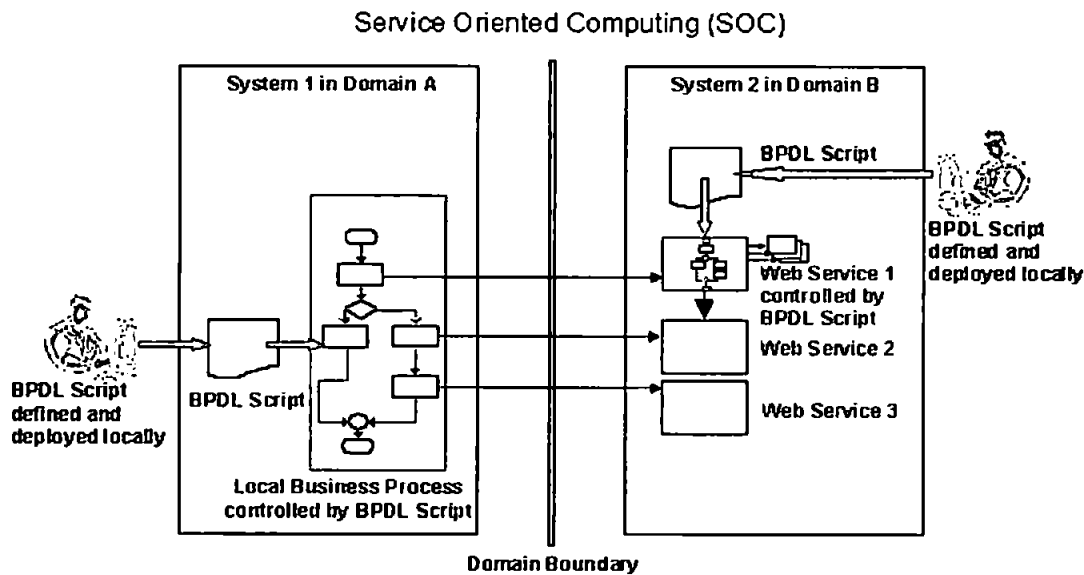


Figure 2: Collaborative Business Process Using Locally Defined Subprocesses

Figure 2 illustrates an exemplary environment for the distributed development and execution of a BPD-defined collaborative business process, with two systems residing in two different domains A and B. Each node depicted in Figure 2 is supposed to belong to a different organisation, but still is capable of running processes defined in a particular BPD.

Consider the case where in domain A there is a need for a CBP, for instance, in a supply chain application, requiring information I_A offered by a Web service W_2 at system 2 in

domain B. Because of restrictions imposed by security policies in domain B, Web service W_2 would not be allowed to be accessed directly from outside domain B, because, for instance, it provides further information besides I_A that must not be leaked from domain B. For solving this conflict with security policy restrictions, a conventional approach would be the provision of an enhanced Web service in domain B, say W_1 at system 2. W_1 would access the information required from Web service W_2 and offer the non-restricted part of the results (*i.e.*, I_A) to system 1 in domain A across the domain boundary. Since a business process defined by a BPD script offers services to its environment, it can itself be considered a Web service. Therefore, in this example W_1 is assumed to be defined by a BPD script S_1 .

2.1 Extended Use of Business Process Definition Languages in CBP Scenarios

In order to allow for fast development and adaptation to changing requirements of business processes, it would be desirable to concentrate the definition of all business processes and enhanced Web services at one particular node and distribute the BPD script resulting from this location to other nodes for execution. This would reduce the coordination overhead implied by distributed definition of the parts of the CBP in different organisations and, therefore, could help to save time and to increase flexibility during the specification and implementation of CBPs.

Since the need for the particular business process in this example arose in domain A, it is very probable that also requests for changes to this business process will arise in this domain. In order to circumvent the requirement that requests for change arising in

domain A must be presented to developers in domain B in order to have them change the Web service W_1 , it would be conceivable that W_1 running on behalf of a business process in domain A will be defined by developers in domain A. The defining BPDL script S_1 will subsequently be brought to execution at system 2 in domain B as indicated by the arc from the developer workstation at domain A to domain B in Figure 3

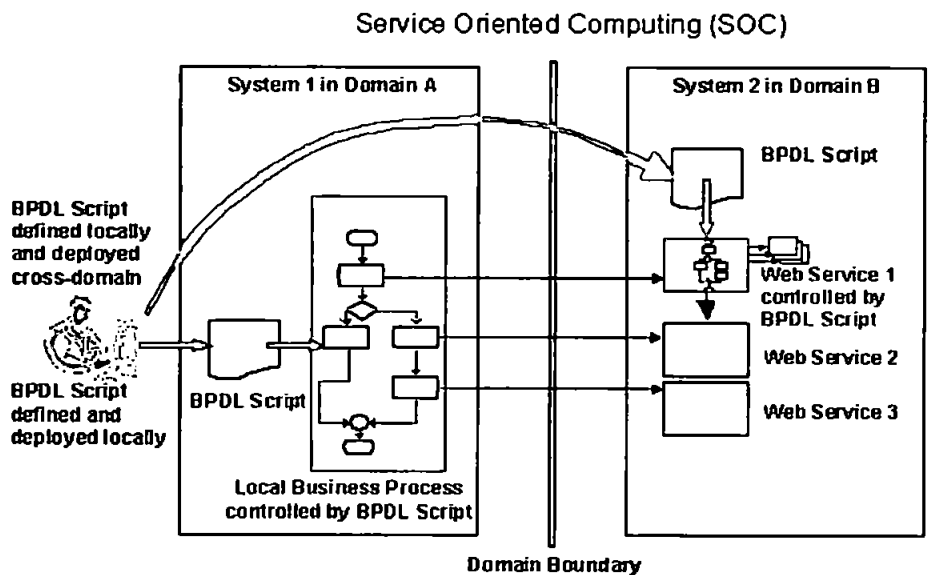


Figure 3: Cross-Organisational Deployment of Business Processes

This approach would greatly facilitate the adaptation of W_1 in domain B to changing requirements originating in domain A. Given both systems are based on a BPDL-enabled platform using the same preferably standardised BPDL, this scenario, as depicted in Figure 3, would be technically feasible. However, it would induce severe security weaknesses in domain B, if S_1 would be executed in domain B without particular precautions. Prior to running S_1 , it has to be determined whether the semantics of W_1 defined by S_1 comply with security policies effective in domain B. Unless these security

issues can be solved, it may prevent this extended use of BPDL scripts from being actually applied in a real-world cross-organisational environment.

2.2 Motivating Example of Cross-Organisational Business Process

In Figure 4, an example from the area of supply chain management (SCM) is shown that will be used to illustrate the security issues arising when remotely defined BPDL scripts are being deployed across enterprise domain boundaries.

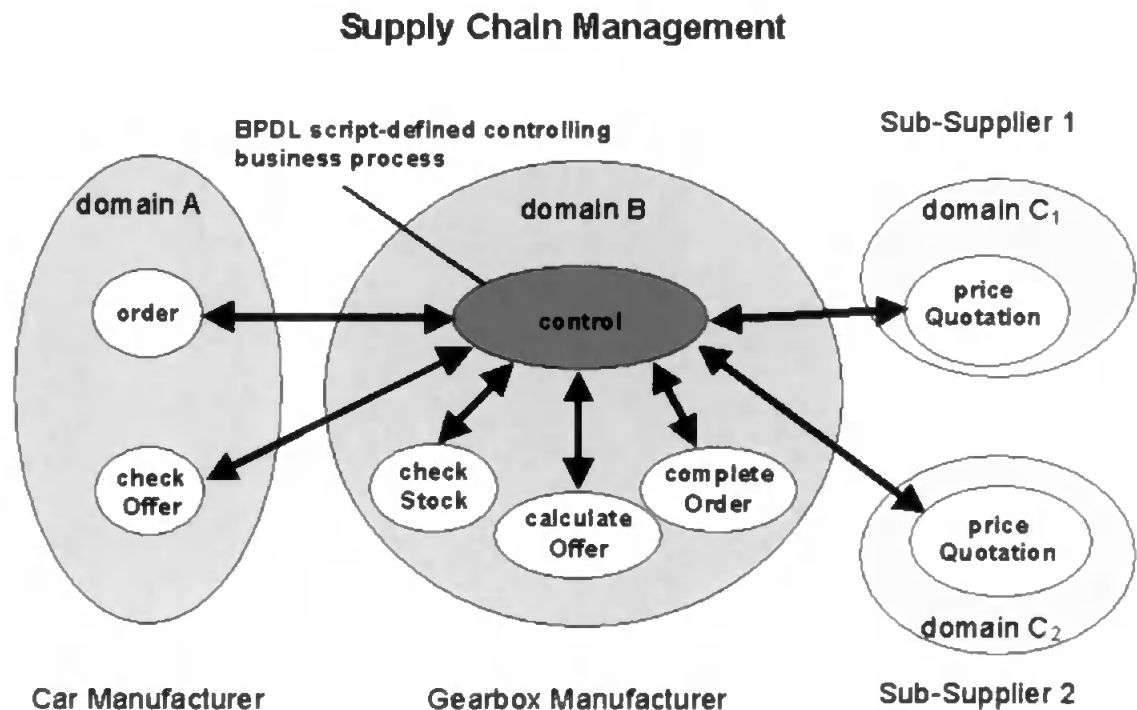


Figure 4: Collaborative Business Process Example

The application context of the distributed business process depicted in Figure 4 is the order processing of a car manufacturer ordering gearboxes or components thereof from a gearbox manufacturer who, in turn, orders components for gearboxes from different sub-suppliers (two in this example).

The business process is set up in a SOC environment where all functions used for the application are provided as Web services and the composition of Web services is accomplished using BPD L for the definition of the controlling workflow. In such a context, BPD L scripts are not required to perform any kind of data manipulation or data processing. Since standardised BPD Ls usually do not provide any language constructs for performing data manipulations, constructs of other languages such as XPath (Berglund *et al.*, 2006) would have to be imported for these purposes. Since in a service oriented application context, all data processing can be kept outside the controlling BPD L scripts, it is assumed that the BPD L scripts considered here only make use of elements imported from XPath, if any, in expressions specifying conditions for flow control purposes not implying any data manipulation.

2.2.1 Description of Business Process Example

In this example, a BPD L script is executed in a system of the gearbox manufacturer defining a controlling business process denoted by *control* in Figure 4. An *order* process of the car manufacturer (that may itself be a Web service or a BPD L-defined business process) invokes the Web service offered by the *control* process at the gearbox manufacturer providing a list of gearbox components to be ordered by the car manufacturer. Before placing an order, the car manufacturer expects a price offer accompanied by a commitment with respect to the delivery date.

The *control* process invokes a *checkStock* Web service for checking the availability of the ordered items in stock. For this purpose, the list of items to be ordered is passed to

this Web service. After checking the availability in stock, the *checkStock* Web service returns two lists of items that are to be ordered from sub-supplier 1 and sub-supplier 2, respectively. Together with these lists of items, a transaction ID for the order in progress and the credentials required to invoke the respective Web services of the two sub-suppliers are returned by *checkStock*.

Upon receiving the response of *checkStock*, the *control* process invokes the *priceQuotation* Web services of the sub-suppliers and provides the respective list of items to each of them. In order to get access to these Web services, the credentials returned by *checkStock* are used by the *control* process. Of course, each Web service of the two sub-suppliers requires its own set of credentials. Therefore, the *control* process has to provide the proper instance of credentials to each of them.

After checking availability of the items on the respective list, each *priceQuotation* Web service returns a list augmented by prices and availability on stock or dates of delivery. The *control* process then invokes a *calculateOffer* Web service of the gearbox manufacturer to prepare an offer for the car manufacturer. For this purpose, the *control* process passes the augmented lists returned from both sub-suppliers to the *calculateOffer* Web service together with the transaction ID that was returned to it before by the *checkStock* Web service.

The *calculateOffer* Web service uses the transaction ID to identify the proper order request of the car manufacturer and to find the information relating to this order in the data base of the gearbox manufacturer provided there by the *checkStock* Web service.

For instance, information about items found to be available in stock and potentially reserved for this order by the *checkStock* Web service could be identified by the *calculateOffer* Web service in the course of its processing. Finally, the offer is returned to the *control* process and will be passed to a *checkOffer* Web service of the car manufacturer. This Web service will return an 'OK' or 'Reject' response to the *control* process after having checked whether the offer would be acceptable to the car manufacturer.

The response from the *checkOffer* Web service is passed to a *completeOrder* Web service by the *control* process. Depending on the type of response, this Web service either completes the order processing within the gearbox manufacturer if the response was 'OK' or discards all intermediate information such as items reserved for this transaction ID if the response was 'Reject'.

After the *completeOrder* Web service has terminated its task, it returns a corresponding result to the *control* process that, in turn, provides this result to the *order* Web service of the car manufacturer as a response to its own invocation, thereby completing the workflow of this business process.

For the purpose of this discussion it is supposed that the *control* process could be specified by the car manufacturer as a BPD script and sent to the gearbox manufacturer for execution within his domain. Reasons for doing so could be the ability to better adapt the order processing with respect to the communication requirements between the car manufacturer and the gearbox manufacturer, and to react faster to

changing requests concerning the workflow on the side of the car manufacturer, thereby providing more flexibility for definition of the collaborative business process to the car manufacturer. However, unless the security issues related with this approach (as discussed in the next section) could be solved satisfactorily, the gearbox manufacturer would not accept this remotely defined BPD script for execution.

2.2.2 Security Policy-Induced Restrictions in Cross-Organisational Business Process Execution

When the controlling BPD script is brought in from the car manufacturer for execution in the domain of the gearbox manufacturer, the processing performed by the controlling business process will be subject to several restrictions derived from security policies of the gearbox manufacturer.

The security policies of the gearbox manufacturer may mandate that the list of items that are not in stock and, therefore, have to be ordered from the sub-suppliers may not be disclosed to the car manufacturer and the respective competing sub-supplier for strategic reasons. The same will obviously hold for the credentials required for granting access to the *priceQuotation* Web services of the sub-suppliers. This information may only be passed to the respective sub-supplier, but neither to the competing sub-supplier nor to the car manufacturer for obvious security reasons.

Other restrictions in the example of Figure 4 may require that the list containing prices and delivery dates for the items to be ordered returned by each of the sub-suppliers has

to be passed unmodified to the *calculateOffer* Web service while the respective source of the lists may not be confused in order to allow for proper calculation of an offer to the car manufacturer. Finally, this information may also not be disclosed to the car manufacturer or the competing sub-supplier. Furthermore, it may be required that the offer containing prices and delivery dates returned from the *calculateOffer* Web service is passed to the *checkOffer* Web service of the car manufacturer without any modification in order to prevent manipulation of this offer, for instance, by changing the committed delivery date or the prices.

A further type of possible restrictions implied by security policies of the gearbox manufacturer may require that particular input parameters of a Web service may not be used, or only be used with a restricted range of allowed values when invoked in a BPD script imported from the car manufacturer. An example of such restrictions could be the *calculateOffer* Web service that could have a further input parameter for controlling the type of rebate to be taken into account in calculating the offer. When invoked by the *control* process defined by the car manufacturer, this parameter may be forbidden to be used at all or may be restricted to one or a few values. Without such a restriction, the car manufacturer could define in the *control* process any amount of rebate the *calculateOffer* Web service is able to provide, even though the gearbox manufacturer usually would only allow a specific amount of discount to this car manufacturer.

2.3 Security Issues Related to Cross-Organisational Deployment of CBP

As can be seen from the foregoing discussion, many restrictions refer to non-disclosure of information passed between Web services within the *control* process to destinations outside the domain of the gearbox manufacturer, in particular to the car manufacturer. The latter restriction is of special interest facing the fact that in the example above this very process is defined by exactly the car manufacturer who is restricted to get some of the information handled by this process.

Other restrictions mandate that the values passed to a Web service originate from a particular other Web service or lie in a particular range of values.

Access control to Web services (*e.g.* Abendroth and Jensen, 2003; Dimmock *et al.*, 2004) and in particular role-based access control (RBAC) (Ferraiolo *et al.*, 2001; Peng and Chen, 2004) may only cover part of these restrictions. When addressed by access control means alone, enforcement of non-disclosure of information outside the local domain would imply that access to the particular information would not be granted to any principal outside the local domain. In this example, the car manufacturer residing outside the local domain of the gearbox manufacturer and, as a consequence, also the BPDF script defined and invoked by the car manufacturer, would not be granted access to visibility restricted information thus preventing the *control* process of this example being remotely defined and deployed by the car manufacturer.

Relaxation of access restrictions, such as granting access provided the values passed to a Web service come from a particular source (for instance values returned from a

specific Web service), require information flow (in backwards direction) to be considered for making decisions upon granting access or not. Thus, information flow analysis has to be applied in addition to purely access control-oriented approaches, in order to cope with this kind of restrictions.

Restrictions with respect to visibility of values returned from a Web service are also not covered by access control measures alone. For this purpose, information flow (in forward direction) has to be analysed, that means the future use of the values returned has to be taken into consideration.

With the approach proposed in this thesis, these restrictions derived from the security policies at the location where a remotely defined BPDF script will be executed can be enforced using the methods proposed, including the restriction that the author of the BPDF script is precluded from getting knowledge about information handled by the business process he has specified. At first sight, the last one may seem to be a restriction contradictory to itself. However, it will turn out during the course of the thesis that it is possible to grant access in such a fine-grained manner to a remotely defined business process and enforce the implied information flow restrictions in a straightforward manner at the executing site.

The security issues arising when remotely defined BPDF scripts are to be executed can be condensed into the following questions:

- Will the business process defined by the BPD script comply with the security policies of the executing domain?
- Which access privileges are required in order to grant access to the business process defined by the BPD script (*i.e.*, to possess the proper privileges for accessing the resources, particularly the Web services, encountered in the course of its execution)?

The second question is addressed by research considering access control (Koshutanski and Massacci, 2003; Mendling *et al.*, 2004), even though not necessarily in the context of BPD script execution (Joshi *et al.*, 2001). The first question, however, is comparatively novel since execution of remotely defined BPD scripts seems currently not to be in practical use very much and, therefore, security aspects inherent in this way of using BPD have not found a lot of attention in research, yet.

This research project strives to propose a framework for coping with these novel security aspects arising from the employment of standardised business process languages. To this end, semantic aspects of the business processes defined by their respective scripts written, for instance, in BPD, are considered at the time, a new script is to be deployed to a node across security boundaries. However, the analysis of the semantics of code written in programming languages is a well-known difficulty (Cousot 1999). Therefore, the need to analyse the semantics of a BPD-defined business process with respect to involved security-relevant semantics would make the approach to specify a business process remotely from the location of execution impractical unless this analysis can be provided automatically, at least to a large extent. The methodology

proposed will make use of the fact, that business process languages offer little to none means for defining data processing or computational tasks as part of the language itself, but rather have to invoke Web services for these purposes or must import constructs from expression languages defined in other XML standards such as Xpath (Berglund *et al.*, 2006).

The extended use of business processes as proposed in Section 2.1 and parts of the framework for assessing compliance of remotely defined BPDF scripts described in chapters 4 through 6 have been published in several workshop, conference, and journal papers (Fischer *et al.*, 2005, Fischer *et al.*, 2006, Fischer *et al.*, 2007a, Fischer *et al.*, 2007b, Fischer *et al.*, 2007c).

2.4 Restriction of Research to WS-BPEL without Loss of Generality

For the definition of Web services, Web Services Description Language (WSDL) 1.1 (Christensen *et al.*, 2001) (expected to be gradually substituted by its newer version WSDL 2.0 (Chinnici *et al.*, 2006)) has been established by the World Wide Web Consortium (W3C) as a single standard broadly accepted for the definition of Web services.

In contrast, for business process definition languages (BPDFs) several approaches to standardisation have been taken by different vendor groups and standardisation organisations, leading to a plurality of standards:

- Web Services Business Process Execution Language (WS-BPEL), formerly known as Business Process Execution Language for Web Services (BPEL4WS or BPEL for short) (Alves *et al.*, 2007), propagated by the Organisation for the Advancement of Structured Information Standards (OASIS),
- Business Process Modelling Language (BPML) (Arkin, 2002), propagated by the Business Process Management Initiative (BPML.org),
- XML Process Definition Language (XPDL) (Workflow Management Coalition, 2002), propagated by the Workflow Management Coalition,
- Web Services Choreography Interface (WSCI) (Arkin *et al.*, 2002), propagated by the World Wide Web Consortium (W3C) and
- ebXML Business Process Specification Schema (Malu *et al.*, 2002), propagated by UN/CEFACT and OASIS.

Though the existence of several parallel standards aiming at the same goal detracts from the very purpose of standardisation, the different standards at least have some obvious commonalities, as all languages are script based using XML (Bray *et al.*, 2006) and facilitate the composition of business processes by invocation of Web services and definition of the communication with other parties (in particular human participants) involved in a business process.

The fact that several business process languages exist in parallel, gave rise to research as to which extent these languages are comparable with respect to their semantic expressiveness (Aalst *et al.*, 2002; Shapiro, 2002; Wohed *et al.*, 2002). In particular,

Aalst *et al.* (2002) and Wohed *et al.* (2002) analysed different languages (*i.e.*, WS-BPEL, BPML, WSCI and some vendor-specific business process languages) with respect to workflow and communication patterns. The results of their work indicate that, to a large extent, the different languages are capable of expressing the same semantics with respect to workflow control and communication behaviour.

As could be expected from these results, the different languages may be convertible to each other as has been shown in an exemplary manner for XPDL and WS-BPEL by Fischer and Wenzel (2004).

In other work (Haller *et al.*, 2006; Haller and Oren, 2006) a process ontology based on multiple meta-models derived from different existing workflow models is introduced in order to facilitate mappings between choreography descriptions defining possible interactions between different partners of a CBP and internal workflows of the partners defined using different workflow languages, workflow models, and choreography languages. Since this research seems to be still in its early stages, only one successful mapping (with manual intervention) between a vendor-specific workflow definition language and Abstract BPEL (definition of abstract, *i.e.*, not executable, business processes defined in BPEL) is reported. Although automatic conversion between different workflow definition languages and BPDs based on their proposition is still for further study, this approach using a specific ontology meta-model as an intermediate during mapping can be expected to be promising towards supporting automatic mapping between different workflow definition languages and different BPDs. Once this

ongoing work will have proven successful, their approach might also be useful for automatic conversion of different BPDs to each other.

Given the fundamental similarity of all different languages used for business process definition and their potential to be converted to each other, the research in this PhD project has been concentrated on one particular representative, namely WS-BPEL. During the course of the research project, WS-BPEL has been accepted by the Organization for the Advancement of Structured Information Standards (OASIS) as an OASIS standard (OASIS, 2007). Prior to this, through support by prominent vendors like IBM, BEA, Microsoft, SAP, and Siebel, WS-BPEL already had emerged as the de-facto standard for business process definition (Wang *et al.*, 2004; Mayer and Lübcke, 2006).

According to the usual practice, for the remainder of the thesis BPEL will be used as a short-hand for WS-BPEL.

2.5 Summary

In this section, the main goal of the research project namely the assessment of compliance of remotely defined BPEL scripts with local security policy has been motivated by discussing some of the security issues arising by executing remotely defined BPEL scripts. It has been shown that availability of fine-grained access control and information flow control may enable sensible tasks to be performed by remotely defined business processes without jeopardizing local security policy.

Since the different standardised BPDs are comparable with respect to their expressiveness for specifying the process logic of a business process and BPEL is considered the de-facto standard for business process definition as backed by related work discussed above, without loss of generality, the research in this PhD project could be restricted to BPEL. Therefore, in the remainder of the thesis, BPEL alone is investigated as the most prominent representative of standardised BPDs.

3 APPROACHES TO SPECIFICATION AND ENFORCEMENT OF SECURITY POLICIES

In this chapter, approaches to cope with security policy enforcement in general, and of Web services and business processes, in particular, will be discussed. Possible methods include validation (or even verification) prior to execution, or by monitoring and intervening during execution of a program. In addition, because a BPEL-defined business process can itself be considered a Web service, approaches to specify security requirements of Web services and to solve security issues with Web services may also relate to business processes defined this way and, therefore, will be considered in this chapter.

Since this research project was particularly interested in scenarios where BPEL scripts are defined at one location and brought to a remote location for execution, approaches to solve security issues arising with execution of mobile code are also considered. This is because the distributed definition and execution scenario for BPEL scripts is, to a large extent, similar to the situation when mobile code is to be executed. Common to both situations is the fact that from the point of view of the executing site, the script or code, respectively, has been defined remotely and is brought in for execution on an ad-hoc basis such as applets contained in a Web page and downloaded via HTTP together with the page content.

As a consequence thereof, it is not clear at first sight what this script or code is going to do when executed; that is, the semantics of the script or code are unknown (at least the

details thereof while the overall semantics, *e.g.*, collecting information for an order in a B2B application) may be known. Because of this, among others, there may be concerns about the possible effects to the local system environment resulting from its execution. In particular, there will be concerns as to whether the script or code will obey security policies effective at the domain executing it.

Unlike other scenarios of executing remotely defined code (such as executing programs developed and installed by the IT department of one's own organisations or programs being part of a product supplied by a well-known vendor), when executing mobile code there is not usually a level of trust that is appropriate to alleviate the concerns about the potential of the remotely defined program to cause harm to the local environment or to violate the local security policies. However, even with programs developed or installed by the organisation's IT department, trustworthiness may be arguable because of potential infection of this software with malicious code injected during Internet communication. This general and apparently increasing risk of getting infected by viruses, Trojan horses or spyware (ITU/UN, 2007) gives rise to employ anti-virus and anti-spyware check software. However, this risk of malicious modification after deployment is not typical to BPEL scripts and may be prohibited by appropriate mechanisms of the platform executing such scripts. Consequently, this risk is deemed not to play an important role in the scenario considered in this research project and will therefore be disregarded.

If developed remotely from the executing site but still within the same security domain, domain-internal regulations such as quality assurance procedures applied in the

development process could help to deem a program or script conforming to security policies of this security domain. Since this does not apply in situations considered in this research project, security concerns with cross-organisational deployment of BPEL scripts and when untrusted, remotely defined code is to be executed are comparable to each other. Therefore, approaches to solving security issues with the execution of mobile code may also be applicable to, or at least may serve as a model for approaches to, solve the comparable issues with cross-organisational deployment of BPEL scripts. An overview of conventional approaches to cope with security issues involved in the execution of mobile code is given by Rubin and Geer (1998).

3.1 Specification of Security Aspects for Web Services

In the context of the definition of Web services, a series of specific standards and proposal for standards exist, most of them propagated by the World Wide Web Consortium (W3C) or OASIS. To address the collection of these Web service-oriented specifications as a whole, they are usually addressed as “WS-*” specifications (the reason for this abbreviation might be the fact that the titles of many of these specifications contain the term “Web services” and have abbreviated identifications starting with “WS-“).

A large number of WS-* specifications already exist, at different stages of their standardisation process, and the number of such specifications is still increasing. Therefore, it is difficult to keep track of the dynamic development of these specifications. However, a recent article in the InfoQ.com website provides a good

overview of the current state of standardisation and adoption by platform vendors as well as of the coherences and interdependencies of specifications in this field (Bustamante, 2007). Unlike the existence of several standardized business process definition languages that could basically replace each other, these different WS-* specifications serve different (though sometimes similar) purposes. However, overlapping functional areas also exist in these standards, proposals, or recommendations.

Since security issues are broadly accepted to be one of the crucial points in using Web services, in particular in cross-organisational application environments, there are also WS-* specifications specifically dedicated to the security aspects of Web services. Some of them will be discussed in more detail. The scope of existing security-related WS-* specifications covers the following aspects:

- Specification of security requirements imposed to Web service invocation and message exchange between Web services or between Web services and their users.
- Specification of protocols that may be used for security related tasks in the context of Web service-based application environments such as acquiring certified tokens for authentication and authorisation purposes or conveying information for access control purposes.

- Specification of policies to determine the rules for granting or denying access to particular resources for particular principals (*i.e.*, users or other system resources acting on behalf of users)

3.1.1 Web Service Security (WS-Security)

Web Services Security usually addressed as WS-Security (Nadalin *et al.*, 2006) is an OASIS standard adopted in 2004 and updated 2006 that provides the basis for secure message exchange in Web service interoperation. The standard defines a security model for authentication and protection of the Simple Object Access Protocol (SOAP) message transfer and provides mechanisms, primarily within a special security header added to a SOAP message, to convey security-related content such as security tokens or information as to which algorithms or procedures to be used for generation and verification of signatures or en-/decryption. Mechanisms to specify which parts of a message and, in particular, which parts of the message header are to be protected for integrity or confidentiality and which specific method of encryption from a variety of alternate methods is to be applied comprise mostly of this standard. WS-Security may be considered the base standard for security in this field since most of the other security-related WS-* specifications rely on the mechanisms provided by this standard to implement their security-oriented communication needs.

3.1.2 *WS-SecurityPolicy*

WS-SecurityPolicy (Nadalin *et al.*, 2007a), also an OASIS standard, offers means to indicate security requirements of Web services that have to be applied in the communication between the partners involved (*i.e.*, the invoker and the provider of a Web service). Such requirements may contain indications which parts of a message exchanged between the partners need protection to assure confidentiality or integrity and what type of encryption algorithms to be used for these purposes. In addition, means are provided to specify requirements for authentication and authorisation in message exchanges and what type of certifications will be accepted for these purposes. The mechanisms provided in this specification are predominantly bound to mechanisms provided in the communication layer of Figure 1, that is, the mechanisms provided by the communication protocol used. In many cases, this protocol will be SOAP (Box *et al.*, 2000) and its amendments, in particular WS-Security (Nadalin *et al.*, 2006).

3.1.3 *WS-Trust*

WS-Trust (Nadalin *et al.*, 2007b) is another OASIS standard that specifies a model and procedures to acquire and exchange security credentials in such a way that communicating partners may establish and maintain a trust relationship between each other. The standard makes use of other WS-* specifications, in particular WS-Security and WS-Policy, and among others allows for secure exchange of security keys or policies.

3.1.4 Web Services Policy Framework (WS-Policy)

Web Services Policy Framework (WS-Policy) (Bajaj *et al.*, 2006), is a W3C specification that may be used to construct policies relevant for a Web service. For this purpose the framework provides mechanisms for the aggregation of policies as combinations and alternatives of basic constraints and requirements of a Web service. The definition of such basic elements, however, is not in the scope of this specification but has to be imported from other WS-* specifications such as WS-SecurityPolicy (Nadalin *et al.*, 2007a) or WS-Security (Nadalin *et al.*, 2006). In addition to aggregation mechanisms, the framework specifies an algorithm for intersecting different policies in order to determine the common alternatives contained in these policies. Although the mechanisms provided are not specific to security policies, the context of the specification and the examples used therein are bound to the field of Web service security.

3.1.5 Security Assertion Markup Language (SAML)

Security Assertion Markup Language (SAML) (Cantor *et al.*, 2005) is again an OASIS standard for the specification and exchange of security assertions with respect to authentication, authorisation, or any relation between attributes and objects. Protocols for requesting assertions from an asserting party and for management of shared knowledge about identities between different providers acting as asserting parties are provided in this standard. One field of application of this standard is the establishment of so-called identity federations that play a central role in single sign-on over Web services from different providers.

3.1.6 eXtensible Access Control Markup Language (XACML)

The eXtensible Access Control Markup Language (XACML) (Moses, 2005) is also an OASIS standard that is intended to specify policies and procedures for access control and authorisation purposes. The standard provides a model for establishing access control decisions, an XML syntax for specifying access control policies as well as algorithms and functions that can be used in policy evaluation and constituting access control decisions.

The main components in the policy-based access control model are a Policy Enforcement Point (PEP) and a Policy Decision Point (PDP) that may be distributed over several nodes of a network. The PEP enforces access control based on policy decisions from the PDP. To this extent, the PEP sends decision requests to a PDP whenever access to a resource in the scope of the PEP is requested and receives responses containing the access decision from the PDP. While the structure and content of the decision requests and responses are specified in XACML, protocols for sending these requests and responses are not defined by this standards. Other standards such as SAML have to be employed for this purpose.

The decision request is accompanied by all required information concerning the requestor (subject), the resource access is requested for, the action requested to be performed on the resource, and the context (environment) in which the access request occurs. On receiving a decision request from a PEP, the PDP, in turn, evaluates rules contained in one or more policies (specified based on the schema provided in XACML for policy definition) that apply to the particular situation using the information

contained in the decision request. The outcome of this evaluation may be “Permit”, “Deny”, “Indeterminate”, or “NotApplicable” and is returned to the PEP in the response to a decision request. The PEP is responsible of enforcing access control based on this decision by granting or denying access to the resource for the requestor.

Lorch *et al.* (2003) report on early experiences with XACML in different application contexts. They discuss the use of XACML in its earlier version 1.0 (Godik and Moses, 2003) in several projects and systems for authentication and authorization purposes. They conclude XACML being suited for specifying complex policies and being used in different distributed environments. Because it is an open standard offering means for extensibility, they argue that XACML fits well into legacy authentication and authorization systems and may act as an intermediate for interoperability between different systems. They further conclude that the benefits gained by XACML’s flexibility and expressiveness come at the cost of being complex and verbose (however, the latter applies similarly to many other XML-based standards, too). As a consequence, working directly with XACML policies “will be hard for average users” (*ibid.*, p. 34). Even when tools will be available to cope with structural complexity and verbosity, the authors still suspect difficulties for users in understanding the meaning of policies expressed in XACML because of its inherent semantic complexity.

3.2 Role-Based Access Control for Web Services and Business Processes

While access control related aspects are predominant with Web services, they are, of course, also an issue with BPDs. For Web services, role-based access control (RBAC)

(Ferraiolo *et al.*, 1995) is commonly used (*e.g.*, Bacon *et al.*, 2002). The main reason for this is that the maintenance effort increases tremendously with the number of principals (*i.e.*, users) and resources for access control systems relating decisions to grant or deny access to a resource with individual principals as in conventional access control systems. Therefore, RBAC relating access decisions with particular roles instead of individual principals is better suited in situations involving a large number of principals as is the case in Web service environments (Coetzee and Eloff, 2003). In addition, since the users of Web services can be distributed over different organisations or are even unknown in advance, administration of access privileges for individual users would render difficult or even infeasible while associating possible invokers of a Web service with some few specific roles is much easier even with users from particular remote organisations and even with users that are unknown at the time the access rules are specified.

Koshutanski and Massacci (2003) address access control issues of business processes defined by BPEL scripts, in particular the problem of providing the evidence of possessing the required access privileges for accessing a particular resource at the right time to the right place during execution of a business process. In their approach, they propose to use mobile processes defined by BPEL scripts as part of messages sent in response to an access request. These mobile processes would be executed at the requesting side to interactively collect further credentials required for granting access to the particular resource. In this context, they also discuss the requirement that the mobile processes have to be subject to a release control policy in order to not disclose the access control policy unless the receiver of this information has already acquired the

proper security level to be allowed to get this information. In order to deduce the missing credentials for an access request at a particular point of a business process and the required security level for disclosing the information which credentials currently are missing, the access control policy and the release control policy have to be available in a formulation that allows for machine-controlled reasoning. The authors argue that algebraic constructs would be best suited to serve as formal foundation for this purpose. However, requiring algebraic specifications for access control or release control policy makes the approach difficult to be applied in practical applications where the skill to define or only understand such formal specifications of a policy cannot be considered to be available with practitioners working in this field.

A similar aspect is addressed by Mendling *et al.* (2004) in their investigation of access control requirements for BPEL script-defined business processes. By extracting RBAC models from BPEL scripts and converting BPEL language constructs in a format suitable for a particular RBAC software component, they provide an automated link of access control enforcement into business processes defined by the BPEL scripts.

Joshi *et al.* (2001) give an overview of access control approaches and their suitability or usability for Web-based applications, in particular distributed workflow management systems (WFMSs). They argue that approaches such as the Mandatory Access Control (MAC) and RBAC are suited for supporting enforcement of security policies in Web applications, particularly confidentiality and integrity of the information. In a MAC model, all subjects and objects are assigned predefined sensitivity levels to be used in the access control enforcement thereby including information flow control aspects into

access control. For RBAC approaches to include information flow aspects, the concept of role hierarchies and constraints has to be employed. Joshi *et al.* state, “Enforcement of MAC policies is often a difficult task, and in particular for Web-based applications, they do not provide viable solutions because they lack adequate flexibility” (*ibid.*, p. 41). They further state, “Achieving secure interoperation in a heterogeneous Web environment is a difficult task, because of the inherent dynamism and evolving security requirements of the underlying autonomous administrative domains” (*ibid.*, p. 44). They come to the conclusion that approaches using RBAC models are suitable to cope with security requirements in distributed Web application environments.

Peng and Chen (2004) propose an extension to conventional RBAC models called WS-RBAC, in order to incorporate Web services and business processes on top of them. In their approach, Web services are subject to access control in lieu of common system resources in conventional approaches. Business processes and enterprises are elements in their WS-RBAC model making it suitable for application to CBPs.

3.3 Relation of Programs and Programming Languages with Security Policies

Algebraic and language-based approaches, not specifically dedicated to Web services, address the relation of programs and programming languages with security policies. These papers address the issue of verifying compliance of programs with security policies and, therefore, are comparable with the scope of the research project of this thesis, albeit from a theoretical view.

Language-based techniques provide means for analysis or monitoring supported by properties or semantics of the particular programming or scripting language. Though the work concerned with these techniques relates to programming languages in general and is not particularly related to Web services or mobile code, the results of this work may also be extended thereto. At least, basic results on access control and information flow analysis, particularly on possible information leakage via certain semantics of programming languages, predominantly related to flow control semantics, also apply to the field of Web services and mobile code. A central role in the research on language-based security techniques is assigned to policies that restrict confidential data from interfering with (*i.e.*, affecting) public or externally observable data. This policy is referred to as noninterference (Goguen and Meseguer, 1982).

Sabelfeld and Myers (2003) give a comprehensive overview of language-based techniques for access control and, in particular, for information flow enforcement. They point out that access control on its own cannot guarantee confidentiality or noninterference of data. Sabelfeld and Myers argue that information flow analysis is required for enforcing confidentiality. This observation is in line with Joshi *et al.* (2001) who argue that models based purely on access rules are not suitable for enforcing confidentiality and integrity of information after amendment, but access control model incorporating mechanisms for information flow control are able to do so. Sabelfeld and Myers also state that static information flow analysis is superior to dynamic information flow analysis since static analysis considers all possible execution paths of a program while dynamic analysis considers only one instance of program execution. They further argue that “the inability to express or enforce end-to-end security policies is a serious problem

with our current computing infrastructure, and language-based techniques appear to be essential to any solution to this problem” (Sabelfeld and Myers, 2003, p. 13)

One particular issue pointed out by Sabelfeld and Myers (2003) is the potential existence of so-called covert channels (Lampson, 1973) and emphasise the difficulty to detect them during information flow analysis. Covert channels denote means for information transfer in a computing system that exploit mechanisms not primarily intended for information transfer. For instance, the number of cycles in a loop or the observation whether a particular exception occurs or not may be exploited to convey information in a manner not conforming to confidentiality policies. This may occur if looping or the condition for throwing a particular exception is based on confidential information thereby leaking this information via externally observable program behaviour.

An overview of algebraic approaches to access control has been given by Wijesekera and Jajodia (2003). While this work is dedicated mostly to theoretical aspects of security policies and their vulnerability by certain semantics of a programming language, enforcement of access control policies is stated as a requirement. However, mechanisms for doing so being, for instance, based on execution monitoring are not considered in this work.

Li and Zdancewic (2005) consider confidentiality and integrity specified by information flow policies. They describe flow control analysis in a security policy context where so-called downgrading policies are established and enforced by the way of a type system

using λ -calculus. The reason for considering downgrading policies as stated in their work is that noninterference being the only concept leads to overly strict limitation of allowed processing that would impede a lot of reasonable processing performed by a program. This theoretical approach to information flow analysis requires all programming logic being expressed in terms of λ -calculus in order to be analysed. In business processes invoking Web services for performing computational tasks or data manipulations, this approach seems to be impractical since, in general, it is unusual that formal specifications in terms of λ -calculus is available or can be made available for all of the programming logic contained in the Web services invoked during the course of a business process.

Another group of approaches to analysing confidentiality and integrity of programs written in different kinds of high-level languages investigate the information flow with respect to classified information. Within this group, type-based approaches and semantic-based approaches can be distinguished. In type-based approaches, for every security level an item of information may be assigned to, a certain type is defined and variables have to be of the same type as the information they contain. With these approaches, checking security properties such as noninterference can be performed by checking the type safety of a program (*e.g.*, Walker, 2000).

Echahed and Prost (2005) present an approach for proofing compliance of a program with information flow restrictions derived from a security policy. For their approach to be applicable, both the information flow restrictions and the program have to be available as algebraic formulations, the former using declarative programming, the

latter as rules of a term rewriting system. The information flow restrictions are formulated based on an ordered lattice of privacy levels where the order is defined from higher to lower privacy levels. This way, allowed or disallowed flows from higher to lower privacy level can be defined as rules in a term rewriting systems.

The approach described by Barbuti *et al.* (2002) is another example of the semantic-based approaches. The authors address security of programs written in Java by checking the Java bytecode. In particular, they investigate a security property of Java programs called σ -security that is weaker than noninterference. The approach employs information flow analysis in abstract interpretation of the program. To this purpose, the semantics of each operation in Java bytecode are defined by inference rules. Given a partially ordered set of security levels and a particular threshold security level σ , they define a program being σ -secure, if only information assigned to security level σ and below are leaked by the program, while information of higher security levels be kept secret. In their information flow analysis, they also take into account the risk of covert channels called implicit flows in their approach as possible ways to disclose information. Abstract interpretation of a program considers the security levels of values stored in variables and in the stack instead of the concrete values. The authors proof that information flow analysis of all possible concrete traces of a program, that is the concrete transition system of the program, can be replaced by information flow analysis of abstract interpretation of the program.

3.4 Verification of Consistency between Program Code and Security Policies

Another approach to cope with compliance of programs with security policy is based on the proposal, that programs are accompanied by information that proofs their compliance with particular security policies. Necula (1997) proposed a scheme to extend a program by verifications that particular security policies are obeyed. This approach is known as Proof Carrying Code (PCC). The proof is performed by the supplier of the code and the executing side has the obligation to verify that the proof provided with the program holds. In order to provide the proof that certain security requirements are met, the security requirements and a formal specification of the restrictions derived from them as well as of the program being executed, is required. The proof that particular security requirements are obeyed may be supported by verifying compilation, which is a compilation that verifies certain security-relevant properties of the code. While the proofs on the side of the producer of the mobile code are comparatively complicated, the verification of the proofs on the executing side is comparatively simple. One important observation states that no trust relation is required between the producing and the executing side besides disclosing the security policy to the producing side. Proofs can only be conducted against known policies. Therefore, the policies have to be disclosed to the producer of the code. In order to embrace them in proofing particular security properties, the policies have to be formulated in a specific formalism in order to be used in formal reasoning.

A combination of the PCC approach with static analysis to overcome some shortcomings of pure PCC approaches has been proposed by Nordio *et al.* (2004). The

main advantages of this approach are to provide proof of compliance when proofs based on type systems fail. The authors state that the size of proofs along their approach is linear to the size of the program considered. Since BPEL scripts usually are not compiled, this approach is of limited applicability to BPEL scripts since they are not going to be compiled before execution.

Walker (2000) also considers certified code, where certification is based on strong type analysis as in Java. However, the approach goes beyond type checking by combining type checking with the approach of Schneider (2000) that employs dynamic checking by code instrumentation. Such instrumentation adds specific code to enforce preconditions and postconditions of function invocations to be met.

Ribeiro *et al.* (2000a) describe a framework to specify security policies in a formal manner and methods to reason about the self-consistency of a security policy defined this way as well as about consistency between such a security policy and another set of rules or constraints. Such other sets of rules or constraints could, for instance, be derived from a workflow specification. In their approach, Ribeiro *et al.* define a Java-like notation for their policy definition language based on first-order predicate logic for specifying constraints with respect to allowed events. Ribeiro *et al.* (2000b) show that a broad range of security policies including discretionary access control (DAC) and MAC policies may be expressed. For the purpose of verifying the consistency of a policy or of several policies they use a tool named Policy Consistency Verifier (PCV). This PCV operates as a term rewriting tool that is controlled by so-called Constraint Handling Rules (CHR) and a solver tool trying to verify different sets of constraint rules with

respect to a set of consistency definitions. To verify the consistency of a workflow specified in a workflow definition language with a particular security policy, the policy first has to be specified in their specific security policy language. As a next step, this formal specification of the security policy and the formal specification of the workflow both have to be converted to sets of CHR rules. As a last step, the PCV tool is used to verify the consistence between these set of rules or detect their inconsistency. In their paper (Ribeiro *et al.*, 2000b) they state that compilers for the conversions of the formal specification of the security policy as well as the workflow into sets of CHR rules have been developed such that the verification process can be performed automatically using these compilers and their PCV tool. However, with respect to verifying consistency between workflows and security policy they concede that they “have not exhaustively tested with many different inconsistency types” (Ribeiro *et al.*, 2000a., p. 11). Nevertheless, they state, “the results we have obtained so far and the flexibility of the underlying platform lead us to believe that PCV is able to find most types of inconsistencies within and between security policies and other specifications” (*ibid.*, p. 12).

3.5 Security Policy Enforcement via Code Instrumentation and Runtime Monitoring

The enforcement of security policies by means of code instrumentation and runtime monitoring is also a broadly used concept in several approaches in literature.

Schneider (2000) discusses which kind of safety properties being part of security policies may be enforced by execution monitoring (EM) and finds that there are safety

properties that may not be enforced by EM of such information flow properties. Like Sabelfeld and Myers (2003), Schneider points out that security mechanisms based on static analysis and semantics of programming languages offer benefits over other approaches not using such mechanisms.

Venkatakrishnan *et al.* (2002) propose a code-rewriting system for Java byte code to enable enforcement of security policies while executing mobile code. This approach aims at allowing for mobile Java code as much functionality as possible without violating security policies. In their system, security-relevant events are intercepted and forwarded to policy enforcement automata prior to execution. They argue that using extended finite state automata (EFSA) for the purpose of runtime monitoring of mobile code avoids the requirement for costly stack inspection techniques. As being an approach particular to Java byte code, this approach is, in general, not suited to be applied to BPDF script-defined business processes.

A similar approach to the problem of executing untrusted code in general (*i.e.*, not specific to Java byte code or business process languages) was proposed by Sekar *et al.* (2003). After having derived information as to the behaviour of the code at the level of system calls from execution monitoring or static analysis at the developing site, this information is mapped to a model describing security-relevant behaviour and carried together with the code to the executing site where this information can both be checked against security policies and used during execution in order to monitor potential deviations from the stated behaviour. Applicability of this approach to business process running on a BPEL-enabled platform seems to be arguable because of lack of means to

monitor system calls and relate them to specific activities of a particular business process. The requirement of extensive testing as explicitly stated in their paper, and the need for observation at the level of system calls during execution, at least, will make the application of the approach in this context very complex.

Sirer and Wang (2002) propose a system where policy enforcement code is derived from security policies by an enforcement machine and translated into platform-specific prologues and epilogues to Web service invocations. The specific enforcement code will be executed by the respective web server, thereby performing access control to Web services as required by security policies. This approach is limited to run-time checking of compliance of Web service invocations and security policies. If applied on its own, this approach shares the drawback of monitoring approaches that a possible violation of security policies may be detected too late to be prevented by intervention. However, when combined with other methods of security policy enforcement this kind of intervening programs may be supportive in order to prevent security policy violations.

In the approach of Vachharajani *et al.* (2004), a specific runtime information flow engine is derived from binary program code prior to execution using special hardware that enables tracking of information flow. It provides dynamic information flow control during execution of program code thereby enabling access control policies or non-disclosure policies to be enforced. This approach, at least, requires binary code of the program being executed to be available for such an 'instrumentation'. For Web services invoked by a business process, in particular in a distributed environment, access to

binary program code cannot be assumed in general. Also when running business processes specified by BPD scripts, the binary code being buried in the platform running these scripts may not be available for instrumentation. In general, the relation between sequences of binary code within the platform running a business process and particular parts of the business process is difficult to be determined. This is particularly true when such relations would be required prior to execution in order to enable instrumentation of the appropriate parts of the binary code.

3.6 Summary

As the discussion of the WS-* specifications for security purposes above shows, most of these specifications deal with aspects related to Web service communication and access control. Since BPEL as a specification language does not provide elements that address access control and secure communication (cf., Section 4.2), these aspects of business process execution are expected to be provided by the platform running these processes (cf., *e.g.*, Mendling *et al.*, 2004). Therefore, when mapped onto the layered SOC architecture in Figure 1, mechanisms required for these tasks reside in the layers below the business process layer, that is, the content layer and the communication layer.

With the exception of WS-Policy and XACML, which may be used for specifying any kind of security policy, these standards do not address aspects that are relevant to the scope of the research project namely assessment of BPEL scripts with respect to compliance with security policies.

Concerning WS-Policy and XACML, since they address policy definition, they could be employed as standardized means to specify security policies when a BPEL script is checked for compliance with them. However, it turned out that they were not considered to be advantageously employed in the context of this research project. The reasons for this will be discussed in more detail in Chapter 4.

Also other approaches to the specification of security requirements of Web services as discussed in Section 3.2 address aspects residing in layers 1 and 2 of Figure 1 or are dedicated to the second security issue in the list of Section 2.3. Therefore, they are not applicable to the security issue stated in the first item of the list in Section 2.3 being the main scope of the current research project.

The approaches in Sections 3.3 and 3.4 do not specifically address security aspects of remotely defined BPEL scripts. Since all these approaches are based on algebraic formulations on programming language semantics and security policies, they are not particularly suited to be applied by practitioners in the field of Web service definition and business process specification. The specific skill required to define and interpret such formal specification may not generally be anticipated to be available for people occupied with specifying Web services and business processes.

Despite the observation that the results from other research mentioned in this section do not particularly address distributed definition and deployment of BPEL scripts in the sense laid out in Chapter 2, some of their approaches may also be applicable to this topic, at least to a certain extent. Particularly, results concerned with access control in

general and access control to Web services in particular, may be applicable to the second security aspect arising in this context as listed in Section 2.3.

Furthermore, the observation by several authors that access control on its own is insufficient for enforcing confidentiality and integrity of information as well as the potential risk of covert channels as discussed above in Section 3.3 was adopted in the methods developed in this research project.

Though none of the results discussed in this chapter deals specifically with the first security aspect given in Section 2.3 (which is the concern of the research project presented in this thesis), some of the work on language-based techniques for information flow control and on instrumentation and monitoring are applicable to this aspect, at least in principle. However, as already discussed above, the algebraic and language-based approaches mentioned may only be of limited use in the business process context because of the program size of the platform running business processes, the fact that program logic of Web services involved is only known to a limited degree and, in general, is far away from being specified in an algebraic formalism that would be required for most of these approaches.

Because of the fast pace of development and updating or reworking cycles that seems to be typical for Web services and business processes, it may be disputed whether such formal algebraic specifications will be produced in the future for applications in this field. In addition, at least for the time being, skills required for providing such algebra-

based formulation seems not to be typically available when developing Web services and business processes.

The research project, therefore, aimed to provide methods for analysing and assessing security-relevant semantics of BPEL scripts that may be applied without requiring profound skills in special formalisms such as algebraic formulation of programming logic. By contrast, the methods developed was to be based on technology and methods well-known to developers of Web services and business processes in order to be comparatively easy to be applied and, therefore, can be expected to be adopted by practitioners in this field.

The next chapters present the approaches taken in this PhD research to reach this aim. To start with, BPEL is analysed with respect to its intrinsic potential to specify behaviour of business processes that could violate restrictions imposed by security policies.

4 ANALYSIS OF SECURITY-RELEVANT SEMANTICS OF BPEL

In this section, the results of the analysis of BPEL as a specification language conducted during the PhD project will be presented. The purpose of this analysis was to identify the intrinsic potential of BPEL to specify business process behaviour that is able to violate restrictions imposed by security policies. Here and in the following chapters, the term “security relevance” when used with respect to particular elements of a programming or scripting language (*e.g.*, BPEL) or to combinations of such elements denotes the potential of these elements or combinations to specify behaviour of a program (or a business process in the case of BPEL) that could violate a security policy-implied restriction. Once the security-relevant semantics of BPEL has been identified, the assessment of compliance between a BPEL-defined business process and a particular security policy will become more operable since checking the BPEL script for compliance can be restricted to looking for security-relevant semantics contained therein.

4.1 Scope of Analysis

For the sake of general applicability, the aim is to analyse security relevance of semantics expressible via BPEL as a specification language as broadly as possible, without referring to specific types of application to which a particular BPEL script-defined business process may be related. For this purpose, the smallest possible pieces of BPEL scripts had to be identified for which assertions with respect to security relevance could sensibly be made. This cannot be the language constructs of BPEL on their own because, similar to many other programming languages or scripting

languages, most or even all of the individual language constructs do not present any security relevance or the security relevance cannot be determined at this “atomic” level.

As can be easily seen, for instance, the security relevance of an assignment operator or command (as present in nearly all programming or scripting languages) cannot be determined when considered in isolation since an assignment operation simply copies values from one location to another usually within registers or main memory of a computer. In order to decide the security relevance of such an operation, further information on the values and the locations involved in this operation is required such as what kind of values are to be copied (*e.g.*, values representing security-classified information) and what operation are to be performed to the target location during the further processing of the program (*e.g.*, stored on an externally accessible storage or displayed to a user on a terminal screen). When considered together with the restrictions that could be imposed to the values and locations involved, the security relevance of an assignment operation becomes easier to be investigated, but still it is not generally decidable for all types of restrictions whether an operation is secure or not.

The whole of a specific program and even the environment in which the program will be executed may have to be considered to decide this. For instance, if the values copied represent information that is restricted by the security policy to not be leaked to users of the program unless they possess a special authorisation to access this information and the target location would be known to get displayed on a user terminal in the further processing of the program, also knowledge about the environment in which the program will be executed would be required to decide whether the assignment operation violates

the security policy or not. If the environment assures that only appropriately authorised persons have access to the room where the particular terminal is installed then the operation may be considered secure. If, however, also people without such authorisation may watch the screen where this information is going to be displayed, that is the environment does not provide measures to avoid this, then the assignment operation would have to be considered insecure.

Admittedly, approaches to security analysis of a programming language usually do not claim to be so far-reaching as to also include considerations concerning the prospective environmental conditions of program execution, but are based on implicit or explicit expectations that these conditions will be appropriate to support security requirements, for example, to prevent inadvertently leakage of information to observers not adequately authorized. Also in this analysis, considerations with respect to environmental conditions as mentioned above will be out of scope. As usual in this type of analyses it is anticipated that appropriately secure environmental conditions are provided by the organisation running the platform on which a business processes is executed. Since here a specification language at business process level is subject to the analysis, which is unable to directly present any information to users (this could, at most, be achieved indirectly via messages sent to a Web service or to an invoker of a business process which usually is also a program), this approach is particularly justified.

4.1.1 Search for Security-Relevant Building Blocks of BPEL Semantics

From the above considerations, combinations of the language constructs with typical restrictions implied by security policies were deemed to be suitable as the smallest parts of BPEL scripts for which sensible statements with respect to their security relevance could be established. Before examining the semantics of these combinations, restrictions derived from security policies for BPEL-defined business processes have been investigated. From this investigation, categories or classes of such policy-derived restrictions have been determined at the abstraction level at which a business process is specified and executed on an appropriate platform.

It turned out that the combination of language constructs of BPEL with classes of restrictions derived from security policies were suitable to identify the security-relevant features of BPEL. The analysis shows that only a subset of the language constructs entails the risk to violate certain classes of restrictions while the rest do not possess any security relevance.

The knowledge of the security-relevant language features in terms of combinations of restriction classes and BPEL constructs provides a clear conception what to look for when analysing a BPEL script for compliance with security policies. In this way, assessment of compliance with security policy is considerably facilitated since a thorough analysis of each and every particular aspect of the semantics of a BPEL script under consideration and comparison with security policy is no longer required. Instead, a direct scan of a BPEL script looking only for the features identified to be capable of violating the security policy will be sufficient for this purpose. Classifying the

restrictions derived from the rules in a particular security policy and relating them with their relevance for BPEL scripts will further make the assessment easier to handle since only those rules in such a policy remain to be considered that are applicable at the level of business process execution.

4.1.2 Trade-Off Between Policy Strictness and Functional Richness

To allow as much functionality as possible in a business process within the limitations imposed by security policies, it is postulated that the restrictions derived from such policies shall be as weak as possible, but at the same time as strict as required to avoid any violation of security policies. This requires a fine-grained concept of specifying access restrictions and information flow restrictions. If, for instance, all internal Web services of the gearbox manufacturer in the example of Figure 4 would either be allowed or forbidden to be invoked by a business process brought into domain B by the car manufacturer, then only such process logic could be specified by a cross-domain deployed BPEL script that could also be performed when running the BPEL script within domain A of the car manufacturer. The only additional requirement for this to happen would be that access would be admitted across the security domain border between the car manufacturer and the gearbox manufacturer for those Web services that were allowed to be accessed in a BPEL script from the car manufacturer when running in domain B.

Though the difficulties to allow such cross-domain access to particular Web services from within domain A (*e.g.*, difficulties to re-define rules for mechanisms controlling

remote access to Web services, typically firewall rules, in such a way that in addition to access privileges to the particular Web services existing before, access would only be allowed for invocations from domain A) could already justify the cross-organisational deployment of a BPEL script, the more interesting cases involve fine-grained access or information flow restrictions. Such restrictions may allow access to a Web service only when passing values returned by former invocations of other Web services or allow information returned by a Web service only to be used in a specific way.

These kind of restrictions could not be controlled when the business process were running outside domain B unless the existing Web services (or at least some of them) would be changed considerably. Without modifications to the Web services in domain B to provide additional mechanisms for authentication and integrity-protection of values passed to a Web service, the source of input values to a Web service invoked from domain A could not be determined by a control mechanism residing in domain B. Similarly, without additional mechanisms for providing confidentiality, values returned across the domain border could not be controlled by domain B as to where they are going to be used in domain A. Allowing cross-organisational deployment of the script defining the business process and checking the script for compliance with the restrictions implied by such fine-grained rules for access control and information flow control would avoid modification to existing Web services and the computational overhead to provide the security mechanisms mentioned above.

4.1.3 Need for Information Flow Analysis in Policy Compliance Assessment

Since the strategy of compliance assessment aims at avoidance of any infringement of security policies, following Dobson (1994, p. 11) access control and information flow control are the mechanisms to be applied. While access control to the Web service offered by the business process under consideration to its environment (being the concern of a complementary security issue as indicated in Section 2.3) was not considered in this research project, access control with respect to the Web services invoked during the execution of the business process and the flow of information from and to these Web services and from and to its environment are to be considered. Hence, the analysis aims at examining whether information or resources accessed and the flow of information are consistent with the limitations of the security policy.

The investigation of restrictions to business processes (in particular those defined remotely from the location of intended execution) imposed by security policy came up with following aspects addressed by them:

- Access control as a whole or to particular parameters of a Web service
- Information flow control as a whole or to particular parameters of a Web service

While the decision whether access to a resource is allowed within the limitations of a policy is comparatively easy to define, distinguishing allowed and disallowed information flow needs further consideration. As discussed in Chapter 3, many approaches addressing information flow control policies use the concept of classified information sources and sinks in order to investigate and even prove noninterference (*i.e.*, the property of a program that no information flow exists from higher to lower security

levels) (e.g., Sabelfeld and Myers, 2003) or that such information flow occurs only in a controlled fashion (Chong and Myers, 2004; Li and Zdancewic, 2005). As stated by Joshi *et al.* (2001), MAC and RBAC (the latter with role hierarchies and constraints) also make use of classified information and thereby allow for information flow control between different levels.

4.1.4 Approach to Dispensability of Security Classification System

To avoid unnecessarily complicating matters, the approach taken here does not explicitly make use of a more or less elaborate classification system of information and resources, but instead simply differentiates between allowed and disallowed information flows in terms of Web service invocations and message exchange with invokers of a business process. To further simplify the definition of allowed and disallowed information flow, it is assumed that

- information flow restrictions in the forward direction (see below for an explanation) are not required within the domain executing the business process (referred to as the executing domain),
- all Web services (both inside and outside the executing domain) a business process is allowed to invoke are explicitly identified,
- restrictions to information flow in the forward direction relate to all external sinks (*i.e.*, information flow crossing domain boundaries is generally affected by such restrictions, possibly with some indicated exceptions) while internal sinks

are excepted from these kind of restrictions for information coming from the same domain, and

- restrictions to information flow in the backward direction relate to particular sources an information has to originate from or restricts information to comply with a particular range of allowed values.

Note: It may be argued that the second aspect of the last item should rather be considered an access restriction than an information flow restriction. For the purpose of the discussion here, and in the following chapters, it does not matter whether a restriction to a particular set of allowed values is treated as belonging to access control or to information flow control.

Thereby, use of classified information is made only implicitly, avoiding the need of defining a classification system (or making use of an existing one) and assigning classes or levels from this system to all resources and users or roles involved in a business process. As a consequence of the assumptions on information flow rules stated above, the implied classification system basically consists of the following security levels:

- information sinks and resources inside the executing domain;
- information sinks and resources outside the executing domain.

However, whenever requirements for a refined classification system occur, refinement takes place implicitly by stating information flow restrictions or indicating relaxations of general restrictions implied by those assumptions. Since no explicit use of classified

information is made when stating information flow rules, there is no need for adapting a classification system prior to making use of its refined version. Therefore, such rules can be formulated as required without caring about predefined security levels and formal aspects of level-crossing information flows.

Besides simplifying the definition of information flow restrictions, this approach also helps to facilitate assessment of compliance with these rules. Since nearly all sinks and sources of information in BPEL-defined business processes are bound to Web services invoked and messages exchanged with invokers of the business process (*i.e.*, invocation of this process' Web service from its environment). Rules formulated in terms of restrictions to Web service invocations, and the information flow related thereto, cover most of the information flow restrictions that apply at all. In addition to explicit information flow to and from Web services and the environment of the business process, the possibility for covert channels is to be taken into account during information flow analysis of a BPEL script since also implicit information flow violating any restriction has to be avoided.

Information flow analysis in the forward direction is understood to consider the flow of information from the point in time during execution that a particular piece of information is brought into a business process (*e.g.*, output of a Web service invocation returned to the business process) to destinations this particular piece of information could flow to in the further processing of the process. By contrast, information flow analysis in the backward direction is understood to consider the flow of information from any sources introducing pieces of information into a process in the past before the

point in time that such pieces of information are passed to a particular sink (*e.g.*, input to a Web service invoked by the business process). Put simply, backward information flow analysis is concerned with the past and forward information flow analysis is concerned with the future of information involved at a particular point during business process execution.

4.1.5 Risks of Policy Violations of Remotely Defined Business Processes

As motivated by the discussion in Section 3.1 relating to security aspects of Web services that can be expressed in the framework provided by WS-* specification, such security requirements are to a large extent dealt with at layers below the business process layer in Figure 1 (namely at the communication layer and the content layer). In particular, access control requirements to Web services as a whole and to parts of the resources and information made available by them may be treated in these layers. However, when remotely defined BPEL scripts are running within the security domain they may inherit access privileges from the local environment. As a consequence, access attempts from within the business process may pass the control mechanisms in the lower layers and be granted in a way not intended for such remotely defined business processes. Therefore, in addition to security policy rules typically applicable to the business process layer, the scope of the analysis of such remotely defined BPEL scripts for potential conflicts with local security policies has to be broadened to accommodate this special situation. In particular, it has to pay attention to policy violations that will be made possible by the fact that these scripts are executed within the local security domain, but would have been prevented by other (usually access control)

mechanisms in layers below the business process layer when executed outside (*e.g.*, in the domain where they were defined). Risks of policy violations by those cross-domain deployed BPEL scripts fall into one of the following categories:

- making information or use of resources available outside the executing domain beyond the limitations imposed by the policy (*e.g.*, reading information with restrictions relating to forward information flow from a database and sending it to an external partner);
- bringing information from outside into an internal data storage that is not allowed to be written to from external sources; and
- using functionality or resources that are not allowed to be used (*e.g.*, altering data in a data base or exercising a system control function).

In the following sections of this chapter, after an overview of BPEL as a specification language, security policy-induced restrictions to Web service invocation are categorised and combined with BPEL constructs. The aim here is the identification of security-relevant building blocks of business process behaviour specified by such combinations.

4.2 Overview of BPEL Semantics

The standardised business process definition language BPEL has been brought into an OASIS standardisation process based on a proposition that originated from merging two vendor-specific BPDs, namely Microsoft's XLANG (Thatte, 2001) and IBM's WSFL (Leymann, 2001). The approaches to specify business process logic were different in these two BPDs and as a compromise in the standardisation process, BPEL still

contains the different approaches to express business logic inherited from these two vendor-specific predecessors. This is the reason why BPEL (in the version adopted as an OASIS standard (Alves *et al.*, 2007)) still comprises two essentially different ways of expressing process flow logic. These are a graph-structured modelling style inherited from WFSL and a block-structured modelling style inherited from XLANG.

Since the beginning of this PhD research in 2004, the definition of BPEL has undergone some modifications that the project has strived to keep pace with. While the discussion in this chapter is based on the version 2.0 of BPEL, which finally has been accepted as OASIS standard, the research prototype is based on previous versions of BPEL specifications. The reasons for this and why this is not deemed to void the proof of concept that has been aimed to be achieved will be discussed in Chapter 7.

Basically, BPEL only provides means for specifying Web service invocation and the exchange of messages with the environment of the business process being specified as well as means for specifying the flow of control and information between these invocations and message exchanges. In addition, BPEL comprises means to specify what should happen when exceptions are raised or errors occur.

While a detailed description of BPEL can be found in its specification (Alves *et al.*, 2007), a comprehensive analysis of its semantics was conducted by Wohed *et al.* (2002) based on a previous version of the BPEL specification. An overview of the language and a comprehensive example is given by Leymann and Roller (2004). The nature of BPEL accommodates the analysis of security-relevant semantics by offering only little

or no means for defining data processing or computational tasks as part of the language itself. For these purposes, BPEL scripts have to invoke Web services, or must import constructs from other XML standards such as XPath (Berglund *et al.*, 2006). In addition, security aspects such as authentication, provision of secure communication channels, and non-repudiation do not have to be considered in this context, since the language does not provide any means related to these security aspects. These aspects usually are catered for by the platform running BPEL scripts. Thus, the analysis can be concentrated on the business or workflow logic that may be expressed in BPEL in order to identify security-relevant semantics.

In BPEL, two types of processes may be modelled: executable and abstract processes. Abstract processes are used to specify a business protocol in order to define the potential sequence of messages exchanged between business partners. Since such protocols should allow the internals of business processes actually performed by the partners to be hidden, abstract processes may comprise some kind of vagueness with respect to process logic performed internally by the business partners. Since abstract processes are not executable by their definition, they are not in the scope of this analysis where BPEL scripts intended for actual execution on a remote platform are considered.

Therefore, only executable processes are subject to this analysis. BPEL scripts intended for this purpose specify workflow logic in terms of activities. The prevalent semantics expressed in BPEL is the exchange of messages with one or several external partners that can be thought of as invoking Web services provided by partners or being invoked as a Web service by partners. In a declaration part, BPEL scripts define the potential

links to external partners by references to WSDL definitions of the Web services involved. Thus, analysing these declarations in a first step yields the set of Web services that may be invoked or are offered by a business process under consideration.

4.2.1 General Structure of BPEL Scripts

In BPEL, like in high level programming languages, there exists a predefined structure of several groups of declarations serving different purposes. Each BPEL script represents an instance of an XML element `<process>` that may contain several parts for defining elements not directly related to normal process flow (except event handlers, cf. explanation below) and one element specifying the process logic of the business process called an activity. This single activity at the top level of a process definition is usually a structured one, which means an activity containing other activities. The parts not directly related to normal process flow are all optional (though at least some of them are required to compose a BPEL script defining a proper process). These parts contain declarations of the interfaces to the environment of the business process (called partner links in BPEL), the variables to be used, and so-called event handlers and fault handlers. In addition, some of these parts may define links to other specifications via XML namespace definitions and by explicit import via an `<import>` element or even extensions of process logic not expressible with BPEL-defined activities. In particular, declarations of partner links refer to WSDL definitions of Web services to be invoked by a business process or defining the Web service provided by the business process specified in a BPEL script. Also the declaration of variables may refer to WSDL definitions but also may be related to definitions of arbitrary XML schemas. The latter

is new in BPEL 2.0 since in former versions of BPEL variables were only allowed to be declared in terms of types imported from WSDL definitions.

While the other declaration parts do not contain any process logic and, therefore, only indirectly influence security-relevant semantics of BPEL, event handlers and fault handlers directly contribute to the process logic. Fault handlers are intended to define process logic to be performed in response to exceptions and errors that may occur during the execution of the normal process. Besides indicating the condition for being selected and executed (*i.e.*, specifying the fault to which a handler reacts), fault handlers specify process logic using activities as in the part specifying the normal process flow. In addition, there are some activities especially reserved to only be used within fault handlers. Since the occurrence of a fault is not considered normal in a process definition, fault handlers specify exceptional process behaviour that might never be executed if no exception or error caught by any of these handlers occurs. However, since the occurrence of such faults cannot be ruled out during the analysis and since these faults may occur unpredictably at any time during process execution, all process logic specified in such fault handlers may be deemed to represent potential parallel flows to the normal flow of the process and may be treated as such when analysing a BPEL script for compliance with security policies.

Event handlers also specified in the declaration part of a `<process>` element specify how a process should react when particular events occur such as incoming messages or timeout events. On one hand side like fault handlers, event handlers specify the event or the timeout condition that trigger their process logic to be executed. On the other hand

side, unlike fault handlers these declarations specify not exceptional, but normal behaviour of a process and, therefore, have to be considered an integral part of the normal flow of process logic. The semantics of such event handlers is very similar to those of the **pick** activity, which will be discussed below. As with fault handlers, the trigger events specified in such a handler may occur at any time during process execution and, thus, the process logic of these handlers may be thought of as potential parallel flows to the process logic specified in the main process stream specified in the BPEL script.

4.2.2 Primitive and Structured Activities in Normal Process Flow

The activities expressing the semantics of a process either in the main stream or in the exceptional or event-triggered streams of a business process may be either primitive or structured. BPEL provides the following primitive activities to be used in the normal flow of process logic (*i.e.*, the process flow collectively specified in the activity of the main stream and the event handlers in contrast to exceptional process flow specified in fault handlers):

- **invoke** invocation of a Web service
- **receive** waiting for a message to arrive
- **reply** sending a reply to a message received
- **assign** assignment of values between two different locations
- **wait** waiting for a specified amount of time
- **throw** indication of exceptions such as failures during execution

- **exit** termination of a process instance. (Note: Was **terminate** in previous versions of BPEL)
- **validate** validation of the content of variables against their type definition in WSDL documents or XML schemas
- **empty** no operation

The structured activities provided by BPEL are:

- **sequence** definition of a fixed execution order
- **flow** parallel execution of activities
- **if** branching between several alternate activities depending on conditions. (Note: Replaces the **switch** activity of previous versions of BPEL)
- **while** iterative execution, *i.e.*, looping as long as loop condition holds
- **repeatUntil** iterative execution, *i.e.*, looping provided loop condition holds. (Note: Added during standardisation process of version 2.0)
- **forEach** iterative execution, *i.e.*, multiple execution for a specified number of iterations either consecutively or in parallel. (Note: Added during standardisation process of version 2.0)
- **pick** waiting simultaneously for several events to occur and proceeding depending on the event that actually occurs; typically, one event waited for is a timeout event

4.2.3 *Additional Flow Control and Structuring Elements*

Additional control of parallel and sequential flows within a **flow** activity may be expressed by so-called links (not to be confused with partner links) that are used to specify dependencies and sequencing of parallel flows. The language constructs applicable for this purpose are:

- **links** definition of links to be used within a **flow** activity (not to be confused with partner links defining external interfaces)
- **source** used to specify an activity to be a predecessor of another one
- **target** used to specify an activity to be a successor of another one

In the examples in Listings 1 and 2, the graph-structured and block-structured modelling provided by BPEL are compared. It should be noted that both examples, though one uses a **flow** activity and the other uses a **sequence** activity, result in identical process semantics. This is caused by the **link** element used in Listing 1. Although the example activities **activity1** and **activity2** which actually serve as placeholders for any BPEL activity occur lexically in reverse order within the **flow** activity, they will be executed in the same order as in the **sequence** activity of Listing 2 due to the **link** named **reverse**. By defining the activity occurring first within the flow as the target of this link while the activity occurring second is defined as the source of the same link, the actual execution order of these two activities will be reversed. Note that reversion of execution order is not effectuated by the name of this link, but only by the way this link is used as a target and source, respectively, in both activities.

```
<flow>
  <links>
    <link name="reverse"/>
  </links>
  <activity2>
    <target
linkName="reverse"/>
  </activity2>
  <activity1>
    <source
linkName="reverse"/>
```

Listing 1: Graph-Structured Modelling

```
<sequence>
  activity1
  activity2
</sequence>
```

Listing 2: Block-Structured Modelling

In addition to structured activities, there is another language construct, named **scope**, similar to structured activities since it also serves structuring purposes but is not considered a structured activity (however, terminology in BPEL standard (Alves *et al.*, 2007) is not consistent with respect to this). This construct is used to define nested structures of scopes for the declaration of particular constructs. Actually, a scope provides virtually the same structure for the declaration of partner links, variables, fault handlers, event handlers, and a single activity as the **<process>** element which may be considered the top-level scope of the hierarchy of nested scopes. In addition, two other types of declarations are particular to scopes - namely termination handlers and compensation handlers¹. Each scope definition may contain at most one of each of these declarations. The purpose of these declarations is to specify process logic in the case of (normal) termination of the activity defined in a **scope** or in the case the activity of a

¹ The concept of termination handlers is new in version 2.0. For compensation handlers, there used to be the possibility to define them at process level in former BPEL versions, but this has been removed in the final version of BPEL 2.0

scope needs kind of roll back, called compensation in BPEL. Rolling back the effects of a (usually structured) activity of a **scope** could be required in response to an error occurring during the execution of this **scope**. Typically, activities to be reversed by a compensation handler are those that have been performed within the particular scope to which the compensation handler refers.

4.2.4 *Special Activities for Fault Handling*

There are some further primitive activities, **compensate** and **compensateScope**, collectively referred to as compensation activities used to initiate rollback actions in transaction-based application contexts, and **rethrow** for passing faults to the enclosing nesting level. They are only allowed to be used within fault handlers. Since compensation activities initiate the execution of one or several compensation handlers they logically link activities defined in such handlers to fault handlers containing these compensation activities. While **compensateScope** is intended to initiate the compensation for a particular scope, **compensate** initiates compensation for the scope related to fault handler issuing this activity as well as for all nested scopes within this containing scope. The **rethrow** activity passes the information that a particular exception occurred possibly accompanied by some fault variable containing further information to its containing scope level or to the process level. Therefore, a **rethrow** activity needs attention in information flow analysis with respect to the fault variable and the exception passed to the next higher nesting level.

4.2.5 Concept of Multiple Instantiation in BPEL

In addition to the activities representing the main part of the semantics of BPEL, there is a concept of multiple instantiation in BPEL that enable several instances of the same business process being defined by one script and being created by messages arrival from external partners. As long as the different instances do not share common variables that is usually not the case though the standard does not compel that each instance uses a separate copy of its variables, these instances may be considered separate copies of the same BPEL script running in parallel. Therefore, multiple instantiation does not add any particular security relevance and, therefore, no particular consideration of multiple instantiation is required during this analysis. Instead, the results applicable for a BPEL script not using multiple instantiation can be applied to each copy independently whether it runs as separate processes or as instances of a single process. If several instances should communicate with each other, this is performed via mutual message exchange as with external Web services invoked by a business process and, thus, does not represent any special case not considered otherwise in this analysis. In essence, multiple instantiation will not be investigated separately and only the requirement is stated that multiply instantiated processes shall not share identical variables because doing so could impose covert channels.

4.2.6 Extensibility of BPEL and Problems for Compliance Assessment Involved

BPEL provides extensibility in several ways. First, BPEL allows for namespace-qualified attributes in any BPEL element and also elements from arbitrary namespaces to appear within elements defined in BPEL. Further, BPEL 2.0 (Alves *et al.*, 2007)

provides three elements for explicitly defining extensions within a BPEL script. These elements are `extensions`, `extensionActivity`, and `extensionAssignOperation` the last one occurring as part of an `assign` activity. The standard clearly defines the conditions when a BPEL implementation may ignore such extensions, but still execute the rest of the script containing these extensions and when it is required to reject a BPEL script for execution that contains particular extensions not supported by the implementation.

Obviously, for the purpose of assessing the compliance of a BPEL-defined business process with local security policies, the presence of any extension in a BPEL script is detrimental since it introduces new semantics that could not be analysed in advance for its security relevance as the other language elements. For the approach to facilitate compliance assessment for BPEL-defined business processes based on an analysis of the security relevance of BPEL as a specification language, BPEL scripts containing such extensions have to be excluded since they escape from this approach. It is anticipated, that business processes in a collaborative environment, in general, can avoid the use of such extensions. However, if the requirement for such extensions exists and it can be assumed that they will be agreed upon between the business partners before using them, the approach proposed in this research may be adapted to also comprise such extensions. Given particular extensions to be used are known beforehand, they can be subject to an analysis for their security relevance similar the one conducted in this research for the standardised language elements. After that, the methods deduced from this analysis as described in the following chapters may be adapted accordingly to also accommodate such pre-defined extensions. However,

dealing with such extensions in BPEL scripts is expected to increase complexity of the assessment procedure and may be particularly difficult to incorporate in automatic compliance assessment. For the considerations on security relevance of BPEL in this research, scripts containing extensions have been excluded.

4.3 Classification of Security Policy-Derived Restrictions for WS Invocation

As discussed above, the language constructs will be investigated in conjunction with different types of Web services because in BPEL scripts access to information or resources may only be gained via Web services. Given a particular set of restrictions implied by a security policy that is associated to a particular set of privileges (*i.e.*, a particular role), Web services may be distinguished with respect to access allowance or restrictions to their input and output parameters. Table 1 shows six different classes of access restrictions to Web services as a whole or to Web service parameters that will be considered in the analysis of security relevance of BPEL. There are additional access restrictions derived from security policy rules that are not covered by these six classes. Reasons for not including them into Table 1 for consideration in this analysis will be given during the discussion in this chapter.

The classes 1 and 2 relate to Web services as a whole while classes 3 through 6 relate to the input and output parameters of Web services. Obviously, class 1 denoting Web services with unrestricted access to all resources and information offered by them does not represent an actual restriction category (since no restriction applies at all) but is added here for completeness of this classification. Class 2 represents the opposite of

class 1, Web services that are disallowed to be invoked at all whatever parts of their resources or information would be concerned.

The restrictions in class 3 relate to output parameters of a Web service invocation and denote the restriction that information provided by those parameter to the invoking party are not allowed to be carried to particular destinations. Following the simplification rules stated in Section 4.1.4, this type of restriction is meant to denote information flow restriction from the domain executing a business process to any destination outside this domain. In order to allow for more flexibility, when applied to an output parameter of a Web service this restriction can be amended by a relaxation statement indicating one or several external destinations to which information flow will be allowed despite this restriction.

The restriction classes 4 through 6 relate to input parameters of a Web service. Class 4 denotes the restrictions with respect to the use of optional parameters. Despite the definition of a Web service parameter as being optional, security policy can require that such a parameter is not allowed to be used or, contrary, has to be used in any invocation of the particular Web service. Reason for prohibited use of an optional parameter could be that the security policy-derived rules applicable for the particular role would prevent an input parameter to be used because it would offer access to resources or information that is not allowed to be used by this role. For instance in the CBP example of Figure 4, an optional input parameter to Web service *checkStock* could effectuate a preferential treatment of the order. In case this functionality would not be made accessible to a

business process remotely defined by the car manufacturer, this parameter would be disallowed to be used by a BPEL script imported from the car manufacturer.

Classes	Description
1	Web service with unrestricted access to all parts of resources or information offered
2	Web service with completely restricted access (<i>i.e.</i> , Web service that is not allowed to be invoked)
3	Output parameter of a Web service with restricted visibility of values returned (<i>i.e.</i> , restriction with respect to forward information flow): Some information made accessible is not allowed to be carried outside the executing domain (<i>i.e.</i> , parameter returned is only allowed to be used within the executing domain, but not in outbound messages to targets outside this domain). Some relaxation of this restriction to dedicated targets may apply as explicitly indicated.
4	Optional input parameter of a Web service with usage restrictions (in two alternate versions): a) optional parameter is not allowed to be used at all b) optional parameter always has to be passed to avoid default definition for this parameter to take effect
5	Input parameter of a Web service with constrained set of values allowed: input parameter may only be used with particular values being a subset of the values allowed by the syntactic definition of this parameter
6	Input parameter of a Web service with values restricted to specific sources: only values from particular sources may be used, for instance, only values returned by a particular Web service or a particular Web service parameter

Table 1: Classification of Access Restrictions to Web Services and WS Parameters

As another case of class 4 restrictions, it could be required that an optional input parameter is required to be used in every invocation of the particular Web service. An example of such a restriction in the business process of Figure 4 could be that an optional parameter of Web service *calculateOffer* would indicate the amount of rebate

offered to the client. In case that this optional parameter has a default value indicating a rebate level that will not be offered to the car manufacturer, restriction rules would require that this parameter would be passed with every invocation from a business process defined by the car manufacturer and that its value lies in a certain range. This example reveals that requiring an optional parameter to be present in a Web service invocation often results in an additional restriction of class 5 or 6 (see below).

Restrictions of class 5 require that only values from a particular set of allowed values be used for the respective input parameters of a Web service. Obviously, this restricted set of allowed values will be a subset of the syntactic allowed values of the particular parameter. An example for this kind of restrictions in the CBP of Figure 4 could be that an input parameter of the *calculateOffer* Web service could indicate the level of rebate provided for in calculating the offer. If the syntax of this parameter would be defined to take on values from the range 5%–50%, but for the car manufacturer only rebates in the range of 5%–30% are offered, then this input parameter would be constrained to the value range [5%–30%] though the syntax of the parameter would allow values in the range [5%–50%]. It should be noted, though this kind of restriction looks like a syntactic one, it actually represents a restriction with respect to the semantics of this parameter since the syntax of the parameter being defined to adopt values in the range [5%–50%] and being checked by a parser in the executing platform would not be changed because of this security policy induced constraint of the value range. Therefore, this restriction cannot be considered a syntactic one because the parameter still is capable to accept values in the range [5%–50%].

Class 6 denotes restrictions with respect to the source of values that are allowed to be passed to an input parameter of a Web service. This kind of restriction does not impose any constraint to input parameters with respect to allowed values but only requires that values passed to these input parameters are restricted to only come from particular sources. In business process context, such sources usually are output parameters of previous Web service invocations.

As can be easily seen, Web services with unrestricted access permission (class 1) as well as Web services with total access restriction (class 2) do not pose any particular challenge for analysis. With these classes, any further distinction between combinations with different activities of BPEL is not relevant. The reason for this is that their allowed or forbidden use in a BPEL script may already be detected by examining the declaration part. No Web service with total access restriction (class 2) must occur in the declaration part, or at least, if such a Web service should occur in the declaration part, it must not be used in any message exchange performed in the business process. Conversely, Web services with unrestricted access permission (class 1) may be invoked freely throughout a business process, irrespective of particular combinations with BPEL activities. The only aspect relevant with Web services of class 1 is the information flow to and from parameters of such a Web service prior and succeeding its invocation, respectively. Any value passed to input parameters of such a Web service must obey possible information flow restrictions of class 3 imposed to output parameters of other Web services. Equally, any value returned by an output parameter of such a Web service is required to observe the restrictions of class 5 and 6 imposed to Web service invocations in the further course of the business process.

The distinction between classes 3 through 6 requires detailed knowledge of the semantics of a Web service. Since such detailed knowledge of external Web services may not be available in the executing domain, external Web services, in general, tend to fall into classes 1 or 2. Conversely, the semantics of internal Web services can be assumed to be well-known within the executing domain such that the differentiation between classes 3 through 6 will be possible.

There is another distinguishable aspect in Web service invocation. This distinction differentiates between Web services accessible independent from the location of the invoker or Web services only allowed to be accessed from inside the executing domain, but not from inside the remote domain defining the BPEL script. For Web services of the executing domain, the latter may be very common since this usually is the reason for bringing the BPEL script from the remote domain to the executing domain. If all Web services invoked would be accessible independent of the location of the invoker, there would be no obvious reason for not running the script in the domain where it is defined with the possible exception that enabling cross-domain invocation would pose problems in the lower layers responsible for access control (*e.g.*, problems with appropriately redefinition of firewall rules to just allow remote access to particular Web services from one particular external domain but still preventing such access from other domains).

Since the location-dependent allowance for invoking a Web service is nothing special for local Web services in the executing domain (*e.g.*, domain B in the example of Figure 4), this situation needs no special observation. However, there may also be external Web services, for example the Web services **priceQuotation** in domain C in Figure

4, that are only allowed to be invoked from inside the executing domain B, but not from inside domain A. In fact, for purposes of the analysis in this section, it has to be determined whether the semantics of the external Web services are known to an extent that allows for classification into classes 1 through 6 above. If this is not the case, such Web services have to be treated as belonging to class 1, because classification of its parameters into classes different from class 1 is not possible due to lack of knowledge about their semantics.

If only Web services with unrestricted accessibility occur (class 1), the business process could also be executed at the domain where it is specified (with the possible exception relating to accessibility mentioned above). The only difference in having such a business process executed in a different domain is the fact, that computational and communicational load involved is moved to this other domain. With respect to security, this is only relevant as bearing the potential for making exhaustive use of computational or communicational resources of this other domain. When driven to an extreme, this could cause a form of denial of service attack in this domain. As such exceptional behaviour may easily be controlled by the runtime environment executing the BPEL script, this is not considered to constitute a security threat in this context that needs particular examination before running a BPEL script. However, detecting such behaviour by analysing the BPEL script prior to execution is also feasible. This aspect, although neglectable in a CBP context, may require further consideration in other contexts where appropriate measures to prevent exaggerated usage of resources cannot be anticipated. A further discussion on this aspect will take place in Chapter 8.

4.4 Security Analysis of Semantic Patterns of BPEL

In this section, the building blocks of BPEL-definable semantics of a business process that are used for the purposes of the security analysis conducted in this PhD project are identified and the results of this analysis are presented.

4.4.1 Definition of Semantic Patterns of BPEL

To determine their relevance with respect to security policies, in particular access control and information flow control, combinations of information passed to or received from Web services associated with restrictions belonging to the classes of Table 1 with the activities defined in BPEL are investigated. These combinations are denoted semantic patterns in this research project and considered appropriate building blocks of BPEL-definable business process semantics for the purposes of analysis of the security relevance of BPEL as a specification language. When activities are directly concerned with Web service invocation or message exchange with partners, the meaning of such combinations is obvious. Combinations with activities not directly concerned with Web service invocation need further explanation. Combining a parameter subject to a restriction of a certain class and a particular BPEL activity denotes the situation where the information passed to or returned by such a parameter has been or will be used in combination with this type of activity. Of course, a particular Web service parameter may belong to more than one of the classes 3 through 6 simultaneously. For the ease of discussion, no combined classes are analysed, since for a Web service parameter belonging to more than one of these classes, the results related to each of the classes it belongs to may be applied simultaneously in this situation.

4.4.2 Results of Security Analysis of Semantic Patterns

As already mentioned in Section 4.3, semantic patterns involving access restrictions of classes 1 and 2 need no further investigation. The results of the analysis of semantic patterns involving information flow restrictions of classes 3 through 6 are depicted in Tables 2 and 3 and discussed in this section. While Table 2 presents the results for semantic patterns formed by combination with primitive activities, Table 3 indicates the results for structured activities.

Tables 2 and 3 each comprise five columns. The second column contains a short description of the semantics of the respective BPEL activity in the first column. In columns three through five, the implications for security assessment are indicated, when the respective BPEL activity is combined with information exchanged with a Web service subject to restrictions of classes 3 through 6. Since the entries for classes 5 and 6 only differ slightly, the indications for these classes are combined in the fifth column.

An entry of “–” indicates that the respective semantic pattern is not relevant in scope of access control and information flow. As shown in Tables 2 and 3, some semantic patterns require special attention with respect to information flow indicated by entry **IFA** followed by a parenthesised letter. The meanings of the different variants of this type are as follows: An entry **IFA(v)** denotes the requirement of forward information flow analysis with respect to information returned by Web service parameters subject to class 3 restrictions. The entry **IFA(r)** denotes the requirement for backward information flow analysis with respect to Web service parameters subject to class 5 restriction (*i.e.*, restricted value range) and entry **IFA(s)** denotes the requirement for backward infor-

mation flow analysis with respect to Web service parameters subject to class 6 restriction (*i.e.*, restricted source of values passed to these parameters).

Security patterns involving class 3 restricted information and one of the activities **invoke** (with respect to the inbound parameters, *i.e.*, the output parameters of the Web service invoked), **receive** or the **on message** part of **pick** (in the latter cases with respect to the inbound parameters of a message received from a partner) are security-relevant since information received from these activities may cause security policy violations when passed to targets outside the executing domain (except those targets were indicated explicitly as exceptions from the general visibility restriction). As can be seen in Table 2, information flow analysis in forward direction is required to determine whether visibility-restricted information returned by the Web service is kept inside the security domain and is not sent outside via one of the activities **invoke** (within an outbound parameter) or **reply** unless the target is indicated explicitly as allowed within the exceptions to the particular information flow restriction.

Primitive Activities		Class 3	Class 4	Cl. 5/6
invoke	Invocation of a Web service	IFA(v)	u	IFA(r/s)
receive	Waiting for a message to arrive	IFA(v)	–	–
reply	Sending a reply to a message received	–	u	IFA(r/s)
assign	Assignment of values between two different locations (see note)	(relevant in IFA only)		
wait	Waiting for a specified amount of time	time(v)	–	–
throw	Indication of exceptions such as failures during execution	except(v)	–	–
rethrow*	Forwarding of exceptions causing fault handler execution to containing scope	–	–	–
empty	No operation	–	–	–
validate	Validate values against type declaration of variable	val(v)	–	–
exit	Termination of a process instance	exit(v)	–	–
compensate*	Initiate compensation as specified by compensation handlers of corresponding scope and all nested scopes	–	–	–
compensate Scope*	Initiate compensation of activities as specified by compensation handler of a specific scope	scope(v)	–	–

Note: For attribute **validate** possibly contained in this activity see discussion below on activity **validate**.

* = activity only to be used within fault handlers

IFA = information flow analysis,

(v) with respect to visibility of values returned from WS,

(r) with respect to ranges of values passed to WS,

(s) with respect to sources of values passed to WS

Table 2: Security Relevance of Semantic Patterns with Primitive Activities

For class 4, only **invoke** (with respect to the outbound parameters, *i.e.*, the input parameters of the Web service invoked) and **reply** need special attention to check that

the restricted input parameters of the Web service or the output parameter in a message sent to a partner will be used conforming to the particular usage restriction indicated by entry **u** (*i.e.*, not used or always present depending on the embodiment of this restriction). Classes 5 and 6 are similar, since with **invoke** (with respect to the outbound parameters) and **reply** information flow analysis is required to determine whether the restricted use of values is obeyed. With class 5, backward information flow analysis related to the values written to restricted outbound parameters is required (indicated by entry **IFA(r)**), whereas with class 6, analysis is required with respect to the sources of such values (indicated by entry **IFA(s)**).

As indicated in Table 2, analysis of information flow has to embrace **assign** activities to observe the movement of information within the business process. If processing such as calculation or string manipulation is performed within a BPEL script using language constructs imported from, for instance, XPath (Berglund *et al.*, 2006), it has to be analysed that no restricted information is involved, or at least, that results from the processing is not used in a manner violating the security policies. Since allowing such kind of processing on restricted information could cause obfuscation of information flow, thereby complicating the analysis of information flow, as a matter of precaution such processing should be generally considered incompatible with security policy, independent of the further use of its results. Since it can be assumed that any such processing will be performed in Web services invoked by a business process such that no need for any such processing exists within the process itself, for the purpose of this research project, incorporation of any elements from XPath or other XML specifications providing data manipulation has been excluded.

The activities **empty**, **compensate**, and **rethrow** involve no security relevance whatsoever. This is quite obvious for the **empty** activity. For the **compensate** activity, this can be seen by the consideration that this activity only initiates compensation from within a fault handler but, by its own, has no effect with respect to observable behaviour of the business process. The business logic performed in the course of a compensation is specified by activities in the respective compensation handlers. The security relevance of these activities is subject to separate examination of the compensation handlers and the outcome of this examination is not associated with the activity initiating these handlers to be executed. Also for the **rethrow** activity, the reason for not being security-relevant relates to the fact that this activity simply forwards the exception that caused the fault handler containing this activity to be executed to the environment of this fault handler that is the scope at the next higher nesting level or the process level. Since passing of information stays within the process being executed, and the exception to be passed is predetermined without any choice for passing different information, no risk for violation of information flow restrictions exist.

However, the **compensateScope** activity which is quite similar to **compensate** bears security relevance of its own. Reason for this is that this activity selects one particular compensation handler for execution. If this selection would depend on visibility-restricted information, the fact that this particularly selected compensation took place could be observed from outside to conclude on the value of the class 3 information and thereby could be exploited to establish a covert channel for information leakage.

Similarly, use of visibility-restricted information gained from Web services of class 3 in the activities **wait** (with respect to duration), **throw** (with respect to exception thrown and information passed along with exception), **exit** (with respect to condition for termination), **if** (with respect to definition of alternate flows), **while** and **repeatUntil** (both with respect to loop control), **forEach** (with respect to loop boundaries as well as to conditions for pre-emptive termination of iteration), and **pick** (with respect to timeout interval) also turn out to be security-relevant as shown in Tables 2 and 3 because of the risk of establishing covert channels. Defining any of the terms indicated in parenthesis with the above activities dependent on visibility-restricted information could be exploited to circumvent restrictions implied by security policy. For instance, if the visibility-restricted information *I* is used to control the amount of loop cycles in a **while** activity, providing some externally observable behaviour such as sending a message to an external Web service from within the loop body could be used to circumvent the visibility restriction on *I*. In this way, an external observer would be able to count the numbers of such messages and deduce the value of *I* from this observation. However, revealing *I* to an external observer would violate the security policy restricting this information from being disclosed outside the domain.

With respect to potential covert channels, also the activity **validate** as well as the attribute **validate** of the **assign** activity require special attention. If variables declared within a BPEL script containing visibility-restricted information are to be validated, possible value range restrictions specified in their types' definition could leak information contradicting security policy implied information flow restrictions. Consider, for example, a variable **receivePriceInfo** declared to be of a fictitious type

belowThousand which has been derived from the simple XML-type **integer** with the additional restriction **xsd:maxInclusive value="999"**. If this variable would be used to store the visibility-restricted output parameter **price** returned from a Web service invocation (e.g., an inquiry similar to Web service *priceQuotation* in Figure 4 indicating the price of a single item), then validation of this variable after storing the price would leak information about the price via externally observable behaviour of the business process. The negative outcome of this validation would cause a standard **bpel:invalidVariables** fault to be thrown. An observer who has written the BPEL script and sent it to the executing domain for performing the business process corresponding to this script would know that the price returned from this Web service was greater than or equal to 1000 when this exception would occur and that the price was less than 1000 when no exception occurs. Obviously, by cascading of validations against varying types, a visibility-restricted information could be propagated to an arbitrary level of detail by causing or avoiding **bpel:invalidVariables** faults in **validate** activities.

The additional flow control and structuring elements of BPEL as introduced in Section 4.2.3 are not included in Tables 2 and 3 because they are not considered activities. The additional flow control via links in **target** and **source** elements of activities within a **flow** activity expose security relevance as indicated above with **while** or **if** activities if their flow control mechanisms are made dependent on information flow restricted information (class 3 restriction) thereby bearing the risk of establishing a covert channel. The Boolean expressions contained in a **joinCondition** with element **target**, and in a **transitionCondition** with element **source**, must

not depend on any visibility-restricted information in order to avoid covert channels with these constructs.

Structured Activities		Class 3	Class 4	Classes 5/6
sequence	Definition of a fixed execution order	–	–	–
flow	Parallel execution of activities	–	–	–
if	Branching between several alternate activities depending on conditions	branch cond(v)	–	–
while	Iterative execution, <i>i.e.</i> , looping	loop cond(v)	–	–
repeat Until				
forEach	Iterative consecutive or parallel execution	iteration bounds(v)	–	–
		preempt(v)		
pick	Waiting simultaneously for several events to occur and proceeding with the first event that actually occurs (see note)	IFA(v)	–	–
		time(v)	–	–

Note: Typically, one of the events waited for is a timeout event, while the other events are messages to arrive

IFA(v) = information flow analysis with respect to visibility of values returned from WS

Table 3: Security Relevance of Semantic Patterns with Structured Activities

From the additional structuring elements of BPEL, event handlers contribute additional security-relevant semantics as will be discussed below. The other structuring elements, that are scopes, fault handlers, compensation handlers and termination handlers, do not provide any security-relevant semantics on their own. Of course, the activities contained in all of these handlers exhibit the same security relevance as if they were used in the

definition of the main stream of a business process. Nevertheless, these structuring elements need to be observed during compliance assessment of particular BPEL scripts since they provide particular execution semantics to the activities contained in them. Fault handlers as well as compensation handlers that can be linked to the execution path of fault handlers via the compensation activities represent process logic to be executed in the case of exceptions or errors, collectively denoted as faults. Since such faults may happen at virtually any time during process execution these fault handlers and the compensation handlers eventually initiated by them can be thought of as potential flows parallel to the main processing flow of the process and, therefore, have to be treated as such during information flow analysis.

In contrast, event handlers contribute to the security-relevant semantics of BPEL in that they specify possible interaction with the environment of the business process. The **onEvent** and **onAlarm** elements contained in such handlers taken together exhibit similar semantics as a **pick** activity. The **onEvent** elements of event handlers like the **onMessage** elements of a **pick** activity work like a **receive** activity, that is they wait for messages to arrive on partner links. Therefore, these elements represent security-relevant semantics when information flow-restricted information (class 3 restriction) is received this way and information flow analysis in forward direction is required in this case to verify that such information is only used in a way conforming to these restrictions. Furthermore, in the same way as the **onAlarm** elements of a **pick** activity, these elements provide the capability of establishing covert channels when the duration of such a timeout surveillance is made dependent on visibility-restricted information.

Though very similar to a **pick** activity, there is a significant difference between event handlers and this activity. While a **pick** activity blocks further processing in its flow until one of the messages waited for has arrived or a timeout occurred, event handlers do not block normal processing but wait for the messages or timeout events in parallel to normal process flow. Furthermore, if one of the messages specified in event handlers arrives or a specified timeout occurs, this waiting for messages or timeout events is not terminated as in the case of a **pick** activity but remains active until the containing scope or the process as a whole (in the case of event handlers specified at process level) terminates. For information flow purposes, event handlers may be thought of as a **pick** activity contained in a endless loop (**while** activity with Boolean constant true as looping condition) that executes parallel to the activity specified in a scope or parallel to the activity specified at process level, that is contained in a **flow** activity together with this scope-level or process-level activity. From this consideration it becomes clear how event handlers have to be treated during information flow analysis during security policy assessment of a BPEL script containing such handlers.

4.5 Considerations with Respect to Separation of Duty Constraints

In addition to the security policy-derived restrictions to Web service invocation from within a business process discussed in Section 4.3, there is another type of restriction derived from security policies not considered in this analysis. This type of restriction is known as separation of duty (SoD) and well-studied in literature (Wijesekera and Jajodia, 2003; Schaad and Moffett, 2002, Schaad *et al.*, 2006, Ribeiro *et al.*, 2000b). Restrictions of this type are either static or dynamic. The static version demands that

multiple roles of a particular set of roles cannot be adopted by the same principal (user) over time (*i.e.*, once a principal has adopted one role he will never adopt any further role of the same set). Applying such constraints to Web service invocations implies that different Web services requiring access privileges associated with different roles in such a set cannot be invoked by the same principal. With respect to business processes, this means that the same process is not allowed to invoke Web services belonging to different sets of access privileges constrained by so-called static SoD policies.

The other form of SoD, called dynamic SoD, is a relaxation of the static variant in that it allows the same principal to adopt different roles subject to SoD constraints, but not at the same time or not in the same operational context. It should be noted that these alternate dynamic conditions sometimes are treated as separate subtypes of dynamic SoD (Schaad and Moffett, 2002, pp. 19, 20). The typical example for this type of constraint is a payment process where the issuer of a payment order is not allowed to release or authorize the same order while he may well be allowed to release a payment not initiated by himself. In the context of Web services and business processes, enforcement of dynamic SoD constraints is based on the history of Web services invoked and instances of business objects handled.

While static SoD constraints may be enforced at business process level by not invoking Web services associated to conflicting privileges in the same process, controlling the obedience of dynamic SoD constraints in business processes based on mechanisms provided by BPEL seems to be difficult or even impossible. Reasons for this are the lack of information and the lack of influence on who is going to invoke the Web service

offered by a business process. Remember that BPEL does not offer any mechanisms for access control. This difficulty exists independently of whether the process has been defined locally or remotely. Approaches to cover dynamic SoD requirements not necessarily specific to business processes or Web services exist (*e.g.*, Schaad and Moffett, 2002, Botha and Eloff, 2001). Obviously, enforcement of dynamic SoD constraints require mechanisms applied at runtime.

Since the approach presented in this PhD thesis is mainly based on static analysis of business process semantics, it is not claimed that this approach will be appropriate to contribute to enforcement of dynamic SoD requirements. However, static SoD constraints may be adequately addressed in this approach. A discussion of this and some sort of workaround for dynamic SoD constraints are contained in Chapter 5.

4.6 Summary

In this chapter, the results of analysing BPEL as a specification language for its security-relevant semantics have been presented. In order to aim for universal results not bound to particular examples of BPEL scripts or application contexts in which business processes are defined, preferably small building blocks of BPEL-definable business process semantics were searched for which sensible observations with respect to security relevance could be made. Combinations of BPEL activities with policy-induced restrictions to Web service invocations have turned out to be suitable for that purpose. These combinations were referred to as security-relevant semantic patterns of BPEL. Such a pattern may be thought of passing information sent or received in

messages exchanged with Web services or invokers of the business process (*i.e.*, invokers of the Web service provided by the business process) and subject to particular access of information flow restrictions through a particular language construct of BPEL.

For the purpose of this analysis, security policy derived restrictions to be obeyed at business process layer (and not already dealt with by security mechanisms provided in layers below the business process layer) when considering CBPs in a business-to-business context have been categorised. Investigation of their security relevance when combined with the different BPEL activities leads to requirements for information flow analysis to be performed when assessing a BPEL-defined business process for compliance with security policy.

The results of the analysis of security-relevant semantics of BPEL-defined business processes, as described in this section, have been published as a conference paper (Fischer *et al.*, 2006), with an extended version being presented in a related journal paper (Fischer *et al.*, 2007b).

Based on these results concerning the security relevance of the semantic patterns, a formalism was defined to specify existing security policies in such a way that checking BPEL scripts for compliance with these policies will considerably be facilitated. How this formalism was established and how security assessment can gain from this formalism, will be discussed in the next chapter.

5 SPECIFICATION OF SECURITY POLICY FOR COMPLIANCE ASSESSMENT OF CBPS

The analysis of BPEL as a specification language in the former chapter has revealed the potential of violating security policy-implied restrictions to Web service invocation, in particular with respect to information flow of values passed to and returned from Web services. One major aim of this research was to define methods that support assessment of remotely defined business processes for compliance with security policies in force at the location of execution.

The methods proposed herein for facilitating this compliance assessment were inspired by concepts developed in conformance testing methodology of open systems as defined in a series of International Standards (CTMF, Conformance Testing Methodology and Framework, ISO/IEC 9646, part 1–7; particularly (ISO, 1994)). In this series of International Standards, a so-called Protocol Implementation Conformance Statement proforma (PICS proforma) has been defined for the following purpose: Having defined a (standardised) test suite for conformance testing of implementations claiming to comply to a specific communication protocol in the OSI protocol stack, the problem occurs that this test suite has to be adapted before testing a particular implementation. Given the variety of implementation options provided by those OSI protocol specifications, it has to be assured that only the functionality an implementation claims to support will be subject to conformance testing. Therefore, the PICS proforma which is specific to a particular OSI protocol specification provides a checklist to be filled in by the implementing side to indicate which options provided by the protocol

specification for implementation choice has been actually chosen and which alternatives have been adopted. Submitting this filled-in PICS proforma to a test centre as a first step during conformance assessment enables the test centre to perform a static analysis of the choices taken for the implementation in order to assess that this particular set of choices is conformant to the standard in question. For instance, a standard may require that a particular choice of an option *A* may only be allowed if a choice of a related option *B* is made in a specific manner (*e.g.*, support both options or none of them). After checking a PICS proforma for conformant choices of options, the test centre will be able to adapt the test suite to be used during conformance testing of the particular protocol implementation to the indications made in this proforma. For example, if a PICS proforma for an implementation under test (IUT) would state that the optional functionality F1 is not supported by the current implementation and the test centre has already verified that this was in accordance with the standard, then the test suite would be adapted in such a manner that test cases that are to test support of functionality F1 would not be performed during the process of conformance testing for that particular IUT and that the non-support of this functionality would be consistent throughout the implementation. For instance, refusing to support optional functionality F1 in one context (*e.g.*, during connection establishment), but supporting the same functionality F1 in another context (*e.g.*, during data transmission) would usually result in a fail verdict of the conformance test assessment.

This approach of indicating a variable set of implementation options to be used for adapting the type and amount of test cases to be performed during conformance testing of a particular implementation that claims to comply to a protocol standard gave rise to

the method proposed in this project in order to support and facilitate the assessment of compliance with security policies for remotely defined BPEL scripts. After analysis of the security-relevant features of BPEL, a checklist comparable to a PICS proforma (ISO, 1994) can be provided, that allows for specification of security policy-derived restrictions to be obeyed during execution of remotely defined BPEL scripts. This way, the security policy of a domain executing remotely defined BPEL scripts is re-specified in order to only contain rules that are relevant at the business process layer in this context. This checklist is called a security policy statement (SPS) proforma or template here and will be used to indicate allowed features of BPEL in compliance with the security policy. Unlike with PICS proformas in conformance testing of OSI protocol standards, the roles of filling in and using the filled-in checklist are distributed differently in a compliance assessment of remotely defined BPEL scripts. The SPS proforma will be filled in by the executing domain to indicate the security policy-implied restrictions applicable to such BPEL scripts. A separate SPS proforma will be required to be filled in for each remote domain that is allowed to remotely define BPEL scripts for execution in a particular executing domain. The indications made in a filled-in SPS proforma (simply called SPS in the following) will determine the kind of inspections to be performed during compliance assessment of a BPEL script from the domain indicated in the SPS as originator. A role comparable to that of a test centre in the conformance testing context is taken by the site performing the compliance assessment with security policies.

It should be noted that though the concept of using an SPS proforma to direct the compliance assessment procedure was inspired by experiences from the field of

conformance testing of open communication protocols, in other respects the methods proposed here for compliance assessment expressly are not based on testing techniques but are rather comparable with code inspection techniques. This distinction matters in particular because testing always requires some sort of execution of the code or script under test but code inspection does not since it may and usually will be performed prior to execution of the object under consideration.

5.1 Redefinition of Security Policy in Terms of Security-Relevant Semantic Patterns

As already indicated in the introduction to this chapter, the security policy is to be re-specified to express the restrictions applicable to remotely defined business processes. This re-specification shall be performed in such a manner that assessing a remotely defined BPEL script for compliance with these restrictions can be performed in an as straightforward as possible way. The results of the analysis of security-relevant semantics of BPEL in the former chapter have shown that such semantics is closely related to restrictions implied by security policies to Web service invocations. Therefore, the idea for re-specifying security policies in order to facilitate compliance assessment is to provide indications of the classified restrictions summarised in Table 1 for all Web services, a remotely defined BPEL script is allowed to invoke. In this way, the assessment process receives its directives what to watch out when assessing a BPEL script. Based on the information contained in an SPS, the assessment process can check whether only allowed Web services are to be invoked in a BPEL script under

consideration and that invocations occur in a manner compliant to the restrictions imposed to them by security policies of the executing domain.

As can be seen from Tables 2 and 3 above, most restrictions imposed to Web service invocations with respect to particular input and output parameters imply information flow analysis in forward and backward direction in order to verify that the restrictions are obeyed. Therefore, indications made relating to restriction classes of Web service invocations already provide an outline of the particular checking methods to be applied when a BPEL script is subject to compliance assessment.

5.2 Security Policy Statement

In a security policy statement (SPS), the security policy of one particular domain (*e.g.*, domain B in Figure 2 that is the executing domain) with respect to one particular other domain (*e.g.*, domain A in Figure 2 that is the domain specifying a BPEL script and sending it for remote execution) is expressed in terms of restrictions or allowance of security patterns identified and analysed in Chapter 4. To this end, the internal and external Web services, that are allowed to be invoked by a business process executing in domain B on behalf of domain A will be indicated together with the restrictions applying to their respective input and output parameters. In order to structure the information contained in it, the SPS is composed of several parts each of which containing particulars related to a group of related restrictions, for instance, related to a specific Web service that is allowed to be invoked.

In order to discuss this approach in more detail, an example presenting some typical information contained in an SPS template is shown in Figure 5. The exemplary entries contained in this SPS are taken from the example CBP in Chapter 2.

5.2.1 *Security Policy Statement Template*

The SPS starts with its main part, called Security Policy Statement Template. In its top part, it comprises information identifying the issuing domain that is the executing domain to which the security policy expressed in the SPS relates (*i.e.*, the domain of the gearbox manufacturer in this example). Furthermore, the application context and the foreign domain to which the restrictions in the SPS relate are identified. Here, this is the application context of processing orders for gearboxes and parts of it for the domain of the car manufacturer sending a BPEL script for execution in domain B.

It should be noted that distinguishing between different application contexts in different SPSs provides the capability to indicate different sets of allowed and disallowed Web service invocations for the same pair of executing domain and defining domain. For example, if the same car manufacturer is also allowed to send BPEL scripts for business processes executed in a context where construction plans for new gearbox models are to be exchanged between the car manufacturer and the gearbox manufacturer and manipulated in cooperation between the development units of both organisations, it can easily be imagined that a totally different set of Web services would be involved and, therefore, a different SPS would apply to this application context even though the same

organisations (*i.e.*, the car manufacturer and the gearbox manufacturer) would be involved.

Security Policy Statement		
For executing domain: <i>GearBoxManufacturer.domainB</i>		
<i>(possibly additional identifying information not of interest in this example)</i>		
For application context: <i>Order management of gear boxes and part of it</i>		
Relating to BPEL scripts from domain: <i>CarManufacturer.domainA</i>		
Invocation of Web services residing outside current domain allowed?		Y/N: Y
If yes, indicate allowed external Web services:		
URI: <i>priceQuotation.SubSubplier1.domainC1</i>	Reference to EWSRS	<i>EWSR1</i>
URI: <i>priceQuotation.SubSubplier2.domainC2</i>	Reference to EWSRS	<i>EWSR2</i>
URI : <i>checkOffer.CarManufacturer.domainA</i>	Reference to EWSRS	<i>EWSR3</i>
Indicate restricted internal Web services:		
URI: <i>checkStock.domainB</i>	Reference to IWSRS	<i>IWSR1</i>
URI: <i>calculateOffer.domainB</i>	Reference to IWSRS	<i>IWSR2</i>
URI: <i>completeOffer.domainB</i>	Reference to IWSRS	<i>IWSR3</i>
Indicate unrestricted internal Web Services:		
URI: <i>none</i>		
<i>(Further indications with respect to allowed semantics (e.g. allowed processing on information gained from Web service invocation may be indicated here)</i>		

Figure 5: Security Policy Statement Template with Exemplary Entries

After this identification part, information follows indicating Web services that are allowed to be invoked by a business process defined by and executed on behalf of the

foreign domain (domain B in this example). First, there is a general indication as to whether invocation of Web services in foreign domains will be allowed at all or not. If invocation of such Web services is not generally prohibited, there will be indications of particular foreign Web services that are allowed to be invoked each identified by its respective URI. In this example, the respective Web services *priceQuotation* of the two sub-suppliers C_1 and C_2 as well as the call-back Web service *checkOffer* of the car manufacturer are foreign Web services allowed to be invoked. For each allowed external Web service, a so-called External Web Service Restriction Statement (EWSRS) will be referenced that contains further information concerning restrictions with respect to the particular Web service. In this example, three external Web services have been indicated. Only those external Web services indicated explicitly in this part of the SPS will be allowed to be invoked by a remotely defined BPEL script from domain A. One could think of some sort of wildcard indication, for example ‘*’ in place of a constituent of an URI, if all Web services of a particular domain or sub-domain are allowed to be invoked. However, since only examples involving a small number of allowed Web services are used in this PhD project, the definition of such notational shortcuts is out of scope in this research.

After indication of the allowed external Web services, there are two further groups of indications in Figure 5 relating to Web services of the executing domain: one group relating to internal Web services for which invocation is restricted and one group relating to internal Web services that may be invoked without any restrictions. Remember that the last group corresponds to class 1 of Table 1, albeit only for internal Web services. For the purpose of this study it is supposed that only internal Web

services of class 1 actually occur and that all external Web services fall into one of the classes 2 through 6. In cases where unrestricted external Web services actually occur, this could be indicated by omission of the reference to an EWSRS for the particular Web service.

While the last type of entry (*i.e.*, Web service of class 1) does not require any further information besides the URI of the particular Web service, for each restricted internal Web service there is a field indicating a reference to a so-called Internal Web Service Restriction Statement (IWSRS) similar to the indication for external Web services above. In this example, the three internal Web services of the gearbox manufacturer depicted in Figure 4 are indicated as allowed internal Web services with restrictions. Both the group of EWSRS and the group of IWSRS referenced in Figure 5 are considered part of the SPS as a whole.

The SPS is understood to indicate all of the security-relevant semantics in a BPEL script from the specific foreign domain (domain A in this example) acceptable for cross-domain deployment. Therefore, all other security-relevant semantics not explicitly stated in an SPS as being allowed, will be prohibited. In particular, only the Web services explicitly stated in this part of the SPS will be allowed for invocation in a BPEL script from domain A. It should be noted that Web services with class 2 restriction (*i.e.*, Web services that are not allowed to be invoked at all) will never occur in an SPS.

At the bottom of the SPS template, there is left room for further indications with respect to allowed semantics in a BPEL script from the particular defining domain. Such indications may include allowed processing to be performed on information returned by Web services invoked. As discussed above, BPEL does not provide any means for any kind of data manipulation (besides assignment from one location to another location). Should there be a requirement to perform data processing within a BPEL script, language elements of other XML-based specifications have to be imported. Usually, XPath (Berglund *et al.*, 2006) will be used for such purposes of data processing in BPEL scripts. In this research, performing data processing as part of a BPEL-defined business process is supposed to always be achieved by Web service invocation such that import of elements of XPath (or similar specifications) are not required. Thereby, considerations with respect to the security relevance of performing data processing within the BPEL script could be avoided. Note that it is always possible to define a Web service to perform a particular data processing (though it may sometimes be more convenient to perform it directly within the BPEL script). Therefore, this assumption made here does not restrict general applicability of the approach proposed in this thesis.

5.2.2 Internal Web Service Restriction Statement

In Figure 6, there is an example of an IWSRS template in order to clarify the typical information contained in this part of an SPS. The example relates to the *checkStock* Web service of the gearbox manufacturer. In this template, there is room for indicating security policy-induced restrictions of any kind that relates to the input and output parameters of the particular Web service. In the heading of this template, the identifier

of the IWSRS used for referencing it in the main part of the SPS is indicated. Further, the URI for invoking the particular Web service and the URI of the WSDL definition of this Web service are given.

Restrictions relating to Web service parameters are those of the classes 3 through 6 in Table 1 above. The indications are grouped by restriction classes starting with the restrictions to input parameters. For class 4 restrictions that always relate to optional input parameters indications may be made whether the particular parameter is prohibited to be used or always required in order to avoid default mechanisms defined for this parameter to be applied. For class 5 restrictions, the input parameters along with the respective allowed values or range of values are to be indicated here. Similarly, for class 6 restrictions, the input parameters along with the respective allowed sources of values passed to these parameters are to be indicated. Such sources may be other Web services or particular output parameters of other Web services.

For the output parameters of a Web service, only class 3 restrictions apply. For every restricted output parameter, a target relaxation may be indicated. While class 3 restricted output parameters are generally allowed to be passed freely to domain-internal Web services (this was anticipated in Section 4.1.4), the values returned by those parameters are restricted to be carried to any external Web service or passed as message or part of a message sent back to the invoker of the business process in a **reply** activity. If there are any exceptions to this restriction, they may be indicated in a separate column by specifying possible external targets (Web services or particular parameters of Web services) to which a visibility-restricted value may exceptionally be

passed while still being restricted from passing to all other external target. This type of relaxation for visibility-restricted information is called target relaxation in Figure 6 and the following parts of the thesis.

Internal Web Service Restriction Statement		IWSRS-ID	IWSR1
URI for invocation: <i>checkStock.domainB</i>			
URI of WSDL: <i>wsdl.checkStock.domainB</i>			
Restrictions with respect to input parameters			
Usage restrictions of optional parameters			
Parameter: <i>ListOfItems</i>		(indicate required or forbidden)	<i>required</i>
Value range restrictions		Allowed values or value range:	
Parameter: <i>ProcessingPriority</i>		<i>Prio1, Prio2</i>	
Restrictions related to sources of values		Allowed source(s) of values:	
Parameter: <i>none</i>		—	
Restrictions with respect to output parameters		Target relaxation	
Parameter: <i>ListOfItemsToOrderFromSubSupplier1</i>		<i>C1.priceQuotation.list</i>	
Parameter: <i>AccessCredentialForSubSupplier1</i>		<i>C1.priceQuotation.credential</i>	
Parameter: <i>ListOfItemsToOrderFromSubSupplier2</i>		<i>C2.priceQuotation.list</i>	
Parameter: <i>AccessCredentialForSubSupplier2</i>		<i>C2.priceQuotation.credential</i>	

Figure 6: Example of Internal Web Service Restriction Statement

In the case of the *checkStock* Web service of Figure 4, the input parameter passing the list of items to be ordered is supposed to be an optional parameter for exemplary purposes only. In practice, it may not be particularly sensible to have this parameter as

an optional input parameter. In the IWSRS of Figure 6, however, though being defined as an optional parameter, the *ListOfItems* input parameter is indicated as required when this Web service is invoked in a BPEL script from the car manufacturer. Also for the purpose of this example, a parameter controlling the priority of order processing is anticipated. Suppose that this parameter is capable of adopting one of the values in the set {Prio1, Prio2, Prio3} where Prio1 indicates the lowest and Prio3 the highest priority. The IWSRS in Figure 6 indicates that business processes specified by the car manufacturer for controlling the order processing in domain B are restricted to the two lowest priority levels while the highest priority level of order processing is not allowed to be used. Source-restricted input parameters (class 6 restrictions) are not present in this example.

With respect to the output parameters of this Web service, several restrictions apply. As discussed in Section 2.2, the *checkStock* Web service is supposed to possibly return two lists of items that are found to be out of stock and, therefore, have to be ordered from the two sub-suppliers. Along with the respective list of items to be ordered, the Web service returns a credential required to access the respective Web service *priceQuotation*. These two pairs of output parameters intended to be passed to sub-supplier 1 and sub-supplier 2, respectively, are visibility-restricted since they are not allowed to be carried outside the domain of the gearbox manufacturer except to the respective Web service of the two sub-suppliers. Therefore, in the IWSRS example it is indicated that the list of items to be ordered from sub-supplier 1 though declared as visibility-restricted is allowed to be passed to the input parameter list of Web service *priceQuotation* of sub-supplier 1. Similarly, the credentials required to be granted

access to this Web service from within the domain B are also declared as visibility-restricted with a target relaxation to the input parameter credential of Web service *priceQuotation* of sub-supplier 1. In an analogue manner, the output parameters of Web service *checkStock* intended for sub-supplier 2 are indicated as visibility-restricted in the IWSRS with target relaxations to the respective input parameters of Web service *priceQuotation* of sub-supplier 2.

5.2.3 External Web Service Restriction Statement

In Figure 7, an example of an EWSRS is shown in order to clarify the typical information contained in this part of an SPS. The content of an EWSRS is quite similar to an IWSRS discussed in the previous section. Both templates differ in the indication whether values of output parameters of the external Web service are allowed to be assigned to input parameters of internal Web services. Such assignments may be prohibited as a matter of precaution in cases where the nature of output values returned by an external Web service is to a large extent unknown at the domain issuing the SPS and, therefore, should not be used as input parameters in invocations of internal Web services. When this restriction applies, the values returned by such an external Web service, unless they are visibility-restricted, may still be used for flow control purposes within the BPEL script or may be passed as input parameters to other external Web services, preferably in the same domain as the Web service addressed by the current EWSRS.

External Web Service Restriction Statement		EWSRS-ID	EWSR1
URI for invocation: <i>priceQuotation.domainC1</i>			
URI of WSDL: <i>wsdl.priceQuotation.domainC1</i>			
Restrictions with respect to input parameters			
Usage restrictions of optional parameters			
Parameter: <i>credential</i>		(indicate required or forbidden)	<i>required</i>
Value range restrictions		Allowed values or value range:	
Parameter: <i>none</i>		–	
Restrictions related to sources of values		Allowed source(s) of values:	
Parameter: <i>list</i>		<i>B.checkStock.ListOfItemsToOrder FromSubSupplier1</i>	
Parameter: <i>credential</i>		<i>B.checkStock.AccessCredentialFor SubSupplier1</i>	
Restrictions with respect to output parameters		Target relaxation	
Parameter: <i>priceDeliveryInformation</i>		<i>B.calculateOffer.infoSupplier1</i>	
Assignment of output values to internal Web services allowed?			Y/N: Y

Figure 7: Example of External Web Service Restriction Statement

The example EWSRS in Figure 7 relates to the external Web service *priceQuotation* of sub-supplier 1 from the CBP example in Figure 4. The Web service is supposed to take two input parameters, *list* and *credential*. The input parameter *list* accepts the list of items inquired while the input parameter *credential* receives the credential required for granting access to this Web service. As can be seen in Figure 7, the input parameter *credential* has simultaneously two kinds of restrictions, namely a usage restriction (class 4) and a source restriction (class 6). This means that though this input parameter

has been defined to be optional, this parameter is required when used within a BPEL script from the car manufacturer and the input value has to be equal to the value of the output parameter `AccessCredentialForSubSupplier1` returned by Web service *checkStock*. Also for the second input parameter of the *priceQuotation* Web service, a restriction apply with respect to sources of the values passed to it. The value passed has to be the value of output parameter `ListOfItemsToOrderFromSubSupplier1` returned by Web service *checkStock*.

The only output parameter of this Web service is visibility-restricted. In the case of an external Web service, such a restriction includes internal Web services of the invoking domain unless exceptions related to specific internal targets apply. In the current example, with the output parameter `priceDeliveryInformation` a target relaxation is contained in the EWSRS indicating that values returned in this parameter may be passed to the parameter `infoSupplier1` of Web service *calculateOffer* in domain B. In addition, the EWSRS indicates that values returned by this Web service may be used as input parameters of Web services internal to domain B, an indication with no specific meaning in this case since the only output parameter is visibility-restricted with an exception referring to an input parameter of a specific Web service in domain B. In other cases, this indication would allow output parameters without visibility restriction to be used throughout domain B as input parameters of internal Web services.

5.3 Approach to Reduce Complexity of Security Policy Statements

In cases where the differentiation between allowed and disallowed semantics (mainly relating to allowed and disallowed processing of information within a remotely defined business process) would be too complicated leading to complex rules in the corresponding security policy statement, the complexity may be reduced in a manner described in this section.

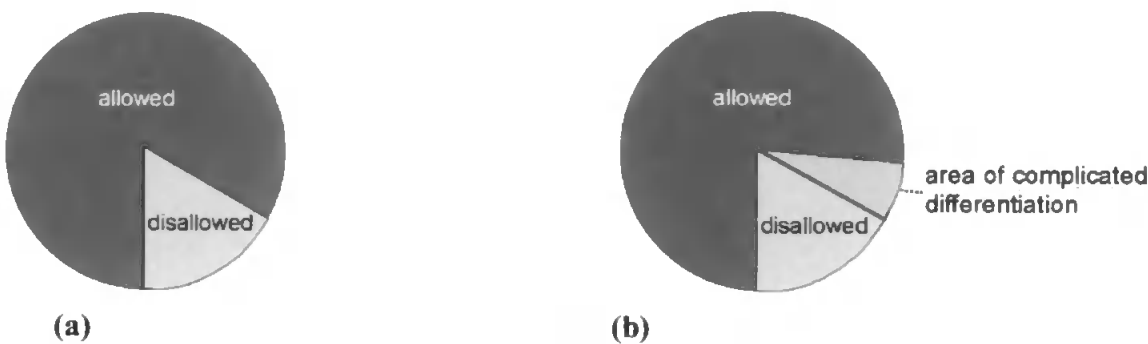


Figure 8: Steps for Reduction of Complexity of Security Policy Statement (Part 1)

In Figure 8a, the allowed and disallowed semantics of a remotely defined business process is depicted within the circle. Consider the situation where part of the allowed semantics would impose complicated differentiation from disallowed semantics as indicated in Figure 8b by the differently coloured section in the allowed part. In order to reduce the complexity of the security policy statement, a local Web service could be established providing the semantics represented by this area. This is indicated in Figure 9a by the section taken out of the circle. After having defined a Web service for this purpose, there is no longer any need for a business process to encompass this part of the allowed semantics as part of its intrinsic processing. Instead, a business process can invoke this newly defined Web service for this purpose.

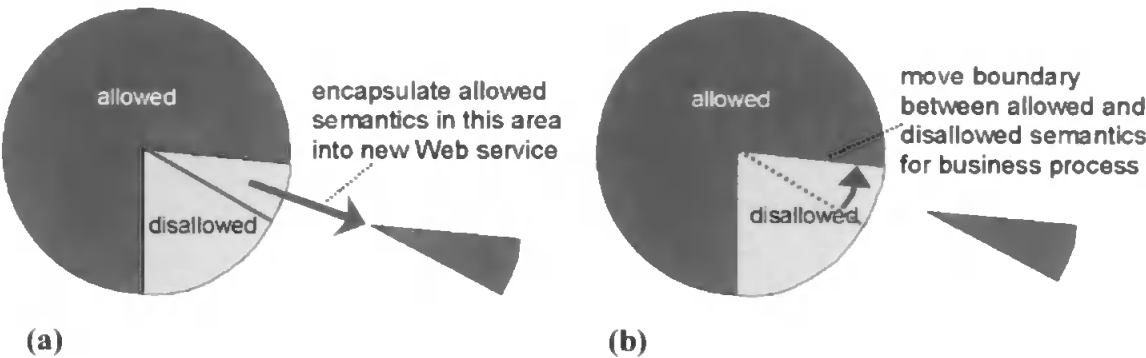


Figure 9: Steps for Reduction of Complexity of Security Policy Statement (Part 2)

Since there is no requirement to perform such processing within a business process, this formerly allowed semantics may be forbidden for a business process. Doing so means to move the boundary between allowed and disallowed semantics to enclose the formerly allowed section into the disallowed area. This step is depicted in Figure 9b. In order to disallow the formerly allowed part being used, the security policy statement would drop the complicated specification of the semantics in the removed area.

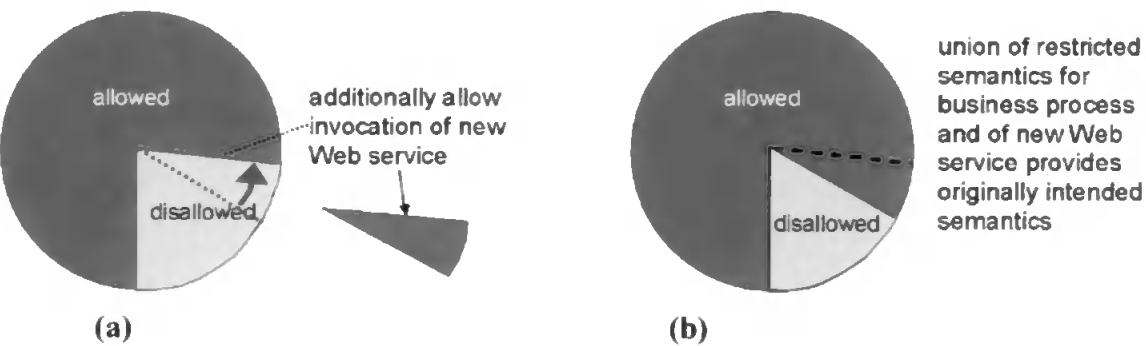


Figure 10: Steps for Reduction of Complexity of Security Policy Statement (Part 3)

Further, to allow the new Web service being invoked by a business process, the security policy statement has to be modified as indicated in Figure 10a. The new security policy

would instead add the new Web service to the list of local Web services allowed to be invoked.

Finally, the complicated differentiation between allowed and disallowed semantics in the security policy statement can be avoided, still preserving the originally allowed semantics of Figure 8a as the overall semantics for a business process. However, as indicated in Figure 10b, the original semantics now is provided by the union of the semantics of the new Web service and the remaining allowed semantics for the business process.

5.4 Coping with Dynamic Aspects in Static Compliance Analysis

The approach presented in the former sections relies on static analysis of a BPEL script prior to execution. Therefore, this approach inherently is not suited to be applied for checking restrictions with respect to Web service invocations that involve dynamic aspects. Obviously, such checking may only be performed at runtime. An example of a restriction to Web service parameters that require dynamic checking can also be given by reference to the example CBP in Figure 4. Consider a restriction of the input parameter `listOfItems` of Web service *checkStock* requiring that only items from a predefined set of items are allowed to be included in this list when this Web service is invoked by the *control* business process on behalf of the car manufacturer. The reasons for such a restriction could be that the gearbox manufacturer produces gearboxes for different car manufacturers and each car manufacturer is only allowed to make inquiries with respect to the gearboxes (or parts thereof) produced for his own types of cars, but

not with respect to gearboxes of competitive car manufacturers. Since the contents of this list passed from the invoker of the business process (*i.e.*, from the car manufacturer in this example) will only be known at runtime, any static analysis will fail to assert the observance of this restriction in a BPEL script received from the car manufacturer.

However, similar to the approach to reducing complexity of the restrictions in an SPS introduced in the former section, a method for coping with dynamic aspects of policy-induced restrictions can be provided. While in Section 5.3, parts of the processing logic of a potential business process requiring too complicate a specification of restrictions has been moved to a separate Web service thereby relieving the requirement to express the complex restrictions in the SPS, here for enabling dynamic validation of restrictions, dynamic checks are moved to Web services defined for this purpose.

In this way, checking of restricted value ranges of input parameters that only can be performed at runtime will be moved from the static analysis prior to execution to dynamic analysis during runtime. In order to still validate that a BPEL script conforms to the security policy during pre-execution assessment, the SPS needs to be amended in order to cope with dynamic aspects of compliance assessment. To this end, the input parameter of the Web service with value range restrictions to be checked during runtime will be specified as an input parameter with source restrictions and the Web service containing the dynamic check of this input parameter against the list of allowed values will be indicated as the only allowed source of values for this parameter.

In the example above, a new Web service *checkItemListFromDomainA* would have to be defined at the site of the gearbox manufacturer (domain B) that would accept the *listOfItems* passed from the car manufacturer as its input parameter and return this list as output parameter in case its content conformed to the value range restriction with respect to the car manufacturer (domain A). When the check failed, this new Web service could return an empty list to indicate this situation or raise some particular sort of exception. In addition to provide this new Web service, the SPS of domain B with respect to BPEL scripts received from domain A would have to be modified to require that values for the input parameter *listOfItems* of Web service *checkStock* are source-restricted (class 6 restriction) with allowed source to be the output parameter of this new Web service *checkItemListFromDomainA*. In this way, it could be checked prior to execution of a BPEL script received from the car manufacturer that the restrictions with respect to the list content passed to the Web service *checkStock* either would have been obeyed or an empty list will get passed to this Web service (possibly causing a fault in this Web service or, alternatively, an exception already would have been raised before invoking this Web service). With this modified SPS, the compliance assessment can still be performed as usual prior to executing a BPEL script and result in a pass verdict even though the actual list contents passed from the car manufacturer is not known at this time. Of course, after this extension to the SPS has been made, a compliant BPEL script from the car manufacturer actually has to invoke the new Web service prior to invoking the Web service *checkStock* and pass the output parameter from this new Web service to the input parameter *listOfItems* of *checkStock*. Important but not particular to this new Web service is the requirement that provisions are in place to securely prevent tampering of the processing logic of this Web service, particularly from outside

domain B or by activities performed in a business process remotely defined and brought into domain B for execution.

This approach to introduce specific Web services for the purpose of performing dynamic compliance checks of Web service parameters at runtime is, to a certain extent, similar to that proposed by Sirer and Wang (2002) where also Web services are amended by specific security policy enforcement code to perform dynamic compliance assessment during execution. In their approach, the security policy first has to be expressed in a special purpose specification language based on first order logic and temporal logic. Once security policies have been specified in this formal manner, instrumentation code is generated automatically to be executed as a preamble in Web service invocation. While this approach relies completely on security policy enforcement at runtime enforcement, the approach presented in this thesis performs as much enforcement as possible during compliance assessment based on static analysis of BPEL scripts prior to execution and uses instrumentation of the business process only for checking that need to be performed at runtime. In contrast to the approach proposed by Sirer and Wang, the additional Web services used herein for checking value (range) restrictions of input parameters of specific Web services are not generated automatically, but have to be hand-coded to suit the particular purposes. This may be considered a drawback compared to the approach of Sirer and Wang. However, rendering specification of security policy in terms of formal logic unnecessary which is the case in the approach proposed here is deemed to over-compensate this possible drawback of not providing automatic generation of Web services for dynamic security checking.

5.5 Summary

In this chapter, the transformation of the results from the analysis of BPEL with respect to its intrinsic security relevance into a method to re-formulate the security policies in terms of allowed and disallowed security-relevant semantic patterns in a BPEL script has been described. The purpose of this is to support the compliance assessment of remotely defined BPEL scripts with security policies in force at the executing site in such a manner that this assessment is facilitated considerably and becomes suited to be performed automatically. To this end, a set of checklist-typed tabular forms have been introduced in this chapter that are intended to accommodate the policy-implied rules to be observed by all BPEL scripts coming from a particular remote site. The whole of the rules derived from security policies and determined to be relevant in the business process layer are referred to as security policy statement (SPS). The rules indicated in these forms relate to Web services allowed to be invoked by such BPEL scripts. If invocations of a Web service is only acceptable with certain restrictions to its input and output parameters, such restrictions are indicated in special forms on a per Web service basis. Though presented in this chapter in a form intended for human readability, it is obvious that the contents of SPSs have to be converted to a form better suited for machine processing when the compliance assessment is to be performed in a automatic manner. This will be further discussed in Chapter 7.

Though compliance assessment is based on static analysis of a BPEL script prior to its execution that by nature is not able to cope with restrictions only checkable at runtime, an approach to also cover such restrictions as much as possible during static analysis

has also been shown. Comparable approaches to the one proposed here to complement the static compliance assessment towards dynamic aspects of information flow control also have been proposed in related work. Though not original to this research, however, this approach to cope with restrictions that can only be checked dynamically combined with the original work presented here seems to be useful to broaden the applicability of the methods proposed for compliance assessment in practice.

In the next chapter, the process of assessing the compliance of BPEL scripts with security policies will be discussed in more detail. Also, different ways to delegate the task of compliance assessment to dedicated nodes within or outside the security domain of an organisation and to share the resources used for compliance assessment (even across organisational boundaries) will be proposed.

6 SECURITY POLICY COMPLIANCE ASSESSMENT FOR BPEL SCRIPTS

After analysis of security-relevant behaviour of BPEL and re-specification of security policies in terms of so-called security-relevant semantic patterns of BPEL, the procedure of assessing compliance of remotely defined BPEL scripts with security policies of the executing domain will be described in this chapter. Further, the workflow of cross-organisational deployment of BPEL scripts including assessment of compliance prior to executing them is considered in more detail. Finally, approaches to delegation of compliance assessment in a distributed environment are presented.

6.1 Procedure of Compliance Assessment

The function of compliance assessment as used in the context of this research is to make sure that only BPEL scripts completely observing the restrictions implied by the security policies of the executing domain will be accepted for execution. Such assessment of a remotely defined BPEL script can be (and usually will be) conducted prior to executing the business process specified by this script. Therefore, the methods proposed here are chosen such that they do not require the business process defined by a particular BPEL script to be executed for testing or monitoring purposes in order to assess its compliance with the policy-induced rules derived from security policies for the business process layer. Since possible violations of such rules can be detected in this way before these violations would be committed by the business process being executed, the approach proposed here provides a very effective way of security policy

enforcement. This procedure of assessing compliance with security policies prior to execution may be considered a check point in the sense of security patterns (Yoder and Barcalow, 1997).

6.1.1 Prerequisites for Compliance Assessment

The main prerequisite for the compliance assessment besides the BPEL script under consideration is the SPS specified by the executing domain with respect to the remote domain sending a BPEL script for execution and the application context of the business process to be defined by this script. Furthermore, the WSDL definitions of all Web services indicated in the SPS are required. Finally, the WSDL definition of the Web service provided by the business process resulting from execution of the BPEL script will be required, in particular in cases when this WSDL definition is specified beforehand by the executing domain in order to indicate the required Web service this business process has to provide to its environment. In the latter case, the messages to be exchanged with the environment are predefined and, therefore, are likely to be addressed in the SPS if subject to security policy-implied restrictions. When, for example, the predefined input messages to be accepted by the business process under consideration are restricted with respect to particular value ranges (class 4 restrictions), then this could be indicated in the SPS as a restriction to the internal Web service that is going to be provided by this business process². Since the names of the Web service and

² Though this Web service will usually be invoked from outside the executing domain, it is considered an internal Web service of the executing domain because it will be provided within this domain.

its input and output parameters will be known from the WSDL definition, restrictions with respect to its input and output parameters can be specified in the SPS.

If such a WSDL definition of the Web service provided by the business process under consideration is not available beforehand because, for example, this definition is provided by the site specifying the BPEL script and varies between different BPEL scripts coming from this site, then this WSDL definition usually will not be available at the time when an SPS is specified and, thus, restrictions to input and output parameters of this Web service cannot be included in the SPS. Nevertheless, restrictions to input and output parameters of this Web service may be implied by other restrictions in the SPS. For instance, one restriction generally applicable to messages sent to an invoker of the Web service in a reply to a message received from this invoker states that such outgoing messages must never contain any visibility-restricted information unless the receiver of this message is indicated as an allowed external target of this information. Even though not addressed in the SPS, the WSDL definition of the business process under consideration is usually required for the purpose of information flow analysis to be conducted during compliance assessment.

6.1.2 Analysis of Declaration Part in BPEL Script

Given all these prerequisites are available, the process of compliance assessment can start with searching the partner link declarations of the BPEL script for Web services invoked by the business process. Each Web service found this way has to be present in the SPS since this contains an exhaustive list of all Web services allowed to be invoked

with or without further restrictions. A Web service found in a partner link declaration, but not in the SPS, could still be acceptable if it can be verified by static analysis of the BPEL script that the particular partner link will not be used in the process definition part. If this cannot be verified or if a more rigorous approach is taken not to accept any Web service in the declaration part that is not indicated in the SPS (independent of its actual use in the business process), then the assessment of the BPEL script already is terminated here with a fail verdict that means the BPEL script does not comply with the applicable security policy.

6.1.3 Checking BPEL Script for Security-Relevant Semantic Patterns

If the BPEL script has passed this first stage of compliance assessment, then the parts defining the process logic have to be searched for invocations of Web services allowed by the SPS. For every Web service invocation it is checked whether for the particular Web service there are restrictions associated with its input and output parameters in the SPS. If restrictions are found, their obedience has to be assessed. For restrictions of classes 3, 5, and 6, information flow analysis in forward or backward direction has to be performed as required. Restrictions of class 4 may be checked by simply verifying that optional input parameters are provided if they are indicated as required or not used if indicated as forbidden. During information flow analysis in forward direction with respect to visibility-restricted information, care has to be taken to watch out for possible covert channels of information flow. Semantic patterns susceptible for the establishment of covert channels have already been identified in Tables 2 and 3 above. Therefore, it is

known what to look for with respect to covert channel detection during compliance assessment.

6.1.4 Example of Covert Channel Establishment in BPEL Script

An example for the establishment of a covert channel is depicted in Figure 11. Suppose that Web service W_A has an output parameter `priceA` indicating the price of an item A that is visibility-restricted (class 3 restriction), that is, it must not be leaked to an information sink outside the executing domain. This Web service is invoked and its output parameter `priceA` is assigned to a variable `P`. After this assignment, a branch occurs in the process flow using an `if` activity. The branching condition depends on the variable `P` containing the visibility-restricted price of item A. If this value is smaller than 100 currency units (of an arbitrary currency that does not matter in this example) then the process flow branches to the invocation of a Web service W_1 . If the value is greater than or equal 100 currency units, then Web service W_2 is invoked.

If at least one or even both of these Web services W_1 and W_2 are external Web services (e.g., Web services within the domain where the BPEL script was specified) or happen to exhibit otherwise externally observable behaviour, then by observing the behaviour of the business process defined by the BPEL script containing the snippet in Figure 11 conclusions can be drawn on the price of item A. Supposing that only the invocation of Web service W_1 is observable from outside the executing domain then, if the observer recognises that W_1 is invoked (either directly because W_1 resides in the domain of the observer or indirectly via the externally observable behaviour of W_1), he knows that this

price is below 100 currency units. Otherwise, if the invocation of W_1 cannot be observed, the observer who can be assumed to know the BPEL script because it was specified at his site can conclude from this observation that W_1 has not been invoked at that point in the business process but that W_2 has been invoked and, therefore, that the price of item A is greater than or equal to 100 currency units. Thus, a covert channel relating to the visibility-restricted information on the price of item A would have been established by the snippet of a BPEL script in Figure 11.

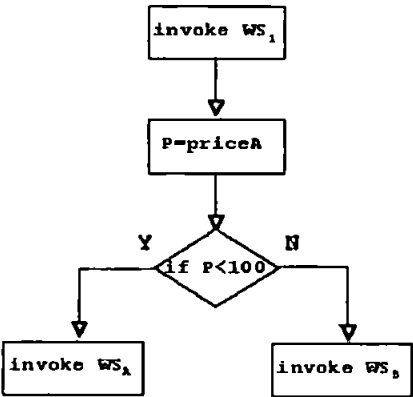


Figure 11: Covert Channel Example

It can easily be seen that the leakage of information relating to the price of item A that is only at a very coarse level in this example (either $P < 100$ or $P \geq 100$) can be refined to arbitrary granularity by cascading a series of such branching dependent on the value of variable P . In order to avoid such covert channels, any flow control decision based on class 3 restricted information would be banned here and, therefore, when detected in compliance assessment, would cause a BPEL script containing such semantic patterns to be considered non-conformant to the security policies under consideration. Note that this rigorous approach to cope with avoidance of covert channels could be relaxed by

applying more sophisticated algorithms for covert channels detection, for instance, checking whether alternative flows selected by branching on visibility-restricted information actually exhibits any distinguishing behaviour observable from outside. However, elaborating such algorithms is beyond the scope of this research project and, therefore, left for further studies.

6.1.5 Information Flow Analysis in Parallel Flows

Besides covert channel detection, also analysis of information flow in parallel flows needs further consideration. During this analysis, actual and potential parallel flows are distinguished. Actual parallel flows are those specified in parallel versions of **forEach** activities or in **flow** activities without any links that restrict the activities contained in a **flow** activity from being performed in parallel. These parallel flows will actually be performed in parallel when the business process is executed. By contrast, potential parallel flows will not be performed in parallel during business process execution but only specify alternatives for the flow of business logic from which only one at a time will actually be chosen during execution. Such potential parallel flows are presented by the alternate flows in an **if** activity and in a **pick** activity as well as the flows specified in event handlers, fault handlers (including flows specified in compensation handlers initiated by those fault handlers), and termination handlers. The flows specified in these handlers can be considered alternate flows to the main flow of the process since the reason for activating the flows specified in these handlers may occur at any time during normal process execution. For example, the activities in a fault handler will be executed instead of the main process flow when the corresponding exception caught by this fault

handler occurs. This usually can happen at virtually every moment during process execution. Therefore, fault handlers establish potential parallel flows to each other and to the part of the process (a particular scope or the whole process) to which they relate. The same is true for event handlers and termination handlers.

For the purpose of information flow analysis, actual and potential flows are not distinguished since the static analysis performed here considers all potential flows in a process at once instead of only one actual choice of them as will be the case during business process execution. For instance, when analysing information flow in backward direction as required for restrictions of classes 5 and 6 applicable to input parameters of a Web service invoked, all potential values that could have been assigned to a variable that will be passed as a particular restricted input parameter have to be considered. Hence, all parallel flows in backward direction from the Web service invocation towards the start of the business process have to be checked for assignments to the particular variable irrespective of whether these flows are actual parallel flows or only potential parallel flows. If at least one value assigned to this variable in any of the (actual or potential) parallel flows would contradict the restriction imposed to the input parameter of the Web service for which the variable is used as actual value, then a violation of the SPS would have been detected resulting in a fail verdict for the compliance assessment. Although the process described here may appear to be complicated, an implementation of this process (or at least important parts of it) in a research prototype has shown that the proposed approach to compliance assessment of BPEL scripts prior to execution is viable and appropriate for automatic processing. Of course, the notation of an SPS as introduced here in a tabular form that accommodates

human readability will have to be converted into another form that is better suited for machine processing. This will be explained in further detail in Chapter 7.

6.2 Workflows in Distributed Definition and Execution of CBPs

In this section, a set of workflows will be defined that combine the tasks required in defining, deploying, assessing and executing BPEL-defined business processes in such a manner that the temporal order of them is clarified. When CBPs are defined and executed in a distributed manner as discussed in earlier chapters, the definition, deployment, and assessment of compliance with security policies prior to execution represent a workflow of its own and is not considered part of executing the business process being defined by a cross-organisational deployed BPEL script. In fact, even several separate sub-workflows can be distinguished in the approach to security policy enforcement proposed in this project. On the executing side, when the approaches proposed in this thesis are to be used, prior to acceptance of any remotely defined BPEL script from a foreign domain, an SPS has to be assembled to define the security policies in a way that is well-suited for compliance assessment of the BPEL scripts accepted for execution. The tasks involved here are depicted in the workflow diagram of Figure 12. As in the example of a CBP in Figure 4, the executing domain is denoted domain B and the domain defining BPEL scripts for execution in domain B is denoted domain A. The workflow of Figure 12 will be performed within domain B. In general, domain B can allow different domains to bring in BPEL scripts for execution. To differentiate between these different domains, an index is added to the domain identifier (*e.g.*, domain A_i)

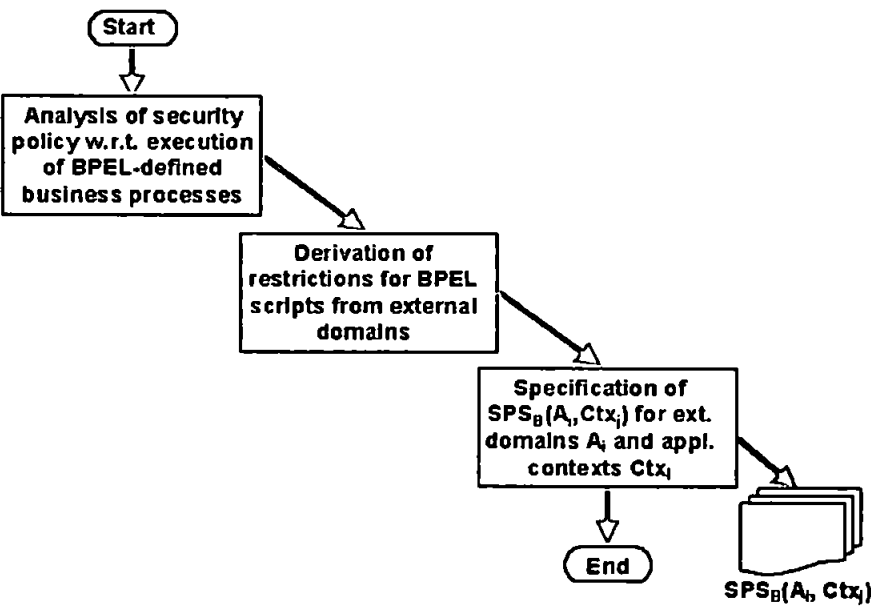


Figure 12: Workflow for Specification of Security Policy Statements

The workflow in Figure 12 starts with an analysis of local security policies to determine which parts of them are relevant at the business process layer. As already discussed in Chapter 4, for example, providing secure communication between partners in a distributed environment is treated at layers below the business process layer. After determination of the security policy-implied rules that are relevant at the business process layer, the restrictions for cross-domain deployed BPEL scripts for the different domains A_i potentially sending such scripts to the executing domain B are derived from these rules.

As a final step in this workflow, the security policy statements are specified for all foreign domains A_i that will be allowed to send BPEL scripts for execution and for all application contexts Ctx_j that are to be distinguished when assessing such scripts for compliance with local security policies. The SPS for the i -th foreign domain and the j -th

application context is denoted $SPS_B(A_i, Ctx_j)$ where the index B is there to indicate that this is an SPS representing the security policy of domain B.

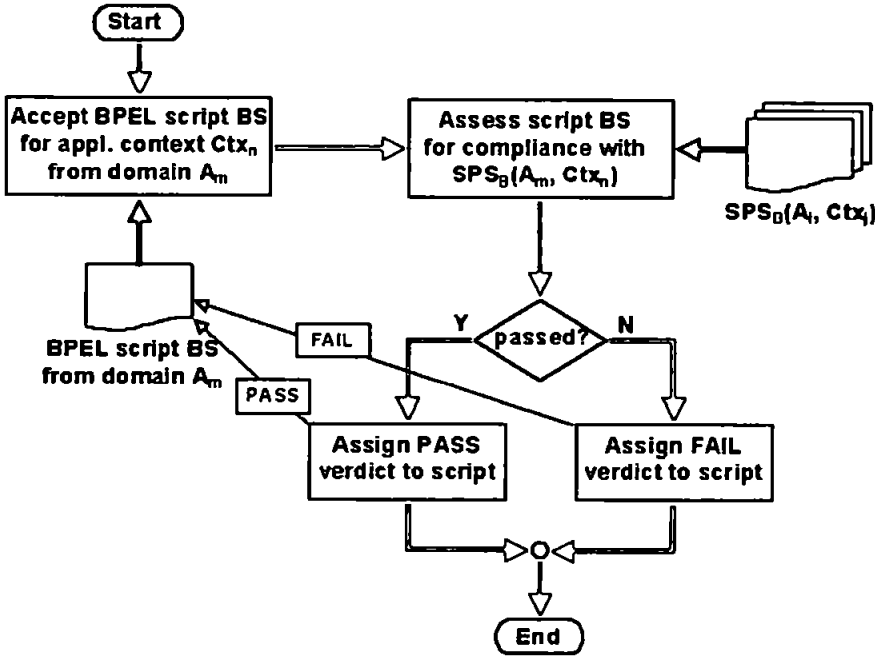


Figure 13: Workflow for Compliance Assessment of BPEL Script

Defining a BPEL script in domain A_i and sending it to domain B for execution constitutes a second workflow not depicted in a figure here because of its trivial nature. This workflow in domain A_i corresponds to the workflow in domain B shown in Figure 13. In this workflow, domain B receives a BPEL script BS for a particular application context Ctx_n from a domain A_m . In the next step, the appropriate security policy statement $SPS_B(A_m, Ctx_n)$ is retrieved and used for compliance assessment of script BS with the local security policies in domain B. As discussed in Chapter 5, given all restrictions derived from security policies relevant at the business process layer have been formulated in terms of allowed and disallowed semantic patterns of BPEL, the security assessment can be performed prior to execution as a straightforward look-up of

the script for allowed patterns and the validation that no disallowed information flow (explicit or implicit) occurs. If the script BS passes the assessment, then a verdict of PASS is assigned to this script. Otherwise, a verdict of FAIL will be assigned to it. It is taken for granted that appropriate provisions are made in the executing domain B to prevent tampering the BPEL script and the verdict assigned to it before and during its execution. Supplying a modification-secure checksum to the script and its verdict, for example, may be a means to fulfil this requirement.

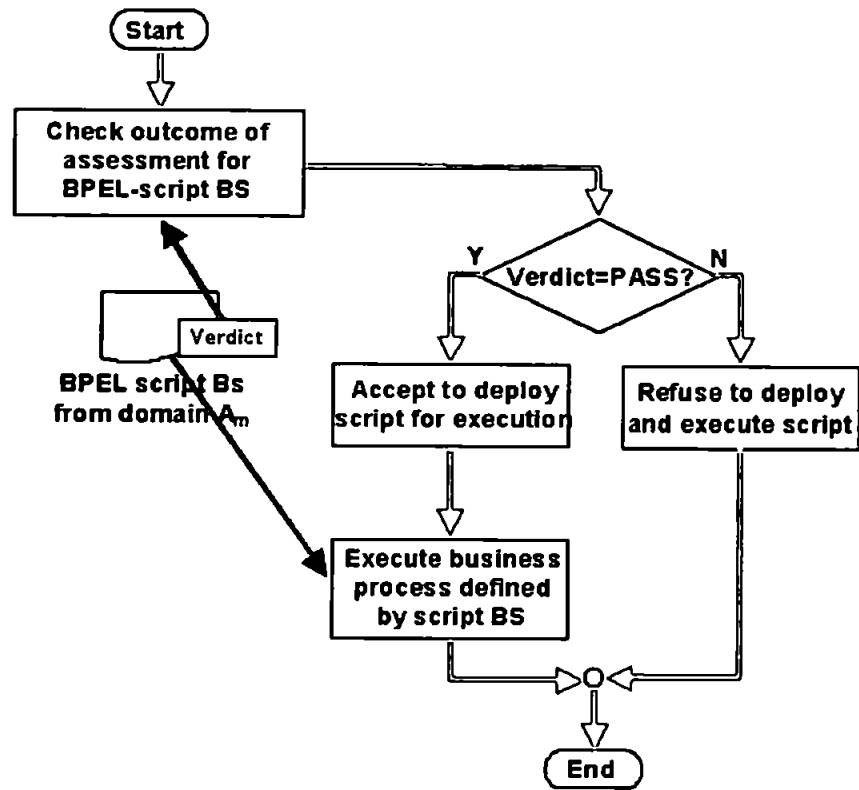


Figure 14: Workflow Deployment and Execution of BPEL Script

As a final workflow, the deployment and execution of the business process being defined by the BPEL script BS is depicted in Figure 14. This workflow, again, is performed in domain B. Before deployment and execution of script BS, this workflow

checks the verdict assigned to the script by the workflow in Figure 13. After termination of this workflow, a BPEL script with a PASS verdict is installed on an appropriate platform of domain B in such a way that it can be used as part of a CBP spanning at least the domains A_m and B. This implies that invocation of the business process (more precisely, invocation of the Web service provided by this business process) will be possible and allowed for invokers from domain A_m (*i.e.*, the defining domain of the script BS).

6.3 Delegation of Security Policy Compliance Assessment

Even with the definition of SPS in the manner described in Chapter 5, the task of analysing security-relevant semantics of BPEL scripts and matching against restrictions imposed by policies still is not, in every case, trivial and it might not always be capable of being performed automatically. Therefore, it may be desirable to reduce the effort for installing appropriate resources in the executing domain by not having the workflow of Figure 13 performed at every node in domain B that will execute remotely defined BPEL scripts. This can be achieved by delegation of at least part of the compliance assessment to dedicated locations. Based on the consideration of the workflows involved as described in the former section, several approaches to distribution of the tasks between different nodes in a cross-organisational environment will be discussed. This distribution may occur within the domain executing the BPEL script under consideration or across domain boundaries.

6.3.1 Domain-Internal Delegation of Compliance Assessment

A promising approach to reducing the effort of compliance assessment is the delegation of parts of the assessment to a dedicated node within a domain B instead of performing this task at every node in this domain. That means that the steps of compliance assessment (step 2) and assigning the verdict related to the outcome of this assessment to the script under consideration (step 3) in the workflow depicted in Figure 13 may be delegated to a dedicated node in domain B. This node is called security assessment centre (SAC) for domain B. Hence, this node is labelled B_{SAC} . Advantages related to this delegation of security assessment to a domain-internal SAC include that human interaction, when required during the assessment of scripts with respect to compliance with security restrictions, may be more easily provided at a single node (or only few nodes, if single point of failure would be an issue) in a domain compared to the situation when being distributed across the domain. It may also facilitate use of specific software required for this purpose when it only needs to be available at a single instance both with respect to potential license fees and effort for user training.

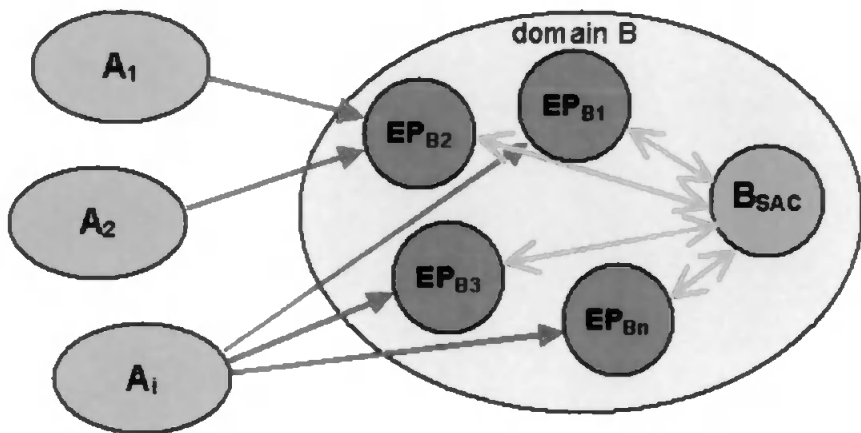


Figure 15: Domain-Internal Delegation of Security Assessment

In Figure 15, this domain-internal delegation is illustrated. After delegation to node B_{SAC} , all other nodes in domain B would access this specific node before executing a remotely defined BPEL script. This security look-up requires, that the BPEL script in question be sent to node B_{SAC} by any executing node (node EP_{B1} , EP_{B2} , EP_{B3} , ... EP_{Bn} , in the example of Figure 15 where EP means executing platform) together with an indication of the domain from where the BPEL script originates, say A_m , and the application context for which the script is intended for, say Ctx_k . On completion, the results of the assessment process will be sent back from node B_{SAC} to the node sending the inquiry for assessment, say node EP_{Bn} , and depending on the result, the BPEL script may be executed on node EP_{Bn} or not. Since the $SPS_B(A_m, Ctx_k)$ of domain B with respect to domain A_m as the origin of the BPEL script and the application context Ctx_k may be supposed to be already available at node B_{SAC} , there is no requirement to also transmit this SPS from node EP_{Bn} to node B_{SAC} in conjunction with the BPEL script.

6.3.2 Domain-External Delegation of Compliance Assessment

In cases where several domains in a CBP context allow for mutual exchange of BPEL scripts and their execution (provided they comply to the respective local security policies), the analysis and assessment could further be centralised to a particular node shared by all domains for this purpose. This node would desirably be a node external to all domains involved in the particular CBP context in order to avoid conflict of interest as much as possible. Such a domain-independent assessment centre (denoted E_{SAC}) is shown in Figure 16. After delegation has taken place, nodes of all domains accepting

BPEL scripts from other domains in this CBP context would inquire node E_{SAC} for security assessment when they receive a new script for execution.

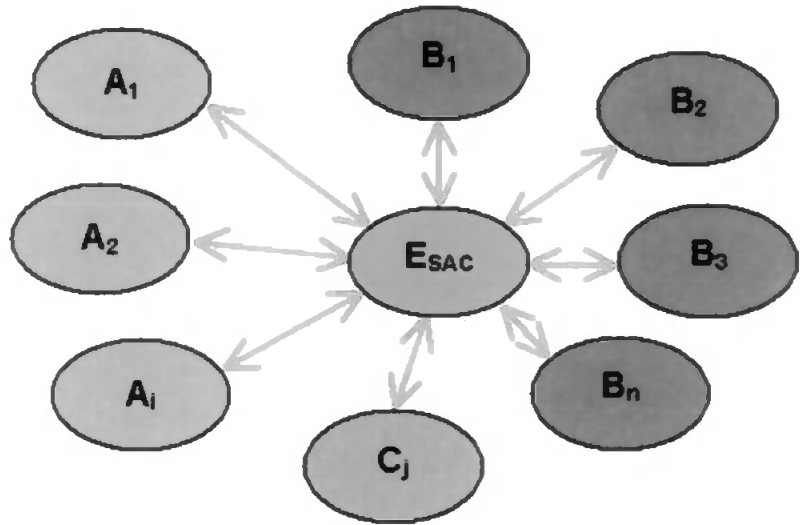


Figure 16: Outsourcing of Security Assessment

In this case, not only the BPEL script subject to security assessment and the indication of its origin and application context has to be conveyed to the assessment centre, but also the SPS against which compliance assessment is required has to be provided to the SAC. This could be done prior to sending the BPEL script for assessment, for instance, at the time when a domain subscribes to the assessment service by sending all relevant SPSs to the SAC. Sending SPSs to the SAC would also be required each time an SPS changes or a new SPS has been defined. Alternatively, the SPS for a specific originating domain can also be sent each time a BPEL script received from this domain is conveyed to the SAC for compliance assessment.

While security and trust aspects do not necessarily play a central role when the delegation of the assessment task takes place within one single domain, these aspects

become important when delegation occurs across domain boundaries. Further, when the assessment task is outsourced to a node outside the own domain, say E_{SAC} as shown in Figure 16, the communication to and from node E_{SAC} is required to be secure both with respect to authentication and data integrity. The results of assessing a particular BPEL script must unambiguously be attributed as coming from the SAC and have not been forged on their way back to the node mandating the assessment. Since mechanisms for achieving authenticated communication and providing integrity of information conveyed over a communication channel are well-known, appropriate provisions are taken for granted and, therefore, this aspect is not discussed here in further detail.

However, the issue of privacy of information contained in security policies that have to be conveyed to the external assessment service, as well as the issue of trust implied in this delegation of assessment, have to be considered in order to render this approach feasible (*e.g.*, questions with respect to trustworthiness of the results returned by the assessment centre have to be coped with). Furthermore, when assessment is delegated to a third party serving several domains, possible conflict of interest may become an issue when the SAC serves both the originating domain and the executing domain of a BPEL script. These aspects need to be considered carefully before taking the approach to install a centralised assessment centre for domain-independent use by different partners involved in a CBP context. However, detailed considerations concerning trust relations required in such a delegation process were beyond the scope of this research project.

6.4 Summary

In this chapter, based on the re-specification of the security policies of the executing site leading to a so-called SPS as introduced in Chapter 5, it has been described how the compliance assessment of a BPEL script under consideration can be conducted as a check for observance of the restrictions indicated in the SPS in a manner similar to desk check that is without any requirement to execute the script for checking purposes. Most of the restrictions to be followed relate to information flow. Thus, the information flow in a BPEL script has to be analysed in order to check the compliance to these restrictions. As a special aspect, information flow analysis in potential parallel flows (*i.e.*, alternate flows in a business process to be chosen a runtime) has to be conducted. It turned out that for the purpose of static information flow prior to execution, potential parallel flows have to be treated quite the same as actual parallel flows in a business process. As already pointed out in the former chapter, detection of potential covert channels that may be suited to leak protected information in an indirect manner by selection between different embodiments of observable behaviour of a business process dependent on such information is also very important.

The different workflows involved in deployment of BPEL-defined business processes across organisational boundaries and in compliance assessment with security policies of the executing domain have also been discussed in this chapter. Ways of delegating the task of compliance assessment from the particular node where a BPEL script is executed to a centralised assessment centre within the same domain as the executing node or to a domain-external assessment centre serving several domains has been

discussed. In particular, with delegation of compliance assessment beyond the boundaries of one's own domain, the issues with respect to privacy of information contained in security policies and to trust with respect to the results returned when domain-external assessment is employed have been addressed. However, the latter aspects were beyond the scope of this project.

Having developed in the former chapters the approaches to facilitate security policy compliance assessment of remotely defined business processes based on a thorough analysis of security-relevant semantics of BPEL and making use of a specified form of security policy definition (called SPS in this project), the proof of concept for these approaches provided by developing a research prototype to show their viability and suitability for automatic processing will be described in the next chapter.

7 PROOF OF CONCEPT BY RESEARCH PROTOTYPE

In the former chapters, the ideas contributed during this research project have been developed and described in detail. In particular, the definition of SPS to facilitate the process of compliance assessment was explained and the procedure of checking a BPEL script for its compliance with local security policies has been outlined. In order to provide an effective and efficient method for security policy enforcement in the context of business process execution where the corresponding BPEL scripts defining the processes have been defined remotely from the location of their execution, the procedure of compliance assessment should preferably be capable of being performed automatically (at least major parts thereof).

Although the aim from the outset was to potentially come up with methods that are suited for automatic processing, it is not clear from their description in the former chapters that this goal has actually been reached. Therefore, a research prototype has been developed in the course of this project that implements essential aspects of the ideas proposed. The purpose of this prototype was to serve as proof of concept for the viability of the approach. The prototype implementation is presented in this chapter and it is discussed to what extent the proof of concept has been achieved in this way.

7.1 Scope of Research Prototype

Before starting the development of the prototype, the scope of the proof of concept and the resulting requirements with respect to the functionality to be covered by the prototype were established.

As already mentioned in Chapter 4, the BPEL standard has undergone modifications during the course of this research project. While the results presented in Chapters 4 and 5 have been adapted to the version of BPEL that finally has been adopted as an OASIS standard (Alves *et al.*, 2007), the work on the research prototype started before this version was available and, hence, has been based on a former version of BPEL (Arkin *et al.*, 2004) that distinguishes from the latest version with respect to some activities added or renamed during the last phases of the standardisation process. However, the principles of automatic compliance assessment based on an SPS can also be demonstrated using the former names of the activities in question.

Since the only purpose of the prototype is to demonstrate that the approach developed during the research project, and presented in the former chapters, is actually suited for automatic processing, the implementation is restricted to a representative subset of the potential functionality. However, the selected elements had to cover all aspects that were essential and predominantly new in this approach. As a starting point for selecting the functionality to be incorporated, the indications in Tables 2 and 3 with respect to the security relevance of the different semantic patterns were taken. These indications denote the required checkings to be performed during compliance assessment in order to verify whether the particular restriction is obeyed or not. The coverage of the different checkings occurring in these tables that are provided by the prototype is indicated in Table 4.

As can be seen from the last column in Table 4, aside from two exceptions, all types of checking required during the compliance assessment process developed in this research

project and described in the previous chapters have either been implemented in the prototype (I) or can be implemented in a trivial manner (T) or its implementation can be deduced from other implemented checking in a straightforward manner (D).

The two exceptions are the checks for observation of value range restrictions in the case of dynamic values (*i.e.*, values only know at runtime because they result from inbound messages received by the business process) being passed in a outgoing message (marked N in Table 4), and the checks for covert channel prevention with the **validate** activity (marked E in Table 4). In the first instance, this type of checking cannot be performed during static analysis of a BPEL script prior to execution since it requires dynamic checking only possible at runtime. However, an approach to cover the requirements for dynamic checking during static analysis as far as possible has been described already in Section 5.4. Following this approach, dynamic checking for compliance to value range restrictions (class 5 restrictions, denoted by IFA(r) in Table 2) is converted to source restrictions (class 6 restrictions, denoted by IFA(s) in Table 2). Since the checking for compliance to source restrictions is implemented in the prototype, this type of checking may be considered covered by the prototype as far as possible by its nature.

Checking Type	Purpose of Check	Coverage
IFA(v)	Check visibility restriction by information flow analysis in forward direction	I
IFA(r)	Check value range restriction by information flow analysis in backward direction (see note 1)	T/N
IFA(s)	Check source restriction by information flow analysis in backward direction	I

Checking Type	Purpose of Check	Coverage
u	Check whether usage of optional input parameter complies to restriction of options (forbidden or required)	T
time(v)	Check that no visibility-restricted information is used to determine timeout period	D
except(v)	Check that no visibility-restricted information is used to determine exception to be thrown or be included as part of exception data passed along with the exception	D
exit(v)	Check that no visibility-restricted information is used to determine reason for termination	D
scope(v)	Check that no visibility-restricted information is used to determine <code><scope></code> to be compensated (see note 2)	D
val(v)	Check that visibility-restricted information are not type-validated with respect to types implying restricted ranges of allowed values (see note 3)	D/E
branch cond(v)	Check that no visibility-restricted information is used to determine branch to be selected in alternate flows (see note 4)	I
loop cond(v)	Check that no visibility-restricted information is used to determine conditions controlling the iteration in a <code>while</code> or <code>repeatUntil</code> activity	D
iteration bound(v)	Check that no visibility-restricted information is used to determine bounds of iteration in a consecutive or parallel version of <code>forEach</code> activity (see note 5)	D
preempt(v)	Check that no visibility-restricted information is used to determine condition for pre-emptive termination of a <code>forEach</code> activity (see note 5)	D

- I Type of checking implemented
- D Type of checking not implemented, but implementation easily deducible from covert channel detection scheme as implemented for the `switch` activity
- T Type of checking not implemented, but implementation considered trivial
- N Type of checking not suitable for static analysis since requiring dynamic checking at runtime (viable by the scheme outlined in Section 5.4).
- E Type of checking not implemented requiring non-trivial extension of current functionality (see note 3)

Note 1: Checking of value range restrictions during static analysis is either trivial (if constant values specified within the BPEL script are involved) or impossible during static analysis (if dynamic values extracted from messages received during runtime are involved)

- Note 2:** The `compensateScope` activity requiring this type of checking has been introduced comparatively late during the standardisation process of BPEL. However, similar to checking for covert channel detection with other activities, its implementation is deducible in an easy way from the covert channel detection scheme implemented for the `switch` activity.
- Note 3:** The `validate` activity has been introduced very late during the standardisation process of BPEL. Therefore, checking for covert channels with this activity is not implemented. As long as it is acceptable to prevent type validation of variables containing visibility-restricted information, this check can be implemented as a straightforward extension of the covert channel detection scheme implemented for the `switch` activity. In this case, the indication D applies. However, when this approach is considered to be overly strict, then a more sophisticated algorithm has to be implemented as outlined in Appendix A.3 that cannot be considered easily deducible from the covert channel detection scheme implemented for the `switch` activity. In this case, the indication E applies.
- Note 4:** At the time the research prototype was conceived, the branching functionality in BPEL was expressed by the `switch` activity that has been covered by the prototype implementation. Lately during the standardisation process of BPEL, the `switch` activity has been replaced by the `if` activity providing the same functionality.
- Note 5** The `forEach` activity has been introduced lately during the standardisation process of BPEL. The two new types of checking for covert channel detection required with this new activity (check that neither the iteration bounds nor the conditions for possible pre-emptive termination of the activity depend on visibility-restricted information) are deducible in an easy way from the covert channel detection scheme implemented for the `switch` activity.

Table 4: Coverage of Checking Functionality by Prototype

With respect to information flow analysis, the prototype was required to cover (real or potential) parallel flows in a BPEL script under consideration. That means, when a value is passed in an outbound message (either in an `invoke` activity or in a `reply` activity), then it has to be checked that no visibility-restricted information encountered in any parallel flows possibly being extracted from an inbound message (either in an

invoke activity, a **receive** activity, or a **pick** activity) occurred before this point in a BPEL script will be included in this message.

The prototype is designed in such a way that it analyses the main activity in the **<process>** element of a BPEL script which is typically a **sequence** activity. The support of **<scope>** elements contained in a process definition was not deemed to be required for the prototype since these elements simply serve structuring purposes to limit the scope of declarations and provide a nested structure as known from other programming languages. This nesting of scopes does not contribute to the security relevance of the behaviour specified in a BPEL script. However, it slightly complicates information flow analysis, as scopes of variable definitions would have to be observed. For instance, if variable A would contain visibility-restricted information I_1 from a Web service invocation and would be declared again in an inner scope, then assignment of another information I_2 to variable A within this inner scope (assumed to be not visibility-restricted) would only conceal the visibility-restricted information I_1 . Thus, passing variable A in an outbound message to an external Web service within this scope would not violate the security policy. However, once the inner scope is left, the variable A would again contain the visibility-restricted information I_1 . Therefore, passing variable A in an outbound message to an external Web service in the containing scope would violate the security policy. In principle, keeping track of respecifications of the same variable in nested scopes does not pose a problem for the implementation of the assessment process but only increases the complexity of the storage management used for the purpose of information flow analysis (see Section 7.4.3 below).

The checking of **links** in **flow** activities (cf. Section 4.2.3) was not considered for implementation in the prototype. Such links are security-relevant when the flow control effectuated by these constructs is made dependent on visibility-restricted information. Checks that are required to prevent the establishment of covert channels using links are very similar to the check `branch cond(v)` that are required for covert channel prevention with `if` activities. Since this checking has been implemented in the prototype (in conjunction with the former **switch** activity), the similar checks for **links** were not deemed to contribute new insights when implemented in the prototype. Ignoring links that are not dependent on visibility-restricted information may possibly make the assessment process overly strict, as sequential flow potentially induced by such links would be neglected in backward information flow analysis. However, this can only lead to refusal of BPEL scripts as non-compliant that could be accepted as compliant when the sequential flow caused by such links would have been honoured during information flow analysis. It is important that ignoring links not involving visibility-restricted information for flow control purposes can by no means lead to false acceptance of BPEL scripts that actually are not compliant with security policies. These considerations justified the decision to disregard links in the prototype.

As for the different handlers a BPEL script may contain (event handler, termination handler, fault handler, compensation handler), these are also not supported by the prototype since this also would only increase the complexity of the implementation without contributing new insights. As discussed in Section 4.4.2, all such handlers except event handlers do not contribute security-relevant semantics but only increase complexity of information flow analysis since all these handlers represent additional

potential parallel flows to the main activity in a BPEL script. However, treatment of parallel flows in information flow analysis already has been catered for in the prototype such that supporting these handlers would not introduce new aspects to the implementation.

Event handlers that contribute security-relevant behaviour to a business process may be treated in a similar manner as the `pick` activity as also argued above in Section 4.4.2. As can be seen from Table 3, the `pick` activity requires both the `IFA(v)` type of checking and the `time(v)` type of checking. Table 4 shows that these both types of checking are covered by the prototype (implemented or deducible from implemented functionality). Therefore, support of event handlers in the prototype has been deemed non-essential for the proof of concept and, hence, is not provided.

Though initially envisaged in the research project, the idea to incorporate the implementation of the prototype within one or several BPEL enabled platforms has been abandoned. The reason for this was the consideration that striving for integration of the security policy assessment into such a platform on one hand side would cause a significant overhead for acquisition of required skills to be able to integrate such procedures properly, and on the other hand side would not contribute significantly to the proof of concept needed in the context of this research project. The question to be answered by the proof of concept was not to demonstrate that integration of compliance assessment procedures is feasible, but rather that checking for compliance between a BPEL script and restrictions indicated in an SPS could be performed automatically with as little as possible human intervention. Even when only available as a program exe-

cutable separately from any BPEL-enabled platform resulting in an assessment of compliance with local security policies, the proof of concept could be regarded as successful. Therefore it was decided to implement the prototype as a stand-alone program not caring about possible integration in a BPEL-enabled platform.

7.2 Machine-Readable Format of Security Policy Statement

While the examples of SPS and its components in Chapter 5 were given in human-readable tabular format, it is obvious that it is straightforward to define appropriate XML schemas in order to be capable of presenting the information in machine-processible form. Details of this XML-based format will be explained in this section. In particular, it is argued why existing approaches to expressing access control policies in terms of Xpath (Fundulaki and Marx, 2004; Kuper *et al.*, 2005), or standardised formalisms for expressing security policies as provided in XACML (Moses, 2005), or SAML (Cantor *et al.*, 2005) have not been adopted and extended for being used for the proposed approach to express restrictions on allowed semantics of BPEL.

A complete XML-based formal specification for the SPS used in the approach to security policy assessment is contained in Appendix A.2. While the schema is provided there using the formalisms of XML Schema (Thompson *et al.*, 2004), the excerpts shown in this chapter use a more condensed notation oriented on the meta syntax of regular expressions. This compact form of schema representation is also used in the BPEL specification (Alves *et al.*, 2007). The notational conventions are explained there (*ibid.*, p. 9) and provide the following meta characters for indicating repetition of

elements and optional parts. An asterisk sign (*) behind an XML element indicates that zero, one or more occurrences of that element being allowed at this place. Similarly, a plus sign (+) behind an XML element means that one or more occurrences are allowed. In addition, a question mark (?) behind an XML element identifies an optional element that may occur once or may be absent. Finally, alternate choices are denoted by a bar (|) between alternatives.

7.2.1 Rationale for Definition of XML Schema in Current Form

The XML schema for the SPS was specified without any recourse to existing approaches for specifying security policies either from standardisation such as SAML (Cantor *et al.*, 2005) or XACML (Moses, 2005) or from research (*e.g.*, Sirer and Wang, 2002). Reason for this was that none of these approaches comprises means of expressing the aspects of security policies that were relevant in this context. On the other hand, defining the required XML schema based on an existing approach to specify security policies would have implied too much an overhead that would have been inherited this way. It has been decided that definition of the required XML schema for SPS based on such approaches only would have unnecessarily complicated the implementation of the research prototype without offering any significant advantages. In contrast, specifying an XML schema to the very purposes of this project could result in a much more streamlined definition and, therefore, any overhead imposing additional effort to the implementation of the prototype could be avoided. The proof of concept achievable with the prototype was not diminished by not using an XML schema based on any existing approach for expressing security semantics.

7.2.2 Annotated SPS Schema in Condensed Notation

In order to explain the XML schema that has been provided to specify an SPS in a machine-readable form, the notational conventions as described above are used to depict parts of the schema in a condensed way. In Listing 3, the overall structure of an SPS is shown.

```
<sps>
  <identifications
    remoteDomain="foreignDomain"
    localDomain="localDomain"
    applicationContext="context"/>
  <iwsrs> ... </iwsrs>*
  <ewsrs> ... </ewsrs>*
  <unrestrIntWs> ... </unrestrIntWs>*
  <unrestrExtWs> ... </unrestrExtWs>*
</sps>
```

Listing 3: Overall XML Structure of SPS

The element `<identifications>` indicates the domain defining the BPEL script and the domain where it is to be executed in the attributes `remoteDomain` and `localDomain`, respectively. The application context the SPS relates to can be specified in the attribute `applicationContext`. For instance, for the car manufacturer from the example in Figure 4, a different set of security policy derived restrictions could apply if he would also be entitled to remotely define business processes in the context of communicating construction plans for new gearboxes with the gearbox manufacturer.

The elements `<iwsrs>` and `<ewsrs>` denote restrictions with respect to internal and external Web services, respectively, one element for each Web service indicated. Si-

milarly, the elements `<unrestrIntWs>` and `<unrestrExtWs>` denote unrestricted internal and external Web services (class 1), respectively.

In Listing 4, the structure of the element `<iwsrs>` is depicted. The element `<ewsrs>` has a similar internal structure. The element `<operation>` denotes the name of a Web service operation and indicates the corresponding port type by a URI. The `<input>` and `<output>` elements indicate restrictions to the corresponding type of Web service parameters, one for each type of message a Web service operation is able to receive or send, respectively.

```
<iwsrs>
  <operation      name="operationName"
                  portType="URIOfPortType">
    <input>      ... </input>*
    <output> ... </output>*
  </operation>*
</iwsrs>
```

Listing 4: Structure of Internal Web Service Restriction Statement

From Listing 5, the structure of the element `<input>` can be seen. It is used to indicate restrictions applying to the input parameters of a Web service. The element may contain the attribute `sourceRestricted` to indicate whether all input parameters are source restricted (class 6) or not. If this attribute is missing it defaults to the value false. If so, the required originating Web service(s) for a value to be allowed is indicated in one or more `<service>` element(s) contained in the `<sourceRestriction>` element. More than one such originating Web service may be indicated to allow for alternative sources.

```
<input message="messageName"
      sourceRestricted="true|false"?>
  <sourceRestriction>
    <service portType=URIOfPortType"
      operation="operationName"/>+
  </sourceRestriction>?
  <part name="partName"
    restrictedOptional=
      "presentOrNot|forbiddenPart|requiredPart"?
    valueRestricted= "true|false"?
    sourceRestricted= "true|false"?
    <sourceRestriction>
      <service portType= "URIOfPortType"
        operation="operationName"/>+
    </sourceRestriction>?
    <valueRestriction>
      <permittedValue> ... </permittedValue>+
    </valueRestriction>?
  </part>*
</input>
```

Listing 5: Structure of Restriction Indication for Input Parameters

In addition, at the part level there is an optional indication (via attribute `restrictedOptional`) whether a specific input parameter in spite of being defined as optional must not be used or is required to be used (class 4). This information is not provided on the message level, that is, for all input parameters at once. Such a shortcut for indicating class 4 restrictions for all input parameters has not been recognized as being required in the schema. It should be noted that having class 4 restrictions for all input parameters is not equivalent to a class 2 restriction for the Web service as a whole. There may be cases, where it is forbidden to pass any value with a Web service invocation, but still the Web service is allowed to be invoked (without passing any value to it).

If not all, but only specific input parameters are restricted, this is indicated in the `<part>` element contained in an `<input>` element. Again, it may be indicated whether an input parameter contained in the message representing the union of all input para-

meters of a Web service is source restricted or not (class 6). If so, the **<part>** element in turn contains an element **<sourceRestriction>** with the same internal structure as discussed above for the message level.

Furthermore, via the attribute **valueRestricted** it can be indicated at the part level that a specific input parameter may only be used with certain values (class 5). The permitted values are specified in one or more **<permittedValue>** elements contained in the element **<part>**. Obviously, the indication of value restriction is only sensible at the part level, since the permitted values have to be specified separately for each input parameter affected by a class 5 restriction.

```
<output message="messageName"
        visibilityRestricted="true|false"?>
  <targetRelaxation>
    <domain name="domainURI"/>+
  </targetRelaxation>*
  <part name="partName"
        visibilityRestricted="true|false"?>
    <targetRelaxation>
      <domain name="domainURI"/>+
    </targetRelaxation>*
  </part>*
</output>
```

Listing 6: Structure of Restriction Indication for Output Parameters

To conclude the discussion of the XML schema for SPS, the structure of the element **<output>** is depicted in Listing 6. Similar to the indication of source restriction in the **<input>** element, visibility restriction may be indicated on the message level and on the part level via attribute **visibilityRestricted**. As a special case, visibility

restriction may be relaxed to cope with the situation in which one or several domains are allowed to see an otherwise visibility-restricted value.

An example for such a relaxation is the lists of items to be ordered from the sub-suppliers in the example of Figure 4. These lists have their visibility restriction relaxed since they are visibility-restricted to all external domains except the specific sub-supplier the list is intended for.

The relaxation of visibility restriction is indicated by the element **<target-Relaxation>** contained within the **<output>** element and contains one or more **<domain>** elements to indicate the domain(s) to which the output parameter may exceptionally be passed. Similar to the **<input>** element, separate parts of the output message, that is, specific output parameters, could be indicated as being visibility-restricted in one or more elements **<part>** contained in the **<output>** element. If target relaxation applies to specific parts, this is indicated by **<targetRelaxation>** elements contained within the **<part>** elements and specifying the domain(s) to which the parameter may be passed. The structures of **<targetRelaxation>** elements are the same at message level and at part level. It should be noted that in an **<output>** element relating to an internal Web service (*i.e.*, an **<output>** element contained in an **<iwsrs>** element), visibility restriction does not apply to the local security domain where the BPEL script is to be executed. Therefore, in an **<iwsrs>** context, this domain will never be indicated in a **<domain>** element within the element **<target-Relaxation>**.

7.3 Architecture of Research Prototype

The research prototype was implemented using Java because of its known characteristic of platform independence. The prototype was designed to provide a GUI for entering the filenames of the SPS and the BPEL script under consideration as well as to display the outcome of the assessment (cf. Figures 18 and 19). The WSDL definitions of the Web services specified in an SPS to be allowed in a compliant BPEL script as well as of the Web services actually being used in a BPEL script subject to compliance assessment should be made available to the prototype via namespace specifications in the respective header of the XML documents containing the SPS and the BPEL script.

Figure 17 provides an overview of the class hierarchy of the prototype. At the top of the diagram, the class **CAnalysator** denotes the top-level class of the prototype. This class will be instantiated by the GUI when the "Start" button has been actuated. The classes **CSpwsProducer** and **CBpelVariableProducer** represent the parser and converter to internal representation for the SPS and the declaration part of the BPEL script, respectively. The classes depicted below the abstract class **ASpws** on the right hand side of the diagram provide the internal representation of the SPS while the classes **CBpelVariable** and below on the left hand side are used for the internal representation of variables declared in the BPEL script and the parts possibly contained therein. The abstract class **AActivity** and the classes derived thereof contain the logic required to perform the compliance assessment checking for the different activities supported by the prototype. As can be seen from the class names, the prototype supports the activities **invoke**, **assign**, **sequence**, **flow**, and **switch**.

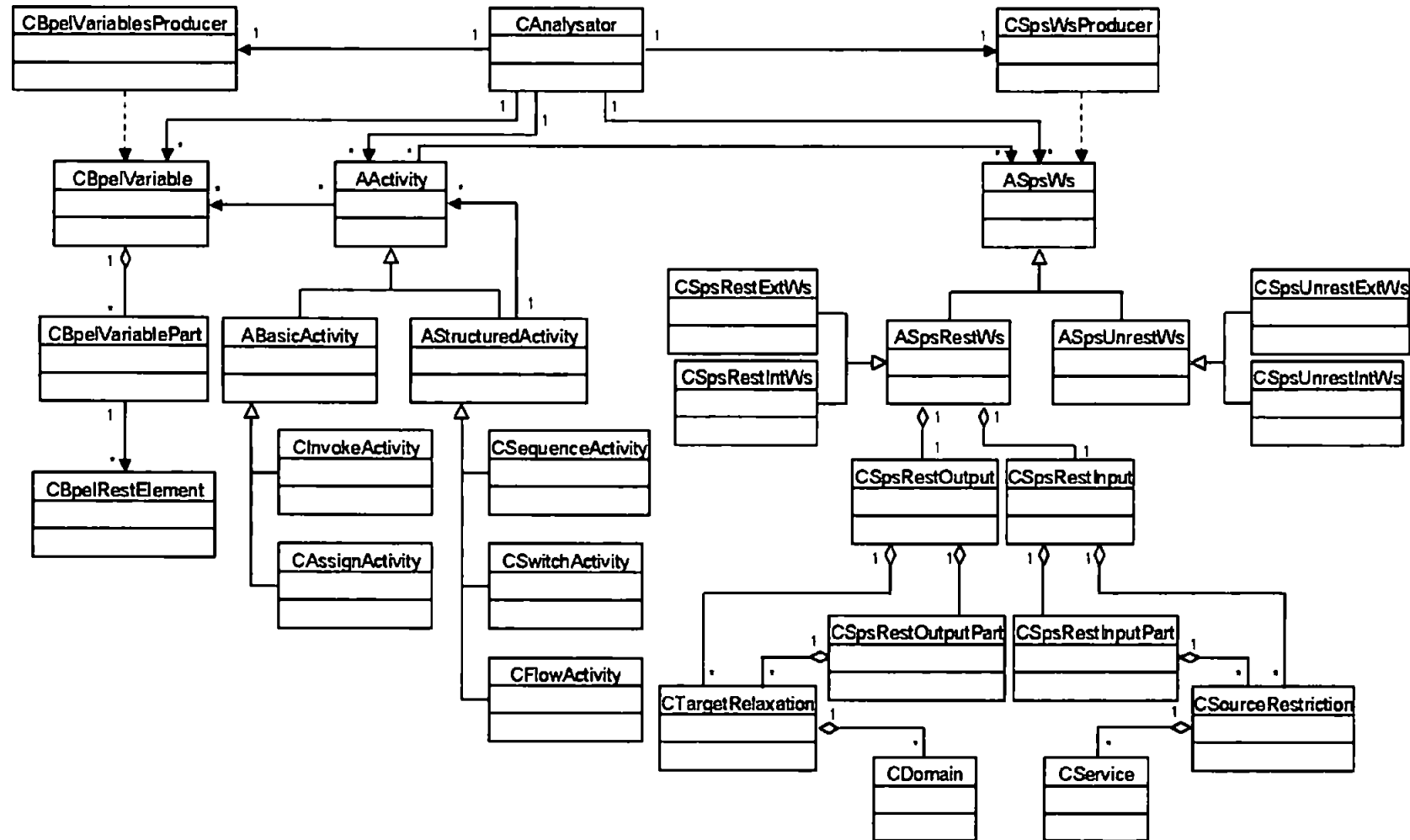


Figure 17: Class Diagram of Research Prototype

7.4 Functionality of Research Prototype at a Glance

The BPEL script to be checked and the SPS defining the security policies are input to the prototype. Furthermore, the WSDL definitions (Chinnici *et al.*, 2006) of all Web services addressed in the BPEL script under consideration are made available to the prototype. While the names of the files containing the BPEL script and the appropriate SPS have to be entered in the GUI of the prototype, the filenames of the WSDL definitions of the Web services indicated in the SPS as well as of those actually invoked in the BPEL script were provided via namespace declarations in the header of the XML document of the SPS.

The screenshot shows a graphical user interface for the Research Prototype. It contains two input fields for file URLs, a display area for the assessment result, and a 'Start' button. The first input field, labeled 'Enter URL of SPS:', contains the text 'file:///evaluation/gearProc/SPS_GT.xml'. The second input field, labeled 'Enter URL of BPEL script:', contains the text 'file:///evaluation/gearProc/orderGearParts.bpel'. Below these fields, the 'Verdict:' is displayed as 'PASS' and the 'Message:' is displayed as 'BPEL script passed compliance check'. A 'Start' button is located at the bottom right of the interface.

Enter URL of SPS:	file:///evaluation/gearProc/SPS_GT.xml
Enter URL of BPEL script:	file:///evaluation/gearProc/orderGearParts.bpel
Verdict:	PASS
Message:	BPEL script passed compliance check
<div>Start</div>	

Figure 18: Successful Assessment of BPEL Script in Research Prototype

Without executing the BPEL script, the prototype inspects it step by step to ensure that the restrictions specified in the SPS are obeyed. If any violation is detected, the program stops its analysis and returns a FAIL verdict. It also indicates the location in the BPEL script giving rise to this verdict together with the restriction in the SPS violated at that location. If the inspection is completed without detecting any violation of the SPS, then the prototype assigns a PASS verdict to the BPEL script.

Enter URL of SPS:	<input type="text" value="file:///evaluation/gearProd/SPS_GT.xml"/>
Enter URL of BPEL script:	<input type="text" value="file:///evaluation/gearProd/orderGearParts.bpel"/>
Verdict:	FAIL
Message:	Violation of security policy detected
Reason:	The following Web service operation: file:///evaluation/gearProd/internalWS_GearProd.wsdl/internalPT/checkStock23 used in an invoke activity is not specified in SPS
<input type="button" value="Start"/>	

Figure 19: Detection of SPS Violation in Research Prototype

7.4.1 Conversion of SPS into Internal Representation

When the prototype is started via the "Start" button, it reads the XML document containing the SPS and converts it into an internal representation. To this purpose, the SPS document is parsed using a DOM parser returning the structure of the XML as a whole. By processing this structure step by step, the program creates internal representations for the Web services indicated in the SPS. For each restricted internal or external Web service (elements `<iwsrs>` and `<ewsrs>`, respectively) found in the SPS, an instance of class `CSPSRestIntWs` or `CSPSRestExtWs`, respectively, is created to contain the name and port type along with the restrictions with respect to the input and output parameters applicable to each Web service. For each unrestricted internal or external Web service (elements `<unrestrIntWs>` and `<unrestrExtWs>`, respectively), an instance of the classes `CSPSUnrestIntWs` or `CSPSUnrestExtWs`, respectively, is created to contain just the name and port type of these Web services.

7.4.2 Conversion of Variable Declarations into Internal Representation

After parsing the SPS and converting it into an internal representation, the XML document containing the BPEL script is parsed. Unlike the parsing of the SPS, the BPEL script is parsed using a SAX parser since this type of XML parser returns the document element by element, which has been found to be better suited for stepping through the BPEL script. For each declaration of a variable encountered, the program creates an instance of class **CbpelVariable** that contains the name of the variable, its message type along with the corresponding name space and all parts within this message type. The parts within a message type are determined by parsing the WSDL definition in which this message type is specified. For the purpose of the prototype it is assumed that the URI indicated in the name space reference with the message type is a direct reference to the file containing the WSDL definition. It should be noted that, in general, such URIs need not to be direct references to files but may also contain some sort of indirect references that have to be resolved first to get access to the WSDL definition. Since such resolution of URIs is not essential for the proof of concept, it has not been implemented but only direct file references have been supported in the prototype.

7.4.3 Combined Forward/Backward Information Flow Analysis

One of the main tasks of the prototype is the information flow analysis both in forward and backward directions to decide whether restrictions of class 3 and class 6 would be obeyed by the BPEL script checked. In order to avoid repeated parsing of the BPEL script, the variables as being the containers of the information to be passed in outbound

messages to so-called partners of a BPEL script and received in inbound messages from these partners have been designed to be represented in a special manner. Besides accommodating the content representing the information stored in these variables, the internal representation of variables has been designed to also encompass both the restrictions associated with the particular information as found in the corresponding SPS (*i.e.*, visibility restriction with or without target relaxation) and the source the information was gained from. This way, whenever an information contained in a variable is to be included in an outbound message of an **invoke** activity or a **reply** activity, it can be checked whether visibility restrictions are obeyed and, in case an input parameter of the Web service invoked is subject to source restriction (class 6), it can be determined whether the source of this information complies to this restriction. By collecting all restrictions implied to an output parameter of a Web service in the variable that accepts this parameter along with its name and the value returned by the Web service, information flow analysis may be performed in forward and backward direction by just evaluating this additional content beyond the pure value of the variable.

As an example, the treatment of a Web service invocation is described in further detail. As this treatment is the most complex one in the assessment since all types of restrictions may apply, describing the steps performed here gives an overview of the actions performed by the prototype with any BPEL activity.

Upon encountering an **invoke** activity, the prototype determines the Web service invoked and looks up the internal representation of the SPS for the information present

therein for the specific Web service. If the Web service is not found in the SPS, the processing stops because invocation of a Web service not defined in SPS as being allowed represents a violation of the security policy. Remember that for every Web service that is allowed to be invoked an entry in the SPS has to exist as stated in Chapter 5.

If the Web service is found in SPS, the restrictions defined there are copied for further use. Since the output parameters of a Web service invocation are stored in a variable defined in the BPEL script, the restrictions contained in the `<output>` element corresponding to the particular Web service are stored in the instance of the class `CBpelVariable` representing this variable. Along with the restrictions, the URI of the Web service invoked is stored in this variable for potential later use in validating potential source restrictions (class 6).

Usually, this process of storing the restrictions for the output part of a Web service in the variable receiving this output will override the information stored there with former uses of this variable in Web service invocations. However, if the Web service invocation was found in an (actual or potential) parallel flow (*i.e.*, within a `flow`, `switch`³, or `pick` activity), then the information does not override the information already stored there but a special treatment of information flow analysis in parallel flows applies as will be described in Section 7.4.4.

³ Remember that the prototype was based on a previous version of BPEL. The `switch` activity has been replaced by the `if` activity in the latest version of BPEL providing essentially the same functionality.

The variable used as input message to the Web service invoked is analysed with respect to the accumulated restrictions already stored in it. In this way it is checked whether visibility restricted (class 3) information is contained in the variable to determine whether conflicts with those restrictions would occur by passing this information to the current Web service. In the case that class 6 restrictions are present for the input parameters of a Web service, the origin of the information contained in the variable will be used to assess compliance or detect potential non-compliance with these class 6 restrictions.

Similar processing as with the input and output parameters in an **invoke** activity applies to the **reply** and **receive** activities (and the receiving parts in a **pick** activity), respectively.

7.4.4 Handling of Parallel Flows in Information Flow Analysis

If an assignment of a message returned by an **invoke** activity or a **receive** activity is encountered within an (actual or potential) parallel flow in the BPEL script, the information stored in the variable will not be overridden. Instead, the information to be stored in the variable is labelled with a hierarchical flow identifier enabling simultaneous collection of information related to all (potential) parallel information flows. This way, the backward information flow analysis can use the restrictions from all former parallel information flows. When information from parallel flows is present and the same variable is re-used as container for the output of a Web service, the hierar-

chical flow identifiers stored with the information has to be considered to decide which part of the information to override and which to keep.

7.4.5 Implementation of Covert Channel Prevention

In order to prevent covert channels (cf., Sabelfeld and Myers, 2003), the prototype takes a rigorous approach in disallowing any visibility restricted information to be used for flow control purposes (*i.e.*, in the activities **exit**, **throw**, **wait**, **compensateScope**, **while**, **repeatUntil**, **switch**³, **forEach**, and the timeout part of **pick**) or in a **validate** activity (or assign activity with attribute **validate="true"**). Remember that only the **switch** activity is actually implemented in the prototype. However, the same processing as implemented for the **switch** activity would also apply for covert channel detection when the prototype is to be amended to also support these other activities.

Whenever such an activity is encountered during parsing the BPEL script, the prototype checks whether any variable is used in this activity. If not, then the activity is considered uncritical with respect to covert channel establishment. However, if a variable is detected in such an activity, then it is checked in the information flow history of this variable whether it contains visibility-restricted information (class 3 restriction) or may contain such information from potential parallel flows. If that is the case, then a violation of the restrictions in the SPS is assumed without further analysis whether the further processing actually would exhibit observable behaviour that is influenced by the

visibility-restricted information in such a manner that conclusion on this information could be drawn.

This rigorous approach to covert channel prevention may be too strict in some instances, but it assures in any case that no BPEL script with undiscovered covert channels will pass the compliance assessment. If refusal based on falsely supposed covert channels because of this rigorous approach would be an issue then more sophisticated algorithms for differentiating between harmless and harmful use of visibility-restricted information in flow control would be required. For instance, a more sophisticated approach for covert channel prevention could try to analyse whether the externally observable behaviour would be distinguishably different depending on the information used in these activities for flow control purposes. One should bear in mind that such analysis is complex and increases the risk to overlook a covert channel that was possibly included in disguise. Therefore, the strict approach for covert channel prevention currently taken should only be weakened if urgent needs would require doing so. Even under these circumstances, utmost care has to be taken not to overdo this relaxation of the rules for covert channel prevention.

7.5 Evaluation of Research Prototype

The research prototype has been evaluated in order to investigate whether the algorithms defined for performing the different checks required during compliance assessment of a BPEL script are capable of distinguishing allowed and disallowed semantics expressed by it. For this purpose, variants of BPEL scripts for the *control*

process of the example in Figure 4 have been subject to an automated security assessment processing simulated by the research prototype. The scope of this evaluation has been concentrated on the aspect, to which extent machine-based analysis of compliance with security policies defined in terms of security-relevant semantic patterns of BPEL scripts may be performed without human assistance. In particular, the reliability of machine-based assessment statements as to compliance with security policies was evaluated. In addition, syntax checking of SPS implemented in the prototype and the issued error messages in the case of syntax error detection were tested.

The BPEL script and SPS examples used for evaluation purposes were chosen based on the CBP example in Figure 4. The BPEL scripts were supposed to define the *control* business process and the SPS to contain the restrictions with respect to Web service invocation as discussed in Chapter 2. BPEL scripts with the following characteristics were used:

- BPEL script completely complying to SPS (example outcome depicted in Figure 18)
- BPEL script invoking Web service not contained in SPS (example outcome depicted in Figure 19 with the BPEL snippet containing the violation depicted in Listing 7 where invalid WS operation is typed in red)
- BPEL script passing visibility-restricted information to external Web service (not indicated in target relaxation)

- BPEL script passing information to source-restricted input message to a Web service where source of information passed does not comply to source restriction
- BPEL script using visibility-restricted information in branch condition of a **switch** activity

Further examples of BPEL scripts used for evaluation of the prototype can be found in Appendix A.5.

```
<invoke      partnerLink="gearProd"
             portType="int:internalPT"
             operation="checkStock23"
             inputVariable="gearProducerCheckInput"

             outputVariable="gearProducerCheckOutput" />
```

Listing 7: Extract from BPEL Script Invoking WS not Defined in SPS

Evaluation of the prototype using these BPEL examples proved successful. The outcome of running the prototype with the particular BPEL script as input indicated the SPS violation intentionally introduced in the script. From these results and the considerations with respect to coverage of the prototype in Section 7.1, it could be concluded that implementing a procedure for automatic compliance assessment of BPEL scripts with security policies specified using the XML schema described in Section 7.2.2 was feasible and the implementation of the assessment procedure as

described in Section 7.4 based on a class hierarchy as proposed in Section 7.3 turned out to be comparatively straightforward.

By implementing selected parts of a compliance assessment procedure based on the methods described in Chapters 5 and 6 it could be shown that the approach proposed in this research project is suited for automatic compliance assessment. Having only realised part of the assessment procedure in the research prototype does not reduce the evidence gained because the discussion in Section 7.1 has clarified that the selection of functionality covered the main aspects of this procedure. One aspect of functionality considered crucial for the automatic performance of compliance assessment is the information flow analysis in forward and backward direction while checking a BPEL script for possible violations of security policy. The essential basis for this information flow analysis has been realised in the prototype by storing the restrictions imposed to information gained from Web service invocations together with the source of an information item in the internal representations of the variables storing the information.

Furthermore, as assembled in Table 4, the way to implement the missing parts of the functionality either can be deduced from the already implemented parts or is straightforward to realise such that no template for its implementation is required. However, even though the research prototype made clear that the construction of a compliance assessment tool covering the whole range of BPEL is feasible and introduced data structures and algorithms appropriate to serve as templates for the missing functionality, it should be noted that the overall effort for building such a tool in product quality would required a significant effort.

7.6 Summary

The proof of concept of the approach to compliance assessment of BPEL scripts with local security policy of the executing site has been conducted by a research prototype implementing essential aspects of the compliance assessment procedure. Though the prototype was not aimed at implementing the full range of functionality of this procedure, it has shown that all kinds of checking required in the course of compliance assessment have either been covered by the prototype, are easy to be covered by straightforward amendment of functionally already implemented, or are straightforward to implement and would add nothing to the proof of concept.

Only in the case, the rigorous approach to covert channel prevention adopted with all other activities prone to covert channels would be deemed not acceptable for the **validate** activity newly added to the BPEL standard, more sophisticated checking for covert channel prevention would be required that are not yet covered by the prototype and cannot be considered straightforward amendments of functionality already implemented. However, these checks may be also implemented without posing essential problems. An outline of the procedure required to perform this type of checking for potential covert channels associated with the **validate** activity is included in Appendix A.3.

During establishing the XML schema for the machine-readable specification of the SPS and the initial design for the prototype based on the example of a CBP in Figure 4, several new insights have been gained that gave rise to adapting the XML schema and

led to amendments of the approach described in Chapters 4 through 6. The following modifications of the initial approach were induced by the development of the prototype:

- The need to provide target relaxation (*i.e.*, allow visibility-restricted information to be sent to specific targets external to the local domain) has been recognised during the attempt to establish an SPS for the example in Figure 4. The capability to specify such target relaxation was not included in initial versions of the approach (*e.g.*, as published in (Fischer *et al.*, 2006)).
- In the same context, the need was recognised to extend the definition of the class 4 restriction that was initially defined to only encompass input parameters forbidden to be used. Since such a restriction can only be applied to optional input parameters of a Web service, the reverse restriction had to be added for completeness, that is, the requirement that a value for an optional parameter has always to be passed to avoid an eventual default value (or default mechanism) for such a parameter to take effect.
- Further it turned out during the design of the prototype to not only allow for one instance of SPS for a particular pair of business partners exchanging BPEL scripts for remote execution, but also provide the capability for having different SPS instances depending on different application contexts in which these partners may perform collaborative business processes. Such instances would typically allow for different sets of restrictions on Web service invocations

(allowing different Web services to be invoked or having deviating restrictions on common subsets of Web services present in different SPSs).

The description of the research results in Chapters 4 through 6 are based on the amendments added as consequences of these insights.

The viability of further proposals made in this research project such as approaches for the delegation of the compliance assessment or for coping with the requirement for dynamic checking in pre-execution assessment of compliance is deemed to be given as granted from its description in the thesis without further requirements for proof of concept. Therefore, providing exemplary implementations thereof was not considered necessary to confirm their feasibility, but would only have resulted in increased efforts spent for software development without contributing new insights.

The description of the XML schema and of the functionality of the research prototype was published as part of Fischer *et al.* (2007a).

Having now presented the results achieved during the research project to the extent envisaged when the project was started, the next chapter considers possible application of these results to related fields. Since also based on BPEL scripts, Grid processes defined on top of Grid services have proven particularly suited for such wider application of the research results.

8 EXAMINING THE WIDER APPLICABILITY OF THE RESULTS

In this chapter, the results achieved during this project in the field of business processes are investigated with respect to their transferability to other fields where comparable circumstances prevail. Though not in the initial scope of the research project, the chapter has been included in the thesis to demonstrate that the techniques developed in the previous chapters for the CBP context can be generalised to also be applicable in related fields. Showing their applicability in a wider context is deemed to further the validity of the approach taken in this research.

The field of Grid computing has been adopted for this purpose due to its similarity to business processes. In Grid processes, Grid services (Tuecke *et al.*, 2003) play a role similar to Web services in the field of business processes. Therefore, BPEL also has found its way to application in Grid context for the specification of long-running processes modelled with BPEL invoking Grid services (*e.g.*, Amnuaykanjanasin and Nupairoj 2005; Gannon *et al.*, 2005). Because of its analogy to using BPEL in collaborative business process (CBP) context, trying a transfer of the results on security policy enforcement for remotely defined business processes as presented in the former chapters to a Grid process context was suggesting itself. Therefore, it was tried to transfer the method of defining security policies in terms of security-relevant semantics inherent in BPEL in order to facilitate the assessment of compliance with such policies from the field of business processes to the Grid context. The discussion evaluates the

extent to which this is successful, and where limitations and issues for further study exist.

A further aspect discussed here is the possibility to delegate the task of assessing compliance of BPEL-defined Grid processes with local security policies. An infrastructure supporting the delegation of this task to one or several dedicated nodes in a network or to specific assessment centres has also been introduced for the CBP context (cf. Section 6.3). This possibility may be of even more interest in the Grid context where typically many small to medium size computers are involved, spread over different locations, and not necessarily belonging to a larger organization (as typically encountered in a CBP context) that can afford or provide the effort required for the task of performing the security policy assessment as proposed in this chapter.

8.1 Motivation for Remote Definition of Grid Processes

In order to motivate why remote definition of a BPEL-based Grid process may be sensible, a typical scenario of Grid service execution is considered. In Figure 20, a provider of processing resources is supposed to operate a BPEL-enabled platform. On this platform, Grid processes defined by BPEL scripts are running that invoke Grid services provided by a variety of service providers and offering enhanced Grid services to service requestors in different roles (roles A and B in the example of Figure 20). In a CBP context, availability of BPEL-enabled platforms at every site involved in such a business process could be assumed, since this already is or soon will be common practice in enterprises engaging in CBPs. Therefore, gaining access to a BPEL-enabled

node was not considered a motivation for remotely defining BPEL scripts. Instead, location-dependent access restrictions gave rise to defining business processes displaced from the intended location of execution. In a Grid context, however, the lack of access to a BPEL-enabled platform could very well motivate definition of BPEL scripts for remote execution since not every location having the need for defining Grid processes may be assumed to have local access to a BPEL-enabled platform. In particular, having (local) access to such a platform may not be considered a standard situation in small or medium-sized organizations. Therefore, defining BPEL scripts for remote execution might be an interesting amendment of current state of the art of using BPEL in a Grid context.

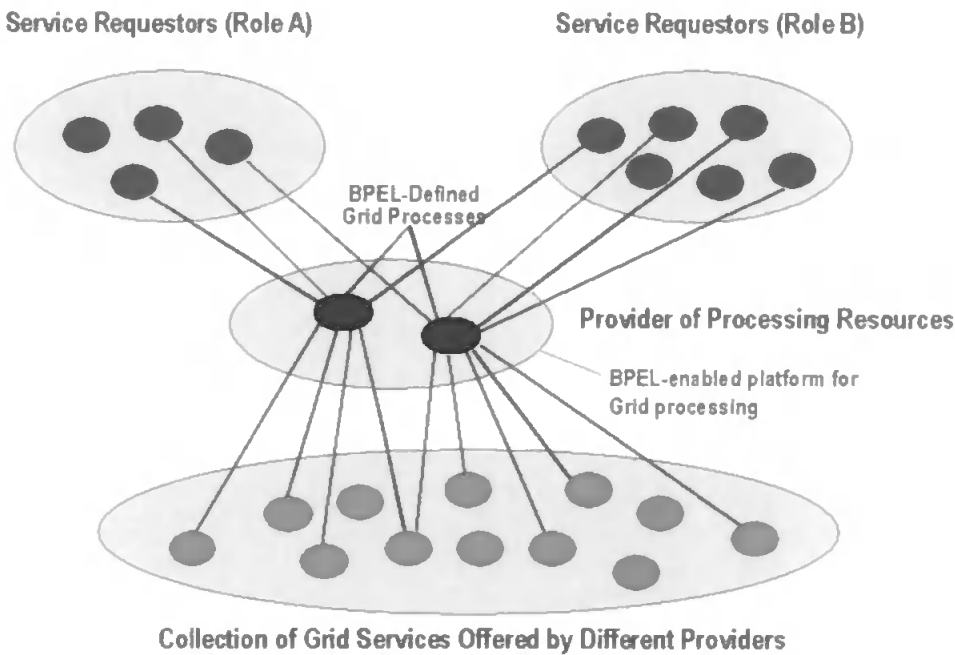


Figure 20: Grid Process Execution Scenario

A further motivation for acceptance of remotely defined BPEL scripts in Grid processing could be the reduction of maintenance overhead that can be gained this way. Consider the situation depicted in Figure 21. Here it is assumed that one particular service requestor in role A, say service requestor A1, would have special requirements differing from the rest of service requestors within role A. These requirements could be accomplished by creating a variant of an existing Grid service on the platform of the Grid processing provider that would, for instance, invoke Grid services differently. As long as only one such variant would be required, the additional maintenance overhead for modifying the existing Grid process and operating the variant for service requestor A1 may be moderate and, therefore, acceptable for the platform operator. However, if an increasing number of service requestors have special requirements that would also lead to variants of existing Grid processes on the platform, the effort for the definition and maintenance of a large amount of variants may no longer be affordable for the platform operator. Therefore, the platform operator could allow that the different service requestors having requirements deviating from the main stream of the service requestors in a particular role (role A in this example) perform the modifications of BPEL scripts on their own and send the modified BPEL script to the Grid processing provider for execution of the Grid process defined by this script. In this way, the effort for the definition of the modified BPEL script and its maintenance in case of changing requirements would be moved to the requestor of the modified Grid service, thereby relieving the platform operator from this effort. As in the CBP context, such definition of BPEL scripts remotely from the location of execution is technically feasible because of the nature of BPEL being a standardised process definition language.

However, in a similar way as with remotely defined BPEL-based business processes, security issues may impede practical application of this approach with BPEL-defined Grid processes. Being able to assess the compliance with local security policies prior to execution would decisively increase the acceptance of remotely defined BPEL scripts for execution, though.

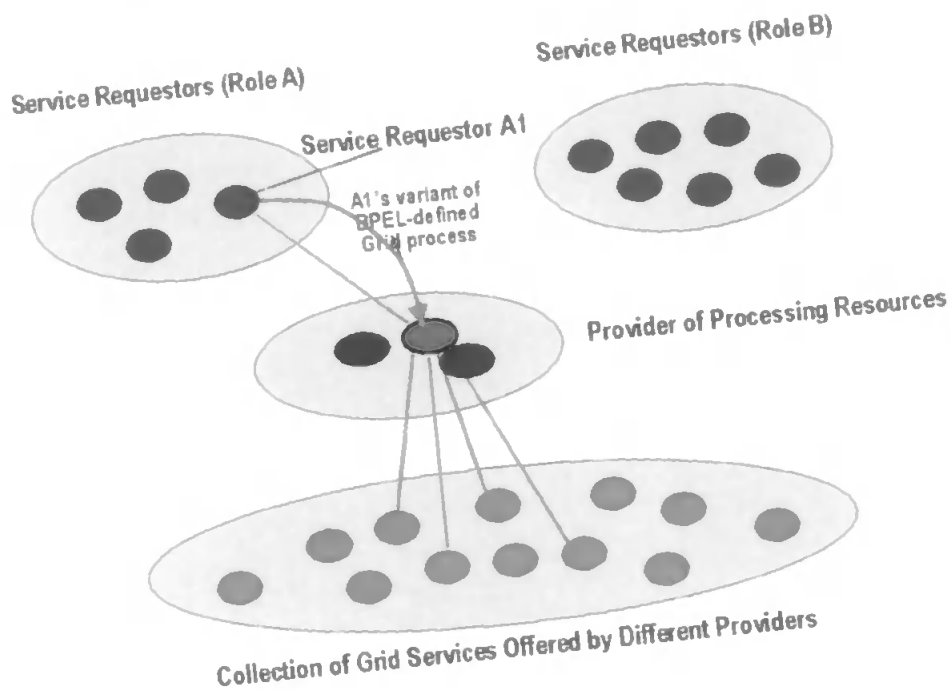


Figure 21: Reducing Maintenance Overhead by Remote Definition of Grid Processes

Making otherwise inaccessible Web services available to a controlling business process while still observing the security policy with respect to non-disclosure of information gained or access to resources granted by invoking such Web services was one motivation for remote definition of business processes in the CBP context. Since the conditions to be observed with respect to access control could be much more diverse in

a Grid context (Chadwick *et al.*, 2006), the investigation of generally granting access to otherwise restricted Grid services as the reason for executing remotely defined BPEL scripts is left to further study.

However, the transfer of the results from the CBP context to the Grid context seems to be most obvious for situations where Grid technology is used for forming virtual organizations (VOs) (Foster *et al.*, 2001). In this context, the number of partners are limited and controlled by regulations for joining a VO, particularly with respect to authentication and authorization. When remotely defined BPEL scripts are used for controlling Grid processes in VOs, there are many analogies to business processes defined by remotely defined BPEL scripts in the CBP context. As with CBPs, local security policies of an organisation offering resources for being used in a VO usually determine access to these resources. These policies will result in restrictions to allowed semantics of remotely defined BPEL scripts that may be accepted for execution from a member of the VO. Such restrictions on allowed semantics may further restrict access to Grid services than access would be restricted by security policies of the sites offering these services alone. Reasons for this could be that allowing invocation of a Grid service in a particular context of a Grid process would violate a security policy such as prevention of generating or relaying mass e-mail from within the domain executing the BPEL script.

Before the transfer of the research results is addressed, a comparison is drawn between the situations in CBP context and Grid context, as summarised in Table 5. With respect to the participants of a CBP or Grid process, the number is small and tends to be

constant over time in the CBP context while in the Grid context this number is larger and tends to vary over time. The number of Web processes possibly involved in a CBP tends to be small whereas the number of potentially involved Grid services may be large. In the CBP context, the location of a Web service matters, that means that it will be differentiated whether a Web service is provided locally in the domain executing the business process or externally either within the domain of the invoker of the business process or in other domains.

Aspect	CPB Context	Grid Context
Participants of a CBP/Grid process	Small in number and tends to be constant over time	Comparatively large in number and tends to vary over time
Number of Web/Grid services potentially involved	Comparatively small	Tends to be high
Location of Web/Grid services	Differentiated between local and external Web service (wrt to executing site)	Location of Grid services tends to be irrelevant
Motivation for remote definition of BPEL scripts	Reduction of coordination overhead (time) when modification of CBP is required	Reduction of maintenance overhead (complexity) when diverging modifications are required
	Allowing controlled access to otherwise inaccessible resources (typically internal services of executing domain)	Increasing flexibility in Grid process specification
		Offering access to BPEL-enabled processing resources
Main focus of security policies	Protection of information and resources against unauthorized disclosure or use	Protection against misuse or excessive use of processing resources (prevention of unreasonable or undue behaviour)

Table 5: Comparison Between CBP Context and Grid Context

The motivation for remote definition of BPEL scripts in the Grid process are the reduction of coordination overhead when modification of the CBP is required, while in the Grid context the reduction of complexity in maintaining lots of diverging modifications for different service requestors may motivate the acceptance or remotely defined Grid processes. Furthermore, allowing access to otherwise inaccessible resources or information in a controlled manner may also motivate remote definition of BPEL scripts in the CBP context whereas in the Grid context increasing the flexibility for Grid process specification and offering access to BPEL-enabled platforms may additionally motivate remote definition of BPEL scripts. The security policies in the CBP context may predominantly be focussed on the protection of information and resources against unauthorised disclosure or use. In contrast, protection against misuse or excessive use of processing resources or, in general, protection of the processing platform offered by a provider against exploitation to perform Grid processes with unreasonable or undue behaviour may amount to the main objective of security policies.

8.2 Approaches to Specification of Grid Service Security

Since security in the Grid context plays a paramount role, much research has been dedicated to this field on Grid computing. In particular, research concerned with expressing security policies in the context of VOs are related to the approach presented herein. Detsch *et al.* (2004), for example, proposed a security architecture for peer-to-peer-based Grid computing where a security layer offering security-related functionality resides between the Grid application layer and the communication infrastructure. In this way, applications do not need to implement such functionality on their own. Security

requirements may be stated by each member of a VO on a peer-by-peer basis or for groups of peers.

Welch *et al.* (2003) have investigated how security functionality can be made available to Grid services, in particular in the context of VOs. A security model for Open Grid Services Architecture (OGSA) (Foster *et al.*, 2002) specifying security services to provide different security functionality is proposed for this purpose. The authors show how security-related specifications from the field of Web services can be used in the context of this security architecture. In their paper, expressing security policies for using a Web service in terms of WS-Policy specifications (Bajaj *et al.*, 2006) and publishing these policies together with the WSDL specification (Chinnici *et al.*, 2006) of the service is also addressed.

It should be noted that security policy expressed in terms of WS-Policy deals with the requirements for security mechanisms to be applied or provided for using a Grid service (such as certificates to be required for accessing a service, or encryption methods to be applied when communicating input and output parameters of a service). In a layered architecture as in Figure 1, these mechanisms are to be provided in layers below the business process layer as already discussed in Section 3.1.4. The security policies expressed in the two approaches above, therefore, address aspects of policies complementary to those that have to be obeyed in the business process layer when remotely defined BPEL scripts are to be executed.

8.3 Security-Relevant Semantic Patterns in BPEL-Based Grid Processes

In order to transfer the results of the analysis of security-relevant semantics of BPEL as a specification language (cf. Chapter 4) to the Grid context, the classes of security policy-induced access restrictions discussed in Section 4.3 (cf. Table 1) are reconsidered here with respect to Grid services (GS) as shown in Table 6.

Compared to Table 1, the term 'Web service' had to be replaced by 'Grid service' throughout Table 6. Apart from that, most descriptions could be transferred otherwise unchanged (classes 1, 2, 4, and 5) or nearly unchanged (class 6). Only the description of class 3 was modified to better fit in the Grid context and a new class 7 was introduced.

While in the CBP context the restriction in class 3 was specified in terms of restricted visibility to targets outside the domain executing a BPEL script, this distinction does not always play an important role in the Grid context. Therefore, the definition of class 3 was abstracted from the location where a target resides to generally express restricted information flow to dedicated targets irrespective of their location. Hence, restrictions will be specified in terms of specific Grid services or particular input parameters thereof that are forbidden to receive the values returned from these parameters. In order, for instance, to prevent a list of e-mail addresses returned by a particular Grid service to be used for generating mass e-mail, this output parameter could be restricted not to be used as input parameter of particular other Grid services known to generate an e-mail to each address passed to it. Obviously, the location of the second Grid service (inside or outside the executing site) does not matter in this case.

Class	Description of Restriction
1	Grid service with unrestricted access to all parts of resources or information offered
2	Grid service with completely restricted access (<i>i.e.</i> , Grid service that are not allowed to be invoked)
3	Output parameter of a Grid service with restricted visibility of values returned with respect to specific targets: information returned by these parameters is not allowed to be carried to specific targets (<i>i.e.</i> , to specific other Grid service or to particular parameters of specific Grid service)
4	Optional input parameter of a Grid service with usage restrictions in two different embodiments: a) optional parameter not allowed to be used b) optional parameter always required
5	Input parameter of a Grid service with constrained set of values allowed: input parameters may only be used with particular values from a subset of the values allowed by the syntactic definition of this parameter
6	Input parameter of a Grid service with values restricted to specific sources: only values from particular origins may be used, for instance, only values returned by a particular Grid service or a specific parameter of a particular Grid service
7	Grid service particularly prone to overload if invoked excessively. For these Grid service, maximum invocation rates or maximum amount of data passed to it to prevent overloading will have to be observed

Table 6: Classification of Access Restrictions to Grid Services and GS Parameters

Primitive Activities		Class 3	Class 4	Cl. 5/6	Class 7
invoke	Invocation of a Grid service	IFA(v)	u	IFA(w/s)	IFA(a)
receive	Waiting for a message to arrive	IFA(v)	–	–	–
reply	Sending a reply to a message received	–	u	IFA(w/s)	–
assign	Assignment of values between two different locations	(relevant in IFA only)			
wait	Waiting for a specified amount of time	time(v)	–	–	–
throw	Indication of exceptions such as failures during execution	except(v)	–	–	–
rethrow*	Forwarding of exceptions causing fault handler execution to containing scope	–	–	–	–
empty	No operation	–	–	–	–
validate	Validate values against type declaration	val(v)	–	–	–
exit	Termination of a process instance	exit(v)	–	–	–
compensate*	Initiate compensation as specified by compensation handlers of corresponding scope and all nesting scopes	–	–	–	–
compensate Scope*	Initiate compensation as specified by compensation handler of a specific scope	scope(v)	–	–	–

u = Observance of restricted use of optional input parameters to Grid service

IFA = Information flow analysis:

- (v) with respect to visibility of values read from Grid service
- (w) with respect to values written to Grid service
- (s) with respect to sources of values written to Grid service
- (a) with respect to amount of data written

Table 7: Security Relevance of Semantic Patterns with Primitive Activities (Grid)

Unlike in the CBP context, where effective runtime mechanisms for prevention of overloading a Web services could be deemed to be in place (in layers below the business layer) at a platform running these services, this might not, in general, be expected from sites running Grid services. Therefore, a security policy of a site accepting remotely defined BPEL scripts in a Grid context could require that a process running on resources of this site shall not cause overload (running the risk to result in an intentional or unintentional denial of service attack) to specific Grid services known to be prone to overload when invoked in a particular manner. Since, in a Grid context, effective runtime prevention of overloading a Grid service shall not be expected to take place at all sites running these services, semantic patterns of BPEL potentially causing such overload have to be identified and looked for in pre-execution compliance assessment to prevent BPEL scripts including such patterns from being executed.

There are two types of overload that may be caused to a Grid service. One type is sending more data in an invocation of a Grid service than can be handled. The other type is invoking a Grid service at a higher rate than this service can cope with. Therefore, performance-related restrictions related to these types of overload may be indicated for a Grid service falling in this new class 7 in the Grid context.

Structured Activities		Class 3	Class 4	Cl. 5/6	Class 7
sequence	Definition of a fixed execution order	–	–	–	FQ
flow	Parallel execution of activities	–	–	–	FQ
if	Branching between several alternate activities depending on conditions	switch cond(v)	–	–	–
while	Iterative execution, <i>i.e.</i> , looping	loop cond(v)	–	–	FQ
repeat Until					
forEach	Iterative consecutive or parallel execution	iteration bounds(v)	–	–	FQ
		preempt(v)			PI
pick	Waiting simultaneously for several events to occur and proceeding with the event that occurs first	IFA(v)	–	–	–
		time(v)	–	–	–

IFA(v) = Information flow analysis with respect to visibility of values read from Grid service

FQ = Invocation frequency to be checked against maximum

PI = Check number of parallel instantiations

Table 8: Security Relevance of Semantic Patterns with Structured Activities (Grid)

The security-relevant semantic patterns again being formed as combinations of BPEL activities with restriction classes of Grid service invocation as in Section 4.4 were adapted from Tables 2 and 3. While all semantic patterns identified there are also relevant in the Grid context and, therefore, could be transferred by simply substituting the term “Grid service” for “Web service”, some new semantic patterns were added as combinations of BPEL activities and the new restriction class 7 in the last column of Tables 7 and 8, respectively. As indicated in this column, attention has to be paid during

compliance assessment to semantic patterns identified there as being capable of generating high invocation frequencies of Grid services. This could be the case when a Grid service is invoked within **while**, **repeatUntil**, **sequence**, **flow**, or **forEach** activities at a high rate or with short intermediate time intervals (marked 'FQ' in Table 8) and by a high amount of parallel instantiations in the parallel version of the **forEach** activities (marked 'PI' in Table 8). Overloading a Grid service could also occur by passing large amount of data to Grid services not designed for coping with such data volumes in **invoke** activities (marked 'IFA(a)' in Table 7). With the exception of the semantic patterns formed with the new restriction class 7 which had been added here, the results of the analysis of security-relevant semantics of BPEL leads to the same results as in the CBP context.

8.4 Rewriting Security Policies to Support Pre-Execution Security Policy Assessment

As in the CBP context, rewriting security policies in terms of security-relevant semantics is also proposed for the Grid process to support compliance assessment of remotely defined BPEL-based business processes with these policies. The concept of an SPS, as introduced in Chapter 5, will also prove useful here to reflect the security policies of a specific domain. In the CBP context, such an SPS was defined domain-specific with respect to two domains, namely the domain where the security policy is in effect (*i.e.*, domain executing BPEL scripts) and the domain defining and sending BPEL scripts for execution. The XML-based schema for specifying an SPS in machine-readable form which has been the basis for implementing the research prototype of an

automatic assessment of BPEL scripts for compliance with security policies has been introduced in Section 7.2.

In the Grid context, since semantic patterns have been modified (definition of restriction class 3) and supplemented (patterns involving new restriction class 7) compared with those found in Section 4.4, the check list as basis of an SPS as well as the XML-based SPS schema for machine-readable versions thereof have to be modified accordingly in order to accommodate this new set of security-relevant semantic patterns.

Unlike in the CBP context, an SPS may not be sensibly defined for a specific foreign domain, since Grid computing is concerned with a potentially large amount of foreign domains that are essentially indistinguishable from the point of view of the domain executing the BPEL-defined Grid processes. However, in a VO environment, when the identities of members and their privileges to execute Grid services are known in advance, defining an SPS similar to the CBP context for each other member in the VO that is allowed to send BPEL scripts for execution could make sense.

Therefore, with the exception of the latter situation, only one or a few SPSs without any relation to a specific external domain will make sense in the Grid context. If more than one SPS will be specified for a domain, they are expected to be differentiated with respect to different application contexts for which they apply (*e.g.*, computational simulation in a particular field, collection of field-specific data such as in meteorology). Although details of application context-dependent SPSs are left to further study, it is

anticipated that such SPSs will be tightly bound to access privileges or roles classifying the sender of a BPEL script.

Specifying security policies in terms of security-relevant semantic patterns identified in Section 8.3 requires an exhaustive list of all Grid services allowed to be invoked by a remotely defined BPEL script. Furthermore, for every Grid service mentioned in this list, the security-relevant semantics of the service and its parameters has to be known in order to determine the access restriction classes appropriate for each of them (cf. Table 6). This requirement may cause additional effort since specification of security-relevant semantics may not be available for Grid services in the first place.

It should be noted that unavailability of semantic specification (at least as far as security-relevant semantics is concerned) may prevent the approach proposed here from being applied. However, unavailability of such specification may also prevent the application of any other pre-execution approach to assessing compliance of Grid processes with security policies. This holds independently of both the location where a Grid process is being defined and executed, and also the manner in which the process is being specified (*i.e.*, independent of using BPEL or any other means for specifying Grid processes). In case of unavailable semantic specifications, the only way of enforcing security policies is monitoring the execution of a Grid process and interfering in cases when violations of security policy have been detected involving the known shortcomings of such approaches mentioned above. And even with approaches based on monitoring it may be required to have some knowledge of the semantics of the Grid services invoked by a Grid process in order to decide whether the invocation of a

particular Grid service would violate any security policy-induced restriction or not. Therefore, also with these approaches, knowledge of the security-relevant semantics of Grid services as required for the assembly of an SPS will be required to a certain extent in order to make them applicable to Grid processes.

Much current research is concerned with describing the semantics of Grid services in order to support identification of matching Grid services for automatic Grid process orchestration (*e.g.*, Lorch *et al.*, 2003; Ren *et al.*, 2006). Bringing the results of this research together with the approach proposed in this chapter in order to define a framework for formally specifying security-relevant semantics of Grid services in terms of well-defined (maybe even standardized) categories is expected to be an interesting field of further study.

A further motivation for research in this direction could be the endeavour to facilitate specification of information flow restrictions of output parameters and value or source restrictions for input parameters with respect to particular characteristics of a Grid service by denoting particular semantics bound to this Grid service instead of particular Grid services themselves. Such semantic characteristics could be “returning lists of e-mail addresses” or “causes sending e-mails to addresses passed”. Means to specify restrictions this way would eliminate the need to analyse every potentially allowed Grid service for falling into a specific restriction class if, in parallel, Grid services and their parameters would have been specified in terms of such characteristics with respect to their (security-relevant) semantics.

If such classification of Grid services would be available, then, for instance, in order to enforce a security policy of avoiding the generation of Spam emails at a Grid node, one could require that any output parameter with the semantic characteristic “returning a (potentially large) list of email addresses” must not be input to any parameter with the characteristic “causes sending e-mails to addresses passed”. Specifying allowed and disallowed semantic patterns with respect to such categories instead of individual Grid services and their parameters obviously would help to shorten the content of an SPS considerably. How far this idea of categorizing Grid parameter semantics for this purpose can be successfully based on or linked with research such as work on semantic Grid services (Goble and De Roure, 2002), semantic matchmaking of Grid service composition (Ludwig and Reyhani, 2005), or workflow ontology of Grid services (Beco *et al.*, 2005) requires further investigation.

Such amendments of addressing semantic characteristics of Grid service parameters in an SPS are expected to involve increased complexity of the assessment task because of required matching of SPS and semantic characteristics of the Grid services actually used in a BPEL script. Even before such amendments are available, it is not obvious and actually will require further investigation whether the assessment of compliance with security policies specified in an SPS is similarly straightforward as it has been shown for the CBP context by implementing the research prototype (cf. Chapter 7). In particular, it is expected that covering semantic patterns involving class 7 restrictions in automatic compliance assessment prior to execution will turn out to be complex or even impossible to a certain extent since this class of restrictions addresses dynamic aspects of a BPEL script that obviously are not easy to be analysed in a static pre-execution

assessment. However, applying the approach to cope with dynamic checking in pre-execution analysis as proposed in Section 5.4 may also help here. For instance, in order to assure that the invocation frequency of a Grid service susceptible to overload by too high an invocation rate, a Grid service could be defined that works like a delay element and this Grid service could be indicated in the SPS as required to be invoked prior to the particular susceptible Grid service.

8.5 Delegation of Security Assessment

As already discussed in Section 6.3, delegation of compliance assessment may be advantageously be applied in distributed environments in the CBP context and may occur in a variety of ways. Delegation of compliance assessment may also be made use of in the Grid context. Actually, it may make even more sense than it already made in the CBP context and additional variants are conceivable.

Assessment can be performed against locally defined SPS (*i.e.*, SPS specified by site executing BPEL script) or against remotely defined SPS (*i.e.*, SPS specified by site defining BPEL script). The latter was not considered to be sensible in the CBP context. Such remotely defined SPS may be sent by the defining site together with the BPEL script as a kind of assertion what the business process defined by the BPEL script is going to do or not to do with respect to security-relevant semantics inherent in BPEL and the business services involved. When this approach is taken, means for checking the correspondence of the SPS and the BPEL script (*i.e.*, SPS belongs to BPEL script and

both are not tampered in any way) may be provided based on appropriate certificates added to both the BPEL script and the SPS.

A remotely defined SPS provided with a BPEL script may be checked against local security policy requirements (*i.e.*, whether indications made in SPS fulfil these requirements or not). After positive assessment of compliance with these requirements, the local site:

- may decide to trust in the assertion provided by the remote site and, after checking integrity and congruence of BPEL script and SPS, execute the BPEL script without any further compliance assessment, or
- may initiate an assessment of compliance in any way mentioned below.

In any of these cases, assessment of compliance with security policies expressed in an SPS may be performed in different ways as follows:

- Locally at the executing site. The potential problem with this approach as already indicated above could be that performing security policy assessment locally might be too elaborate a task to be conducted by small footprint computers (*e.g.*, stand-alone personal computers) or small organisations that cannot afford specific checking tools or acquire specific skill required for this task.

- Remotely (in an assessment centre) on behalf of the site executing the BPEL script. The SPS will be sent together with the BPEL script to the trusted assessment centre for checking compliance of BPEL script and SPS-defined security policies. In case of a centrally defined SPS, a reference to this centrally defined SPS may be sent instead of the SPS itself. The results will be returned to the executing site as certified verdicts (*i.e.*, passed or failed, the latter possibly accompanied by the reason(s) for this verdict).
- (Not applicable for locally defined SPS) Remotely (in an assessment centre) on behalf of the site defining the BPEL script with respect to an SPS defined by the remote site or centrally defined. BPEL script and SPS are sent to the assessment centre as in the previous case. The results of the assessment may be certified by the assessment centre and sent back to the defining site together with the certified (with respect to integrity and identity) BPEL script and SPS. The defining site may then pass the certified BPEL script and SPS to the executing site possibly accompanied by the certified results from the assessment centre. If an assessment centre adheres to a published policy to only certify BPEL scripts and SPSs that received a passed verdict when checked for compliance, then sending the result from the defining site to the executing site can be abandoned since, in this case, having a certificate from such an assessment centre implies the passed verdict for the BPEL script.

From the current point of view, these alternatives for performing security assessment of remotely defined BPEL scripts seem to be versatile enough to cover the requirements in

the Grid context and, therefore, there seems to be no particular need for further research in this area.

8.6 Summary

In this chapter, an approach to transfer the results achieved in this research project for the field of BPEL-defined business processes to another field of application has been presented. Grid processes based on Grid services were chosen for this approach since BPEL is also used for the definition of the process logic in this context. Since the number of participants in a Grid process, as well as the Grid services potentially invoked by such a process may be considerably higher than in a CBP context, the transfer of the results (though to a large extent possible with no or only minor modifications) may render difficult to handle because of the size and amount of SPSs involved. However, the transfer of the results from the CBP context is comparatively easy to be accomplished with respect to VOs, where the number of participants (or at least the number of roles involved) is in the same order of magnitude as with CBPs. Also the admission to become a member of a VO usually is regulated at least to a certain degree such that the members of a VO are comparatively constant over time and known in number. Therefore, VOs are commensurable with the situation in CBPs and best suited for transfer of research results from the CBP context. Transfer of the results from the CBP context to other areas of Grid computing may be for further study.

Further research, in particular with respect to an alignment of this research on security relevance of BPEL with results of research on Grid service semantics, may help to

reduce the amount of information to be handled and may also prove successful in specifying restrictions indicated in an SPS at higher levels of abstraction. Advancing research in this direction was beyond the scope of the current project.

The results of the attempt to transfer the achievements of the research project from the field of collaborative business processes to the field of Grid processing have been published in Fischer *et al.* (2007d).

9 CONCLUSIONS AND DIRECTIONS OF FURTHER RESEARCH

To conclude the thesis, this chapter summarises the achievements and limitations of the research. It also considers possible directions of further research based on the results of this project.

9.1 Achievements of the Research

The increasing need for business-to-business applications has led to the specification of collaborative business processes (CBPs) using standardised specification languages. The de facto standard for this purpose is WS-BPEL (BPEL for short) that has been adopted as an OASIS standard in April 2007. Making full use of the fact that BPEL is a standard for specifying business processes and, therefore, allows for definition of processes in a platform-independent way motivates the approach to specify a CBP at one location and have the different parts constituting this CBP executed on BPEL-enabled platforms of the respective partners involved in the CBP. Though technically feasible because BPEL-defined business processes are executable on any such platform, security issues involved in the execution of remotely defined business processes stand in the way of turning this approach into practical application. To mitigate or even eliminate these security issues, the research project aimed to develop methods for assessing the compliance of remotely defined business processes with local security policies prior to their execution. This assessment should preferably be performed automatically with as little as possible human intervention. Being able to have a remotely defined business process assessed for compliance with local security policies

in an automatic way should allow for execution of the business process without security concerns.

In order to find methods that support compliance assessment in the manner aimed for in this research, the security-relevant behaviour expressible in BPEL scripts has been investigated. The results of this investigation have been presented in Chapter 4. Based on an analysis and classification of security policy-induced restrictions to Web service invocation, combinations of restriction classes with BPEL activities called semantic patterns have been analysed for their potential impact related to compliance with security policies. Checkings required for verifying whether a BPEL script specifies behaviour that would violate security policies have also been indicated in Chapter 4.

Based on the identification of security-relevant semantics of BPEL, a method for specifying security policies in such a way that the assessment of compliance with these policies is essentially facilitated has been introduced in Chapter 5. To this purpose, so-called security policy statements (SPSs) are used that indicate security policy-induced restrictions to Web services that are allowed to be invoked by a remotely defined business process. An approach to possibly reduce the complexity of an SPS is also introduced in this chapter, as well as an approach to cope with dynamic aspects of security policy-induced restrictions that by their very nature may only be checked at runtime of the process defined by a script.

The procedure of compliance assessment resulting from and enabled by these preparations is described in Chapter 6. How a BPEL script under consideration is

examined in order to assess its compliance with security policies as indicated in an SPS was described there. Further, the workflows involved when the assessment is performed in a distributed environment have been considered in order to discuss possibilities for delegation of the assessment procedure for economising the efforts required.

The viability of the methods for automatic performance of compliance assessment in the way proposed has been proved by implementing the essential parts of the assessment procedure in a research prototype. Chapter 7 describes the machine-readable version of SPSs used and the architecture and algorithms implemented in this prototype. It further discusses the coverage of the total functionality required for automatic compliance assessment that has been achieved by this implementation. The discussion comes to the conclusion that the essential functionality of automatic compliance assessment has been implemented and that the missing parts are deducible in an easy manner from the functionality already realised or are straightforward to implement such that no templates are required to validate their feasibility. The evaluation performed led to the result that the methods proposed are suitable for automatic compliance assessment of BPEL scripts.

To further complement the achievements reached so far, the result of the research project have been transferred to another field of application where similar conditions as with CBPs exist. The field chosen is the area of Grid processes that can also be defined by BPEL scripts. The extent to which this transfer was successful within the given time scale of the project is discussed in Chapter 8. Most of the results could be transferred in a straightforward manner to the area of Grid processing when virtual organisations

(VOs) are considered. However, new semantic patterns not considered in the context of CBPs had to be taken into account in the context of Grid processing. Obvious limitations mainly resulting from the larger amount of partners involved and of Grid services eligible for invocation in a BPEL script defining a Grid process give rise to further research in this area, but are not detrimental to the achievements reached with respect to the objectives of the research project because Grid processing was not in the initial scope of this research. However, having shown that the results are transferable in principal to a related field of application is deemed to increase their significance.

Several papers referring to different aspects of the results achieved in this research project have been presented at refereed conferences or published in journals (cf. Appendix A.1) and have received positive comments from delegates and reviewers.

9.2 Limitations of the Research

Despite having met the objectives of the research project, some decisions had to be taken that resulted in limitations imposed on the work. The decisions were caused by practical reasons, or to limit the effort spent in areas where no new insights could be expected. These limitations are summarised below.

1. The research prototype was restricted to only implement as much functionality of the assessment procedure as required to prove that the approach taken for facilitating compliance assessment was viable and that the methods developed were actually suited for automatic performance of this assessment. Therefore,

the prototype does not cover all language features provided by the BPEL standard and, hence, is not suited to check arbitrary BPEL scripts for compliance with security policies. However, the XML schema provided for SPSs is complete in the sense that any security policy-induced restriction to Web service invocation as discussed in Chapter 4 may be specified. The reason for restricting the range of functionality implemented in the prototype was to limit the effort spent for software development which as such was not in the scope of the research. Implementing the missing parts to cover all of the BPEL capabilities would have caused a lot of additional effort to be spent without contributing new insights with respect to feasibility of an automatic compliance assessment procedure.

2. The algorithms used for covert channel detection in the prototype have been chosen to take a rigorous approach for effective prevention of any covert channel from being established. However, these algorithms could turn out to be overly strict in some situations, for instance, when a branch is made dependent on a visibility-restricted information and all alternative flows to be selected would not exhibit any distinguishable behaviour observable from outside. In such a situation, no covert channel would have been established by making the branch dependent on a visibility-restricted unit of information, but nevertheless a BPEL script containing this logic would have been refused by the prototypic compliance assessment procedure. Finding more sophisticated algorithms for covert channel detection that would be able to distinguish between actual covert channels and behaviour that only exhibits *prima facie* characteristics of a covert

channel without actually establishing one have not deemed to be essential for a proof of concept. As already stated above, the definition of such algorithms that are both more tolerant with respect to covert channel detection and still secure in the sense that they do not leave any covert channel undetected may be difficult. Leaving decisions on doubtful behaviour possibly not suited to establish a covert channel to human intervention may also be a viable approach in cases where the rigorous approach for covert channel prevention implemented in the research prototype is found to be overly strict.

3. Similar to the previous item, restricting any inclusion of data manipulation facilities from other XML specifications such as Xpath in a BPEL script in order to be acceptable as compliant may also be deemed to be overly strict under certain circumstances. However, relaxation of this restriction without taking the risk to miss possible security policy violations during compliance assessment could also turn out to be a difficult task. In the same way as described for reduction of the complexity of security policy statements in Section 5.3, also any need for data manipulation in accordance with security policy that would require elements from Xpath or other XML specifications to be included in a BPEL script can be moved into a Web service defined for that purpose. Therefore, this limitation is also not considered essential for the approach proposed.
4. Trying to integrate the prototypic implementation of a compliance assessment procedure into a BPEL-enabled platform though initially envisaged has been dropped. Reason for this was that access to such a platform for development

purposes was not easy to obtain and this task would have required a tremendous amount of platform-specific know how to be acquired before the actual work would be possible. After all, this integration would by no means have contributed any particular insight or increased the confidence of viability. In effect, the proposed approach does not require that an automatic assessment procedure is integrated into the platform where the BPEL script under consideration is intended to be executed once compliance assessment has been passed. In contrast, a stand-alone implementation of the assessment procedure serves even better the intended goal to prevent a non-compliant BPEL script to be executed since it in fact prevents such a script from entering the executing platform at all.

5. Since the research has been limited to only investigate BPEL as the most prominent representative of a standardised business process definition language (BPD), when it became obvious that BPEL had emerged the de facto standard in this field, the attempt to transfer the approach proposed in this research to other BPDs could be the objective of further research. However, probably before starting such research, additional evidence should be obtained that the use of these other BPDs has gained sufficient momentum to justify the dedication of research efforts to the particular BPD chosen for such a transfer.

Despite these limitations, the research project has led to valid contributions to knowledge and provided sufficient proof of concept for the approaches proposed.

9.3 Directions of Further Research

The research project has advanced the field of security policy enforcement for script-based business processes. However, a number of areas for future work can be identified that build upon the results achieved. Some ideas have already been addressed in former chapters. These areas and some new ones are detailed below.

1. Though already discussed as potentially difficult to find, the development of more sophisticated algorithms for covert channel detection in order to get rid of the rigorous yet effective approach taken in the research prototype could be undertaken. The directions to be taken in an endeavour to relax this rigorous restriction have been indicated in the previous section. An outline of an algorithm for the relaxation of the restriction with respect to visibility-restricted information imposed to the **validate** activity and the attribute **validate** with a value of **true** in an **assign** activity can be found in Appendix A.3.
2. Additional effort could be spent for completion of the prototypic implementation of the compliance assessment procedure. Though no new insights are expected to be gained thereof as argued above, having an implementation covering the whole of the capabilities provided by BPEL can be used for application to real world examples of BPEL scripts. This could assist in propagation of the ideas developed in this project to a broader audience beyond academia.
3. In the attempt to transfer the results from the CBP context to the Grid context, several issues for further research have been encountered. Amongst them the

classification of (security-relevant) semantics of Grid services and their parameters is deemed to be, at the same time, the most challenging and the most promising field for further study. Having such a classification of Grid service semantics could advantageously be applied to reduce the amount of indications required in an SPS since enumeration of all Grid services allowed for invocation in a BPEL script would no longer be required. In contrast, only the allowed Grid service semantics would have to be indicated in an SPS. This approach would allow for compliance assessment of BPEL scripts invoking arbitrary Grid services provided the semantics of the Grid services would also be specified in terms of the semantic classification scheme developed.

4. Investigating how the approaches proposed in Chapter 8 could be applied based on Grid environments or Grid middleware such as The Globus Toolkit (2007) or OurGrid (2007) and which adaptation would be required in order to be successful in doing this could be another interesting direction of further research.

APPENDICES

A.1. Published Papers

In this appendix, the papers published in the context of this research project are listed together with their abstracts. Copies of selected full papers as published are provided following the References.

1. Fischer, K. P., Bleimann, U., Fuhrmann, W., and Furnell, S. M. (2005) "A Security Infrastructure for Cross-Domain Deployment of Script-Based Business Processes in SOC Environments". In *Proceedings of the 5th International Network Conference, INC'2005*, pp. 207–216, 2005.

Abstract: *This paper addresses security aspects arising in service oriented computing (SOC) when scripts written in a standardized scripting language such as WS-BPEL (formerly: BPEL4WS or BPEL for short), BPML, XPDL, WSCI in order to implement business processes on top of Web services are deployed across security domain boundaries. It proposes an infrastructure and methods for checking the scripts deployed, prior to execution, for compliance with security policies effective at the domain in which a remotely developed script-based business process is to be executed.*

2. Fischer, K. P., Bleimann, U., Fuhrmann, W., and Furnell, S. M. (2006) "Security-Relevant Semantic Patterns of BPEL in Cross-Organisational Business Processes". In *Proceedings of the 6th International Network Conference, INC'2006*, pp. 203–212, 2006.

Abstract: *This paper presents results of the analysis of security-relevant semantics of business processes being defined by WS-BPEL (Web Services Business Process Execution Language, BPEL for short) scripts. In particular, security issues arising when such scripts defining cross-organisational business processes on top of Web services are deployed across security domain boundaries, give rise to this investigation. The analysis of security-relevant semantics of this scripting language will help to overcome these security issues making further exploitation of BPEL as a standard for defining cross-organisational business processes more acceptable. Semantic patterns being combinations of particular language features and Web services with specific access restrictions implied by security policies are defined and analysed for this purpose. Applications of the results of this analysis to distributed definition and*

execution of BPEL-defined business processes may be found in a previous paper of the authors.

3. Fischer, K. P., Bleimann, U., Fuhrmann, W., and Furnell, S.M. (2007a) "Security Policy Enforcement in BPEL-Defined Collaborative Business Processes". In *Proceedings of the 1st International Workshop on Security Technologies for Next Generation Collaborative Business Applications (SECOBAP'07)*, IEEE Computer Society, pp. 685–694, 2007.

Abstract: *This paper presents an approach to security policy enforcement with collaborative business processes defined using BPEL and deployed across enterprise domain boundaries for execution. The assessment of compliance with security policies at the location where a BPEL script is to be executed is facilitated by re-formulating the security policies with respect to the potential of violation inherent in BPEL. The results of an analysis of the security-relevant semantics of BPEL-defined business processes conducted for this purpose indicate the paramount role of information flow analysis in business processes. Based on these results, the paper proposes an XML-based schema for specifying security policies for cross-organisational business processes that allows for automatic checking of BPEL scripts for compliance to these security policies. The paper also introduces a prototype implementation of an automatic compliance check that approves the feasibility of the method for practical application in security policy enforcement.*

4. Fischer, K. P., Bleimann, U., Fuhrmann, W., and Furnell, S.M. (2007b) "Analysis of Security-Relevant Semantics of BPEL in Cross-Domain Defined Business Processes". *Information Management & Computer Security*, 15(2):116–127, 2007

Abstract:

Purpose – *Aims to identify security-relevant semantics of business processes being defined by WS-BPEL (Web Services Business Process Execution Language, BPEL for short) scripts, in particular, when such scripts defining collaborative business processes on top of Web services are deployed across security domain boundaries.*

Design/methodology/approach – *Analysing potential of BPEL to define behaviour of business processes violating restrictions implied by security policies.*

Findings – *Semantic patterns being combinations of particular BPEL features and Web services with specific access restrictions implied by security policies are defined and their implications for analysis of BPEL scripts during compliance assessment of cross-domain defined business processes are identified.*

Research limitations/implications – *The results of the research part of which are reported here have been applied in a research prototype to BPEL scripts of*

limited size and comparatively simple business logic. Real-world examples of BPEL scripts with respect to size and complexity should be examined for further approving suitability of the algorithms used.

Originality/value – *The results can be used to specify security policies in terms of security-critical semantics of BPEL scripts in order to facilitate compliance assessment. In conjunction with other results of this research, this will help to overcome security issues arising from cross-domain definition of business processes by enabling automatic compliance assessment prior to execution.*

5. Fischer, K. P., Bleimann, U., Fuhrmann, W., and Furnell, S.M. (2007c) "Security-Relevance of Semantic Patterns in Cross-Organisational Business Processes Using WS-BPEL". In *Proceedings of the 3rd Collaborative Research Symposium on Security, E-learning, Internet and Networking (SEIN 2007)*, University of Plymouth, pp. 67–83, 2007.

Abstract: *This paper gives an overview of the research project considering security aspects in the context of business process management. In particular, security issues arising when scripts written in the standardized scripting language WS-BPEL (formerly: BPEL4WS or BPEL for short) implementing cross-organisational business processes on top of Web services are deployed across security domain boundaries, are being investigated. It analyses the security-relevant semantics of this scripting language in order to facilitate checking for compliance with security policies effective at the domain of execution.*

6. Fischer, K. P., Bleimann, U., and Furnell, S.M. (2007d) „Pre-Execution Security Policy Assessment of Remotely Defined BPEL-Based Grid Processes“. In *Proceedings of 4th International Conference on Trust, Privacy & Security in Digital Business (TrustBus'07)*, Springer, LNCS 4657, pp. 178–189, 2007.

Abstract: *In this paper, results from research on security policy enforcement for cross-domain defined business processes specified in BPEL are transferred to the field of Grid computing, where BPEL is used to define Grid processes. In order to facilitate the assessment of remotely defined BPEL-based Grid processes for compliance with security policies prior to execution, a method for specifying security policies with respect to security-relevant semantic patterns in BPEL is applied. The paper shows the extent to which transfer of the former results was successful and indicates limitations and areas of further research. Where the situation is similar to cooperative business processes, such as in forming dynamic virtual organizations using Grid technology, the results turned out to be transferable with minor modifications, whereas for a transfer to the Grid context in general further investigation is required (in particular with respect to formal specification of security-relevant semantics of Grid services).*

A.2. XML Schema for Security Policy Statement

This appendix contains an XML Schema specification for the security policy statement proforma introduced in Chapter 5 that has been transferred into a machine-processible XML-based form for the research prototype as set out in Chapter 7. The meaning of the elements and attributes defined in this schema have been explained in Chapter 7. Therefore, they are not annotated in this schema definition.

```
<?xml version="1.0"?>

<xsd:schema
  xmlns:xsd="http://www.w3.org/2001/XMLSchema"
  xmlns="http://www.example.org/sps/SPS_Schema.xml"
  elementFormDefault="qualified"
  attributeFormDefault="unqualified"
  targetNamespace="http://www.example.org/sps/SPS_Schema.xml">

  <xsd:element name="sps">
    <xsd:complexType>
      <xsd:sequence>
        <xsd:element ref="identifications"/>
        <xsd:element ref="iwsrs" minOccurs="0"/>
        <xsd:element ref="ewsrs" minOccurs="0"/>
        <xsd:element ref="unrestrIntWs" minOccurs="0"/>
        <xsd:element ref="unrestrExtWs" minOccurs="0"/>
      </xsd:sequence>
    </xsd:complexType>
  </xsd:element>

  <!-- ++++++ -->
  <!-- ++++++ identifications ++++++ -->
  <!-- ++++++ -->

  <xsd:element name="identifications">
    <xsd:complexType>
      <xsd:attribute name="remoteDomain" type="xsd:anyURI"
        use="required"/>
      <xsd:attribute name="localDomain" type="xsd:anyURI"
        use="required"/>
      <xsd:attribute name="applicationContext" type="xsd:anyURI"
        use="optional"/>
    </xsd:complexType>
  </xsd:element>
```

```

<!-- ++++++ restricted WS ++++++ -->
<!-- ++++++ external WS ++++++ -->

<!-- ++++++ external WS ++++++ -->
<xsd:element name="ewsrs">
  <xsd:complexType>
    <xsd:sequence>
      <xsd:element ref="operation" minOccurs="1"
        maxOccurs="unbounded"/>
    </xsd:sequence>
    <xsd:attribute name="internalUseAllowed" type="xsd:boolean"
      use="optional" default="true"/>
    </xsd:complexType>
  </xsd:element>

  <!-- ++++++ internal WS ++++++ -->
  <xsd:element name="iwsrs"/>
  <xsd:complexType>
    <xsd:sequence>
      <xsd:element ref="operation" minOccurs="1"
        maxOccurs="unbounded"/>
    </xsd:sequence>
  </xsd:complexType>
</xsd:element>

  <!-- ++++++ operation ++++++ -->
  <xsd:element name="operation">
    <xsd:complexType>
      <xsd:sequence>
        <xsd:element ref="input" minOccurs="0" maxOccurs="1"/>
        <xsd:element ref="output" minOccurs="0" maxOccurs="1"/>
      </xsd:sequence>
      <xsd:attribute name="name" type="xsd:string" use="required"/>
      <xsd:attribute name="portType" type="xsd:string"
        use="required"/>
    </xsd:complexType>
  </xsd:element>

  <!-- ++++++ input ++++++ -->
  <xsd:element name="input">
    <xsd:complexType>
      <xsd:sequence>
        <xsd:element ref="sourceRestriction" minOccurs="0"
          maxOccurs="1"/>
        <xsd:element name="part" minOccurs="0"
          maxOccurs="unbounded">
          <xsd:complexType>
            <xsd:sequence>
              <xsd:element ref="sourceRestriction" minOccurs="0"/>
              <xsd:element ref="valueRestriction" minOccurs="0"/>
            </xsd:sequence>
          </xsd:complexType>
        </xsd:element>
      </xsd:sequence>
    </xsd:complexType>
  </xsd:element>

```

```

    <xsd:attribute name="name" type="xsd:string"
        use="required"/>
    <xsd:attribute name="sourceRestricted" type="xsd:boolean"
        use="optional" default="false"/>
    <xsd:attribute name="valueRestricted" type="xsd:boolean"
        use="optional" default="false"/>
    <xsd:attribute name="restrictedOptional" use="optional"
        default="presentOrNot">
        <xsd:simpleType>
            <xsd:restriction base="xsd:string"
                <xsd:enumeration value="presentOrNot"/>
                <xsd:enumeration value="forbiddenPart"/>
                <xsd:enumeration value="requiredPart"/>
            </xsd:restriction>
        </xsd:simpleType>
    </xsd:attribute>
</xsd:complexType>
</xsd:sequence>
<xsd:attribute name="message" type="xsd:string"/>
<xsd:attribute name="sourceRestricted" type="xsd:boolean"
    use="optional" default="false"/>
</xsd:complexType>
</xsd:element>

```

```

<xsd:element name="sourceRestriction">
    <xsd:complexType>
        <xsd:sequence>
            <xsd:element ref="service"
                minOccurs="1" maxOccurs="unbounded"/>
        </xsd:sequence>
    </xsd:complexType>
</xsd:element>

```

```

<xsd:element name="valueRestriction">
    <xsd:complexType>
        <xsd:sequence>
            <xsd:element name="permittedValue" type="anyType"
                minOccurs="1" maxOccurs="unbounded"/>
        </xsd:sequence>
    </xsd:complexType>
</xsd:element>

```

```

<xsd:element name="service">
    <xsd:complexType>
        <xsd:attribute name="portType" type="xsd:string"/>
        <xsd:attribute name="operation" type="xsd:string"/>
    </xsd:complexType>
</xsd:element>

```

```

<!-- ++++++ output ++++++ -->
<xsd:element name="output">
  <xsd:complexType>
    <xsd:sequence>
      <xsd:element ref="targetRelaxation" minOccurs="0"/>
      <xsd:element name="part"
        minOccurs="0" maxOccurs="unbounded">
        <xsd:complexType>
          <xsd:sequence>
            <xsd:element ref="targetRelaxation" minOccurs="0"/>
          </xsd:sequence>
          <xsd:attribute name="name" type="xsd:string"
            use="required"/>
          <xsd:attribute name="visibilityRestricted"
            type="xsd:boolean" use="optional" default="true"/>
        </xsd:complexType>
      </xsd:sequence>
      <xsd:attribute name="message" type="xsd:string"/>
      <xsd:attribute name="visibilityRestricted" type="xsd:boolean"
        use="optional" default="false"/>
    </xsd:complexType>
  </xsd:element>

<xsd:element name="targetRelaxation">
  <xsd:complexType>
    <xsd:sequence>
      <xsd:element name="domain" type="xsd:anyURI"
        minOccurs="1" maxOccurs="unbounded"/>
    </xsd:sequence>
  </xsd:complexType>
</xsd:element>

<!-- ++++++ unrestricted WS ++++++ -->
<!-- ++++++ -->

<xsd:element name="unrestrExtWs">
  <xsd:complexType>
    <xsd:sequence>
      <xsd:element name="operation"
        minOccurs="1" maxOccurs="unbounded">
        <xsd:complexType>
          <xsd:attribute name="name" type="xsd:string"
            use="required"/>
          <xsd:attribute name="portType" type="xsd:string"
            use="required"/>
        </xsd:complexType>
      </xsd:element>
    </xsd:sequence>
  </xsd:complexType>
</xsd:element>

```



```
<xsd:element name="unrestrIntWs">
  <xsd:sequence>
    <xsd:element name="operation" minOccurs="1"
      maxOccurs="unbounded">
      <xsd:complexType>
        <xsd:attribute name="name" type="xsd:string"
          use="required"/>
        <xsd:attribute name="portType" type="xsd:string"
          use="required"/>
      </xsd:complexType>
    </xsd:element>
  </xsd:sequence>
</xsd:element>

</xsd:schema>
```

A.3. Outline of Sophisticated Covert Channel Prevention for Activity **validate**

In order to allow for type validation of a variable containing visibility-restricted information in cases when no risk of information leakage exists, it has to be made sure that throwing the standard **bpel:invalidVariables** fault does not allow conclusions to be drawn as to the value of the information currently contained in this variable. Validation with respect to the proper type of the value contained in a variable may either be caused by a **validate** activity or by indication of attribute **validate="true"** in an **assign** activity. A more sophisticated check for covert channel prevention with type validation than that proposed in the main part of the thesis would require to assure that no value restricted subtype of a type is being applied in validation.

Therefore, the more sophisticated check for covert channel detection with type validation would allow a variable containing visibility-restricted information to be validated provided its type definition does not imply any restrictions with respect to the value of this variable. This can be checked by inspection of the message type in a WSDL definition or the type definition in an XML schema containing the type definition for the variable under consideration. The XML type definition found for the particular variable must neither contain any **<restriction>** element nor must the type be defined by a **<list>** element nor by a **<union>** element containing any type definition constrained by any of the aforementioned elements.

If the type can be verified in this way to not implying any value range restrictions for the variable under consideration, then type validation may be allowed even in the case where the variable currently contains a value that represents visibility-restricted information.

A.4. Java Code of Research Prototype

The Java code of the research prototype is included on the CD-ROM in the addendum to this PhD thesis. The Java code may be found there in the subtree under directory **prototype/java**.

A.5. Examples of BPEL Scripts Used for Validation of Research Prototype

The BPEL examples used for the validation of the research prototype are included on the CD-ROM in the addendum to this PhD thesis. The examples may be found there in the subtree under directory **prototype/validation**.

A.6. Copies of Web Pages Referred in Section References

For convenience of the reader, copies of the Web pages referred to in this PhD thesis have been provided on the CD-ROM in the addendum to this PhD thesis. The copies may be found there in the subtree under directory **webpages**.

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A Security Infrastructure for Cross-Domain Deployment of Script-Based Business Processes in SOC Environments

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Abstract

This paper addresses security aspects arising in service oriented computing (SOC) when scripts written in a standardized scripting language such as WS-BPEL (formerly: BPEL4WS or BPEL for short), BPML, XPD, WSCI in order to implement business processes on top of Web services are deployed across security domain boundaries. It proposes an infrastructure and methods for checking the scripts deployed, prior to execution, for compliance with security policies effective at the domain in which a remotely developed script-based business process is to be executed.

Keywords

Security Policy, Policy Enforcement, Service Oriented Computing (SOC), Service Oriented Architecture (SOA), Business Process Management, Web Services, Web Services Business Process Execution Language (WS-BPEL)

1. Introduction

Service oriented computing (SOC) is currently considered one of the most promising new paradigms for distributed computing (Papazoglou and Georgakopoulos 2003). Though comparatively new, a significant amount of research has already been dedicated to this area (e.g. Deubler et al. 2004). Web services, and the composition or orchestration of them, play a central role in current approaches to service oriented computing (Berardi et al. 2003). Service orientation is also expected to have an important influence in the area of grid computing, where the provisioning of computing resources within a conceptual huge network of collaborating computers and devices can also be fostered by services (so called grid services in this context) provided by different nodes (Tuecke et al. 2003).

In service oriented approaches using Web services a layered architecture for composing new services from existing services or for executing processes based on existing services has emerged (Medjahed et al. 2003). The request for fast adaptation of enhanced services and processes to changing requirements as well as the request to avoid dependency on certain platforms (vendor lock-in) lead to the specification of platform independent, standardized process definition languages for the definition of enhanced Web services or business processes in the top layer of this architecture. However, several different standardization approaches for such a language have been taken, leading to a plurality of standards: Web Services Business Process Execution Language (WS-BPEL), formerly known as Business Process Execution Language for Web Services (BPEL4WS or BPEL for short) (Arkin et al. 2004), Business Process Modelling Language (BPML) (Arkin 2002), XML Process Definition Language (XPDL) (Workflow Management Coalition 2002), Web Services Choreography Interface (WSCI)

(Arkin et al. 2002), and ebXML Business Process Specification Schema (Malu et al. 2002). Though the existence of several parallel standards aiming at the same goal detracts from the very purpose of standardization, the different standards at least have some obvious commonalities, as all languages are script based using XML and facilitate the composition of business processes by invocation of Web services and definition of the communication with other parties (in particular human participants) involved in a business process. It should be noted that a business process defined using one of these languages can itself be considered a Web service from the point of view of external communication parties.

The existence of several business process languages gave rise to research as to which extent these languages are comparable with respect to their semantic expressiveness (Aalst et al. 2002, Shapiro 2002, Wohed et al. 2002). In particular Aalst et al. (2002) and Wohed et al. (2002) analysed different languages, i.e. WS-BPEL, BPML, WSCI and some vendor-specific business process languages, with respect to workflow and communication patterns. The results of their work indicate that, to a large extent, the different languages are capable of expressing the same semantics with respect to workflow control and communication behaviour. As a result these languages could be expected to be convertible to each other as has already been shown in an exemplary manner for XPDL and WS-BPEL by Fischer and Wenzel (2004). Given the fundamental similarity of the different languages used for business process management, without loss of generality we will concentrate our proposition on one particular representative, namely WS-BPEL propagated by the Organization for the Advancement of Structured Information Standards (OASIS). For the remainder of this paper we will use BPEL as a shorthand for WS-BPEL.

2. Security Issue in Cross-Domain Business Process Definition

As security already is an important issue in distributed applications in general, this topic is also of paramount importance for the application of business process languages. Security of Web services is well studied and several approaches for access control to Web services exist (e.g. Nadalin et al. 2004, Abendroth and Jensen 2003, Dimmock et al. 2004). Koshutanski and Massacci (2003) and Mendling et al. (2004) are considering security aspects in the context of employing business process languages, in particular BPEL. While access control related aspects are predominant with Web services and are, of course, also an issue with business process languages, further security aspects arise from the employment of standardized script languages such as BPEL. From their nature of being standardized and platform-independent, these languages involve the capability of defining business processes across platforms. Use of this capability introduces new security issues that have not been present in Web services before the business process languages came in. By employing standardized business process languages it will be feasible to define a business process at one location and execute it at a different location. It is conceivable that the two locations belong to different security domains within the same or different organisations or corporations. The new security issue arising from this approach leads to, but is not limited to, the following questions:

- Are the semantics of a remotely defined business process or enhanced Web service compatible with the security policy effective at the node where it is to be executed?
- Which classification, with respect to access control, is required for the Web service offered by the remotely defined business process or enhanced Web service in order to be compliant with the security policy in the domain the executing node belongs to?

While the second question again arises in the context of access control, albeit from a different point of view to that which usual access control approaches address, the first point addresses a completely new security issue, that, by its nature, had not needed to be considered in the context of Web services as it is not relevant with their basic incarnation.

In this paper we propose an infrastructure and a methodology for coping with the first one of these novel security aspects arising from the employment of standardized business process languages. We consider semantic aspects of the business processes defined by their respective scripts. The methodology proposed makes use of the fact, that business process languages offer little or no means for defining data processing or computational tasks as part of the language itself, but rather have to invoke Web services for these purposes or must import constructs from other XML standards such as Xpath (Berglund et al. 2004).

3. Infrastructure for Distributed Development and Execution of Business Processes: An Example

In an SOC environment we consider the situation where the task of defining business processes and enhanced Web services using BPEL is concentrated at a particular node and distributed to other nodes for deployment and execution.

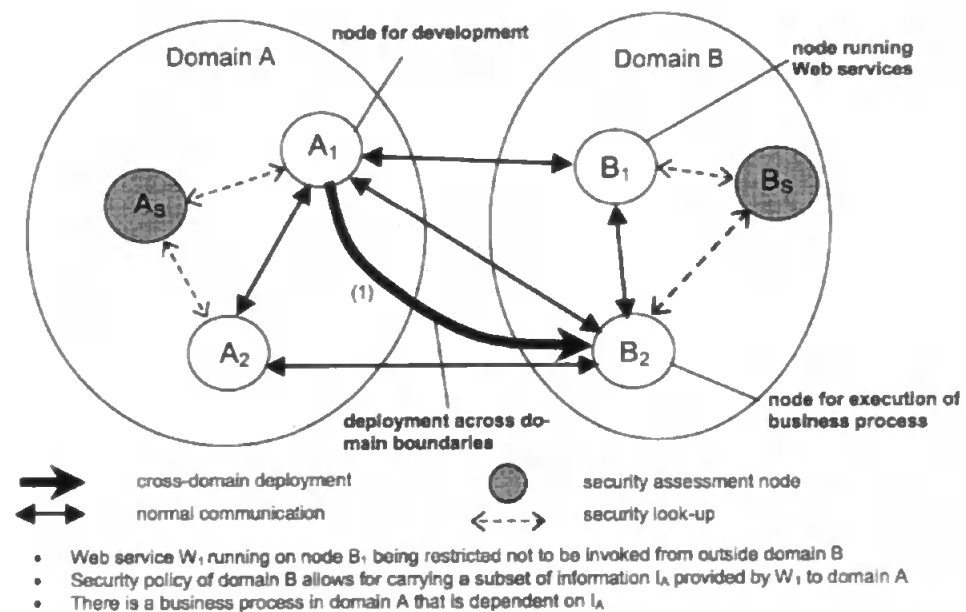


Figure 1 - Distributed Development and Execution of Business Processes in SOA

Figure 1 illustrates an exemplary environment for the distributed development and execution of a BPEL script with six nodes residing in two different domains A and B. We further suppose that each node depicted in Figure 1 is capable of running BPEL-defined processes.

We consider the case where in domain A there is a need for a business process, e.g. in a supply chain application, requiring information I_A offered by a Web service W_1 at node B_1 . However, because of restrictions imposed by security policies in domain B this information cannot be accessed directly from outside domain B. For solving this conflict with security policy restrictions, a conventional approach would be the provision of an enhanced Web service in domain B, say W_2 at node B_2 . W_2 would access the information required from Web service W_1 and offer the non-restricted part of the results, i.e. I_A , to nodes in domain A across domain boundaries. While it would be possible not to use any business process language for this purpose, we assume that W_2 is defined by a BPEL script S_2 .

Since the need for the particular business process in this example arose in domain A, there is some probability that also requests for changes to this business process will arise in this domain. In order to circumvent the requirement that requests for change arising in domain A must be presented to developers in domain B in order to have them change the Web service W_2 , it would be conceivable that W_2 running on behalf of any node in domain A will be defined at node A_1 and the defining BPEL script S_2 will subsequently be brought to execution on node B_2 as indicated by the arc (1) from A_1 to B_2 .

This approach would greatly facilitate the adaptation of W_2 in domain B to changing requirements originating in domain A. However, it would induce severe security weaknesses in domain B, if S_2 would be executed in domain B without particular precautions. Prior to running S_2 , it has to be determined whether the semantics of W_2 as defined by S_2 comply with security policies effective in domain B.

The analysis of the semantics of code written in programming languages is a well-known difficulty (Cousot 1999). Therefore, the need to analyse the semantics of W_2 with respect to security-relevant semantics will make this approach of cross-domain definition and execution impractical unless this analysis can be provided automatically, at least to a large extent.

Fortunately, the nature of BPEL (as well as of other business process languages) accommodates this analysis, further supported by the fact that no thorough analysis of each and every particular aspect of the semantics will be required, but instead only a direct search for features violating the security policy of the target domain. To further facilitate this analysis the security policy of the target domain may be expressed with respect to potentially security critical features of the language being used, i.e. BPEL in our example. Given these pre-conditions, the task of analysis becomes appropriate to be performed automatically, at least in cases when it is sufficient to express the security policy of a domain in the way exemplarily described in the following section.

4. Security Policy Definition for Business Process Analysis

Based on concepts developed in conformance testing methodology of open systems as defined in a series of International Standards (CTMF, Conformance Testing Methodology and Framework, ISO/IEC 9646, part 1–7; particularly (ISO, 1994)), after analysis of the security-relevant features of BPEL a checklist comparable to a protocol implementation conformance statement proforma (PICS proforma) (ISO, 1994) can be provided, which allows for definition of security policies with respect to execution of remotely defined BPEL scripts. This checklist is called a

security policy statement (SPS) proforma and will be used to indicate allowed features of BPEL in compliance with the security policy. Hence, while CTMF is dedicated to black box test environments, we extend the concepts of CTMF to the situation where code inspection being a specific method in white box testing will be employed in order to analyse the security-relevant semantics of BPEL scripts. In order to discuss our approach a short example presenting some typical information contained in a SPS proforma is shown in Figure 2.

Security Policy Statement		
For domain:		
...		
(additional identification information not of interest in this example)		
Relating to BPEL scripts from domain:		
Invocation of Web services outside current domain allowed?		Y/N
If yes, indicate allowed external Web services:		
URL:	Ref. to EWSRS	
URL:	Ref. to EWSRS	
Indicate restricted Web services in own domain:		
URL:	Ref. to IWSRS	
URL:	Ref. to IWSRS	
Indicate unrestricted Web Services in own domain:		
URL:		
URL:		
... (statements with respect to other security relevant language features may follow)		

Figure 2 - Example of Security Policy Statement Proforma

After indication of identification information concerning the domain to which the SPS relates and the domain, which is allowed to provide remotely defined BPEL scripts, there is an indication as to whether invocation of Web services in foreign domains will be allowed or not. If invocation of such Web services is not prohibited in general, there may be indications of particular foreign Web services each identified by its respective URL that are allowed to be invoked in a BPEL script. For each allowed Web service a so-called External Web Service Restriction Statement (EWSRS) may be referenced that contains further information concerning restrictions with respect to the particular Web service. In this example there is only room for up to two such Web services, but it is understood that the proforma may be extended to accommodate any number of list-type elements present in this example.

After indication of external Web services that are allowed, there are two further groups of indications in Figure 2 concerning Web Services of the current domain: one concerning Web Services for which invocation is restricted and one concerning Web Services that may be invoked without any restrictions. While the last type of entry does not require any further information besides the URL of the particular Web service, for each restricted Web service there is a field for indicating a reference to a so-called Internal Web Service Restriction Statement (IWSRS) similar to the indication for external Web services above. Both the group of EWSRS and group of IWSRS referenced in Figure 2 are considered part of the SPS as a whole. The SPS is understood to indicate all of the security-relevant semantics accepted in a BPEL script for cross-domain deployment. Therefore, all other security-relevant semantics not explicitly stated in SPS as being allowed, will be prohibited.

In Figure 3 there is an example of an IWSRS proforma in order to clarify the typical information contained in this part of an SPS. There may be indications concerning restrictions related to particular input parameters of the Web service by indicating the XML-name of the parameter as well as indications concerning restrictions related to allowed processing with respect

to particular output parameters, e.g. type of computations performed or flow control dependent on values of output parameters or assignment to outbound messages allowed.

Internal Web Service Restriction Statement	IWSRS-ID
Restrictions with respect to invocation parameters	
Parameter:	
Restrictions with respect to processing of output parameters	
Parameter:	
Assignment of output values to outbound messages outside own domain allowed?	Y/N
... (statements with respect to other security relevant use of output values may follow)	

Figure 3 - Example of Internal Web Service Restriction Statement Proforma

In our example (Figure 1), if W_2 would be the only instance in domain B where remotely defined BPEL scripts would be allowed, the SPS for domain B with respect to domain A would state that only invocation of Web services within domain B is allowed, and W_1 is the only internal Web service allowed to be invoked. Further restrictions apply with respect to the output parameters of W_1 , since only the information I_A intended for external use is allowed to be carried outside of domain B. This would be specified in an IWSRS for W_1 indicating the restrictions with respect to the output parameters that may not be assigned to outbound messages.

While the examples are given in human-readable tabular format it is obvious that it is straightforward to define appropriate XML schemas in order to be capable of presenting the information in machine-processable format.

5. Analysis and Assessment of Security-relevant Semantics of Business Processes

Specifying the restrictions derived from security policies as indicated in this example makes it easier to analyse a BPEL script than it would be without specifying the security policies in such a SPS. The statements in SPS are focused on the security-relevant elements in BPEL. Therefore, during analysis these elements can be searched for in a straightforward manner.

However, this approach involves consequences with respect to the language features that may be employed:

- If only domain internal Web services are allowed then, in order to allow for checking the domain part of a URL prior to execution, only URLs explicitly predefined within the script (at least the domain part of a URL) are allowed in a BPEL script
- If restrictions with respect to particular Web services apply, also the part of the URLs containing the Web service name has to be present explicitly

Obviously, this may limit the expressiveness of BPEL scripts. However, as is the case in Figure 1 and many other applications, the URLs of nodes involved in foreign domains are known and fixed throughout the runtime of the script. In many cases this also holds for names of Web services invoked. Therefore, these restrictions, though looking very tight at first sight, still leave room for useful applications. Without going into details it is apparent that the more fine grained analysis is implied by the policy, the more likely is the need for human support during analysis. Therefore, in cases where it would be too complicated to differentiate between

allowed semantics for cross-domain defined BPEL scripts and semantics not allowed by the way of indications in an SPS of domain B, it would still be possible to extract allowed semantics from the Web service being remotely defined and encapsulate it into another Web service, say W_3 , defined within domain B. Thus, it would be possible to define an SPS indicating even more restricted semantics for remotely defined BPEL scripts, since semantics required for the functionality now present in W_3 may also be excluded. By just adding W_3 to the list of allowed Web services for invocation in the SPS for domain B it would again be possible to provide the originally intended overall semantics of a remotely defined BPEL script.

Even with the definition of SPS in the manner described above the task of analysing security-relevant semantics of BPEL scripts and matching against restrictions imposed by policies still is not, in every case, trivial and it might not always be capable of being performed automatically. Therefore, it may be a promising approach to perform this task at a dedicated node within a domain, say node B_3 in our example, instead of performing this task at every node in domain B. Human interaction, when required during the analysis of scripts and comparison to security restrictions, may be more easily provided at a single node (or only few nodes, if single point of failure would be an issue) in a domain compared to the situation when being distributed across the domain. It may also facilitate use of specific software required for this purpose when it only needs to be available at a single instance both with respect to potential license fees and effort for user training.

Again, approaches in conformance testing as described in CTMF (ISO, 1994) gave rise to this approach to concentrate assessment in dedicated nodes within a domain. In our example, if domain A permits acceptance of remotely defined BPEL scripts from domain B, it could also be useful to perform examination of the scripts against the appropriate SPS at one particular node in domain A, say node A_5 , independent of where the script is to be executed later on. In such cases of mutual exchange of BPEL scripts, the analysis and assessment could further be centralized to a particular node shared by both domains for this purpose. However, the issue of privacy of information contained in security policies as well as the issue of trust implied in this delegation of assessment have to be considered in order to render this approach possible. Going into details on these aspects is beyond the scope of the present paper.

6. Related Work

Sekar et al. (2003) propose an approach to the problem of executing untrusted code, in general, i.e. not specific to business process languages, by deriving information as to the behaviour of the code at the level of system calls from execution monitoring or static analysis at the developing site. The information derived is mapped to a model describing security-relevant behaviour and carried together with the code to the executing site where this information can both be checked against security policies and used during execution in order to monitor potential deviations from the stated behaviour. Though this approach appears to be very close to the one presented in this paper, there are important differences which tend to make this approach more difficult to be applied, at least in the context of business processes, if it will be applicable to this area at all. The requirement of extensive testing as explicitly stated in this paper, and the need for observation at the level of system calls as well as the monitoring during execution, make application of the approach very complex. By contrast, these requirements are not present in our approach as it is based on code inspection techniques applied at script level.

Mendling et al. (2004) present an approach to addressing the second aspect in the list in section 2. By extracting RBAC models from BPEL scripts, and converting BPEL code in a format suitable for a particular RBAC software component, they provide an automated link of access control requirements into business processes defined by the BPEL scripts.

Koshutanski and Massacci (2003) also address access control issues of business processes defined by BPEL scripts, in particular the problem of providing the required evidence of possessing the required access privileges at the right time to the right place during execution of a business process. This approach does not address any issues from the list in section 2.

Fischer and Wenzel (2004) extend the scope of services or processes being defined by business process languages to the area of grid computing and grid services. Among others they provide a conversion of scripts written in one business process language, XPLD (Workflow Management Coalition 2002) in this case, into scripts in another business process language, namely BPEL. The scenarios for using scripts written in business process languages in a grid computing environment add another example of the approach to execute remotely-defined business processes, e.g. in BPEL, to the example discussed in the present paper.

7. Conclusions and Future Research

In this paper, we have presented an approach to one of the security aspects arising from executing business processes or enhanced Web services defined outside the domain of execution, by checking the semantics of the BPEL script defining the process via inspection and comparison with the security policies effective at the site of execution. To this extent, we have proposed a method for defining the security policy based on an SPS proforma focusing on the security-relevant semantics of BPEL. This facilitates analysis of security-relevant semantics of business processes and matching it against restrictions imposed by security policies. Since, in contrast to (Sekar et al. 2003), there is no need for testing or monitoring during analysis and execution, the application of our approach is straightforward and well-suited for automated execution in the context of business processes in SOC. This is an important feature considering the lightweight nature of fast changing business applications, the high level of abstraction above system calls and platform-independence of business process languages. Further, an infrastructure has been introduced for separating the task of analysis and assessment out of the particular node executing the business process and delegating it to a dedicated node in a domain. In this way, capabilities and resources required for this purpose may be centralised and reused from throughout the domain. Future work will be dedicated to more exhaustive description of the security-relevant aspects of business process languages. Furthermore, the issue of increasing trust in distributed multi-domain environments will be investigated, in order to make it viable to tap the full potential of outsourcing the analysis and assessment task, even across domain boundaries.

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IMCS
15,2

116

Analysis of security-relevant semantics of BPEL in cross-domain defined business processes

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Abstract

Purpose – Aims to identify security-relevant semantics of business processes being defined by WS-BPEL (Web Services Business Process Execution Language, BPEL for short) scripts, in particular, when such scripts defining collaborative business processes on top of web services are deployed across security domain boundaries.

Design/methodology/approach – Analysing potential of BPEL to define behaviour of business processes violating restrictions implied by security policies.

Findings – Semantic patterns being combinations of particular BPEL features and web services with specific access restrictions implied by security policies are defined and their implications for analysis of BPEL scripts during compliance assessment of cross-domain defined business processes are identified.

Research limitations/implications – The results of the research part of which is reported here have been applied in a research prototype to BPEL scripts of limited size and comparatively simple business logic. Real-world examples of BPEL scripts with respect to size and complexity should be examined for further approving suitability of the algorithms used.

Originality/value – The results can be used to specify security policies in terms of security-critical semantics of BPEL scripts in order to facilitate compliance assessment. In conjunction with other results of this research, this will help to overcome security issues arising from cross-domain definition of business processes by enabling automatic compliance assessment prior to execution.

Keywords Internet, Business environment, Data security, Information

Paper type Research paper



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The paper from Fischer *et al.* is the first in a series of papers that will appear during this volume of *IM&CS*, based upon works presented at the Emerald – sponsored Sixth International Network Conference (INC 2006), which ran in Plymouth, UK, from 11 to 14 July 2006. The conference included a strong stream of security-related papers, and those selected for the journal were all rated highly in the original conference review process. The paper presents an update of the version that appeared in the conference proceedings, allowing the authors to incorporate feedback received during the conference and reflect the latest developments in their research.

Introduction

Using business processes defined on top of web services is considered a promising approach to turn service-oriented computing (SOC) into practical application (Berardi *et al.*, 2003). The request for fast adaptation of business processes to changing requirements as well as for platform – independent definition of business processes lead to the specification of standardized business process definition languages. While several competing standards have been developed for this purpose, Web Services Business Process Execution Language (WS-BPEL) (Arkin *et al.*, 2004), usually abbreviated BPEL, seems to have emerged the *de facto* standard for web service composition (Mayer and Lübke, 2006; Wang *et al.*, 2004). Since, this standard is supported by several platform vendors, BPEL is particularly useful for the definition of collaborative business processes spanning several enterprise domains.

Being multiplatform enabled facilitates cross-domain definition of business processes using BPEL, that is, definition of business processes at one location (e.g. a first enterprise) and execution of them at a different location (e.g. a second enterprise). The security issues involved, however, impede this approach from being turned into practical application. In particular, uncertainty about the semantics of remotely defined BPEL scripts, notably with respect to their compatibility with local security policies, gets in the way of executing them at a foreign location. Being able to assess (in an easy and preferably automatic way) that the semantics of such scripts comply to local security policies, could foster the further exploitation of BPEL as a standard by allowing remotely defined scripts being executed without jeopardizing security requirements.

In this paper, we analyse the security-relevant semantics inherent in BPEL as a first step towards facilitating assessment of compliance with security policies. Security-relevant semantics in this context considers the functional behaviour of business processes that may be expressed by the different language elements of BPEL with respect to potential security issues involved. Once security-critical semantic patterns of BPEL have been identified based on the results of this analysis, local security policies can be expressed in terms of allowed and disallowed semantic patterns in remotely defined BPEL scripts as has already been set out in another paper of the authors (Fischer *et al.*, 2005). Finally, if this is done in a format well-suited for automatic processing, the assessment of compliance with local security policies can be performed for BPEL scripts in an automatic way prior to executing them (Fischer *et al.*, 2007).

Cross-domain definition of collaborative business processes

Figure 1 shows an exemplary scenario for distributed definition and execution of a BPEL script in two different domains, A and B. The two domains are considered to belong to two different organisations (e.g. enterprises). Each of the systems shown in Figure 1 is capable of running BPEL-defined processes. Since, a business process defined by a BPEL script offers services to its environment, it can itself be considered a web service. Therefore, in this example one of the web services used by the business process in system 1 is realized as a business process controlled by a BPEL script. For this scenario it is assumed, that this BPEL script is defined in domain A and deployed across the domain boundary for execution in system 2 of domain B. Given both systems are based on a BPEL-enabled platform, this scenario would be technically feasible. However, security issues involved in this cross-domain approach of defining

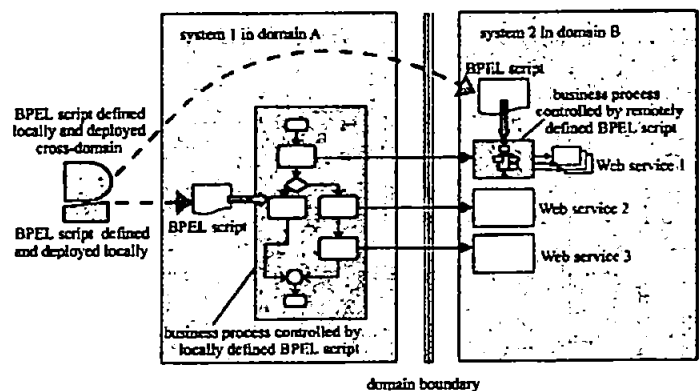
Security-relevant
semantics of
BPEL

117

IMCS
15,2

118

Figure 1.
Distributed definition and
execution of business
processes using BPEL



and running a business process may prevent this scenario from being applied in a real-world cross-organisational environment.

Security issues of cross-domain defined business processes

Since, security already is an important issue in distributed applications in general, this topic is also of significant importance for business processes, particularly for business processes crossing domain boundaries. Security of web services is well studied and several approaches for access control to web services exist (Abendroth and Jensen, 2003; Dimmock *et al.*, 2004). Role-based access control (RBAC) (Ferraiolo *et al.*, 2001; Peng and Chen, 2004) is the widely used concept for dealing with security aspects in this field. However, novel security aspects not covered in the aforementioned approaches arise from the distributed definition and execution of business processes. The following questions have to be answered in this context:

- Are the semantics of a remotely defined business process compatible with the security policy effective at the system where it is to be executed?
- Which classification, with respect to access control, is required for the web service offered by the remotely defined business process in order to be compliant with the security policy in the domain where it will be executed?

While the second question again arises in the context of access control, albeit from a different point of view than the aspect addressed by usual access control approaches, the first question addresses a new view of access control and beyond, that had not needed to be considered in the context of web services as it is not relevant with their basic incarnation. Since, obeying the restrictions implied by security policies is always important when developing distributed applications, this aspect is not considered an issue particularly associated with business processes, when developing them locally. However, this aspect will gain predominant importance that is particular to business processes, when remotely defined script-based business processes are to be executed.

Security aspects in web services concern questions like: what kind of privileges are required for invoking a particular web service? In the cross-organisational deployment scenario of Figure 1, the view to security is taken from an opposite direction, aiming at questions like: what functionality is allowed to be provided by a remotely defined business process with respect to the security policy effective in the domain of execution? The answer to this question may in most cases depend on the intended use of the web service provided by this business process. To keep it simple, without loss of generality we assume, that

- the domain where the BPEL script is specified and from where it is sent cross-domain to the system where it will be executed, is identical with the domain invoking the new web service provided by the business process, for instance domain A in the scenario of Figure 1;
- with respect to access control and potential other security aspects relevant in the relation between both domains, all potential external invokers of this new web service (i.e. invokers residing outside the domain running it, e.g. invokers in domain A) are provided the same set of privileges.

Given these preconditions, the answer to the above question concerning the allowable functionality of the business process is related to the set of privileges owned by the invokers of it as a web service. In terms of RBAC (Ferraiolo *et al.*, 2001), due to precondition b) all external invokers are associated with the same role. Hence, the answer is related to this role, this means in the above scenario, it depends on the role associated with invokers in domain A with respect to domain B. At this point, it becomes obvious that both security issues identified above are closely related. They may be considered to be complementary to each other, since the first issue is taking the view from inside to outside, while the second one is taking the view from outside to inside.

In this paper, the inside-out view of the first issue will be considered. For this purpose, the results of a detailed analysis of the security-relevant semantics of BPEL that need special attention in the security assessment of business processes are presented.

Related work

While access control-related aspects are predominant with web services, they are, of course, also an issue with BPEL. In related work, Koshutanski and Massacci (2003) address access control issues of business processes defined by BPEL scripts, in particular the problem of providing the required evidence of possessing the proper access privileges at the right time to the right place during execution of a business process.

Peng and Chen (2004) propose an extension to conventional RBAC models called WS-RBAC, in order to incorporate web services and business processes on top of them. In their approach, web services are subject to access control in place of common system resources in conventional approaches. Business processes and enterprises are elements in their WS-RBAC model making it suitable for application to collaborative business processes.

In other related work, Mendling *et al.* (2004) investigate access control requirements of BPEL script-defined business processes. By extracting RBAC models from BPEL

IMCS
15,2

scripts, and converting BPEL language constructs in a format suitable for a particular RBAC software component, they provide an automated link of access control enforcement into business processes defined by the BPEL scripts.

120

Though the papers mentioned in this section do not specifically address distributed definition and execution of BPEL scripts, their approaches also are applicable to the second security aspect arising in this context as listed above. However, none of the related work deals with the first security aspect in the list above, being the concern of the results presented herein as well as of the approaches introduced in a previous paper of the authors (Fischer *et al.*, 2005).

Analysis of security-relevant semantic patterns of BPEL

While a detailed description of BPEL can be found in its specification (Arkin *et al.*, 2004), a comprehensive analysis of its semantics was conducted by Wohed *et al.* (2002) based on a previous version of the BPEL specification. An overview of the language and a comprehensive example is given by Leymann and Roller (2004). The nature of BPEL accommodates the analysis of security-relevant semantics by offering only little or no means for defining data processing or computational tasks as part of the language itself. For these purposes, BPEL scripts have to invoke web services, or must import constructs from other XML standards such as XPath (Bergtund *et al.*, 2005). In addition, security aspects such as authentication, provision of secure communication channels, and non-repudiation are not considered in this context, since the language does not provide any means related to these security aspects. These aspects usually are catered for by the platform running BPEL scripts. Thus, the analysis can be concentrated on the business or workflow logic, that may be expressed in BPEL, in order to identify security-relevant semantics.

Adjusting the scope of analysis

For the sake of general applicability, we aim at analysing security relevance independent from the application contexts of particular BPEL script-defined business processes. Therefore, we relate language constructs with typical restrictions implied by security policies. Analysing security relevance in this way entails the opportunity that, once the security-relevant features of BPEL are identified, no thorough analysis of each and every particular aspect of the semantics will be required during the assessment of BPEL scripts for compliance with security policies. Instead, a direct search independent from application contexts looking only for the features identified as security-critical will be sufficient for this purpose.

To allow as much functionality as possible in a business process within the limits imposed by security policies, it is anticipated that the restrictions derived from such policies shall be as weak as possible, but at the same time as strict as required to avoid any violation of security policies. Since, the strategy aims at avoidance of compromising security policies, following Dobson (1994) access control and information flow control are the mechanisms of choice. Access control to the web service offered by a business process under consideration is the concern of a complementary security issue not addressed in this paper as stated above. Hence, the analysis addressed herein aims at examining whether information or resources accessed and the flow of information from inside to outside the domain and vice versa are consistent with the limitations of the security policy.

Possible violations of the policy are:

- making information or use of resources available outside the domain beyond the restrictions imposed by the policy (e.g. reading restricted information from a database and sending it to an external partner);
- bringing information from outside into an internal data storage that is not allowed to be written to from external sources; and
- using functionality or resources that are not allowed to be used (e.g. altering data in a data base or exercising a system control function).

Security-relevant
semantics of
BPEL

121

In BPEL, two types of processes may be modelled: executable and abstract processes. Since, abstract processes are not executable by their definition, they are not in the scope of our analysis. Executable processes specify workflow logic in terms of activities. The activities expressing the semantics of a business process may be either primitive or structured. The prevalent semantics expressed in BPEL is the exchange of messages with one or several external partners, that can be thought of as invoking web services provided by partners or being invoked as a web service by partners. In a definition part, BPEL scripts define the potential links to external partners by references to WSDL definitions of the web services involved. Thus, analysing these definitions in a first step yields the set of web services that may be invoked or are offered by a business process under consideration.

Classification of web service access restrictions

Since, the language constructs are not security-relevant as such, they have to be examined in the context of access to information or resources. Hence, the language constructs will be investigated in conjunction with different types of web services because in BPEL scripts access to information or resources may only be gained via web services. Given a particular set of restrictions implied by a security policy, that is associated to a particular set of privileges (i.e. a particular role), web services may be distinguished with respect to access allowance or restrictions to their input and output parameters. In Table I, six different cases are defined.

Invoking web services belonging to the cases of Table I in combination with the activities defined in BPEL will be investigated as semantic patterns to determine their

Cases	Description
1	WS with unrestricted access to all parts of resources or information offered
2	WS with completely restricted access, i.e. web services that are not allowed to be invoked
3	WS with restricted visibility of read values access: some information made accessible are not allowed to be carried outside domain A, i.e. parameters returned by WS are only allowed to be used within domain B, but not in outbound messages to targets outside domain B
4	WS with restricted write access: some of the input parameters of the web service are not allowed to be used at all
5	WS with restricted set of values allowed in write access: some of the input parameters of the WS may only be used with particular values, while others may be used without restrictions
6	WS with values in write access restricted to specific sources: for some of the input parameters of the WS only values from particular sources may be used, for instance, only values returned by a particular WS

Table I.
Classification of access
restrictions to web
services

IMCS
15,2

122

relevance with respect to security policies, in particular access control and information flow control. Of course, a particular web service may belong to more than one of the cases 3 through 6 simultaneously. For the ease of discussion, we analyse no combined cases, since for a web service belonging to more than one of these cases, the results related to each of the cases it belongs to may be applied simultaneously in this situation.

As can be easily seen, web services with unrestricted access permission (case 1) as well as web services with total access restriction (case 2) do not pose any particular challenge for analysis. In these cases, any further distinction between combinations with different features of BPEL is not relevant. The reason for this is that their allowed or forbidden use in a BPEL script may already be detected by examining the definition part. No web service with total access restriction (case 2) must occur in the definition part, or at least, if such a web service should occur in the definition part, it must not be used in any communication performed in the business process. Conversely, web services with unrestricted access permission (case 1) may be invoked freely throughout a business process, irrespective of particular combinations with BPEL activities. The only aspect relevant with web services of case 1 is the information flow from and to parameters of such a web service prior and succeeding its invocation, respectively. This has to be considered during information flow analysis from and to restricted parameters of web services in cases 3 through 6.

The distinction between cases 3 through 6 requires detailed knowledge of the semantics of a web service. Since, such detailed knowledge of external web services may not be available in domain B, in general, external web services tend to fall into cases 1 or 2. Conversely, the semantics of internal web services can be assumed to be well-known within domain B, such that the differentiation between cases 3 through 6 will be possible.

Analysis of security-relevant semantic patterns

The results of the analysis of semantic patterns involving web services of cases 3 through 6 are depicted in Tables II and III. While Table II presents the results for semantic patterns formed by combination with primitive activities, Table III indicates the results for structured activities.

Primitive activities		Case 3	Case 4	Cases 5/6
Invoke	Invocation of a web service	IFA(v)	W	IFA(w/s)
Receive	Waiting for a message to arrive	IFA(v)	-	-
Reply	Sending a reply to a message received	-	W	IFA(w/s)
Assign	Assignment of values between two different locations	(Relevant in IFA only)		
Wait	Waiting for a specified amount of time	Time(v)	-	-
	Indication of exceptions such as failures during execution	Except(v)	-	-
Throw empty	No operation	-	-	-
Exit (*)	Termination of a process instance	Exit(v)	-	-

Table II.
Security relevance of
semantic patterns with
primitive activities

(*) Notes: Construct exit was terminate in previous versions of BPEL; WS = web service; IFA = information flow analysis (v) with respect to visibility of values read from WS (w) with respect to values written to WS (s) with respect to sources of values written to WS

Structured activities		Case 3	Case 4	Cases 5/6	Security-relevant semantics of BPEL
Sequence	Definition of a fixed execution order	-	-	-	
Flow	Parallel execution of activities	-	-	-	123
Switch	Branching between several alternate activities depending on conditions	Switch cond(v)	-	-	
While	Iterative execution, i.e. looping	Loop cond(v)	-	-	
Pick	Waiting simultaneously for several events to occur and proceeding with the first event that actually occurs (see note)	IFA(v) Time(v)	-	-	

Notes: Typically, one of the events waited for is a timeout event, while the other events are messages to arrive; WS = Web Service; IFA(v) = information flow analysis with respect to visibility of values read from WS

Table III.
Security relevance of semantic patterns with structured activities

Tables II and III each comprise five columns. The second column contains a short description of the semantics of the respective BPEL activity in the first column. In columns three through five, the implications for security assessment are indicated, when the respective BPEL activity is combined with a web service of cases 3 through 6. Since, the entries for the cases 5 and 6 only differ slightly, the indications for these cases are combined in the fifth column.

Entry “-” indicates, that the respective semantic pattern is not relevant in scope of access control and information flow. As shown in Tables II and III, some activities require special attention with respect to information flow. As indicated by entry IFA(v), analysis of information flow is required, if a web service belonging to case 3 is used in one of the activities invoke (with respect to the inbound parameters, i.e. the output parameters of the web service invoked), receive or the on message part of pick. This is to determine whether visibility-restricted information returned by the web service is kept inside the security domain and is not sent outside via one of the activities invoke (within an outbound parameter) or reply.

For case 4, only invoke (with respect to the outbound parameters, i.e. the input parameters of the web service invoked) and reply need special attention to check that the restricted input parameters of the particular web service will not be used at all (i.e. written to as indicated by the entry w). Cases 5 and 6 are similar, since with invoke (with respect to the outbound parameters) and reply information flow analysis is required to determine whether the restricted use of values is obeyed. With case 5, information flow analysis related to the values written to restricted outbound parameters is required (indicated by entry IFA(w)), whereas with case 6, analysis is required with respect to the sources of such values (indicated by entry IFA(s)).

As indicated in Table II, analysis of information flow has to embrace assign activities to observe the movement of information within the business process. If processing such as calculation or string manipulation is performed within a BPEL script using language constructs imported from, for instance, XPath (Berglund *et al.*, 2006), it has to be analysed that no restricted information is involved, or at least, that results from the processing is not used in a manner violating the security policies. Since, allowing such kind of processing on restricted information could

IMCS
15,2

cause obfuscation of information flow, thereby complicating the analysis of information flow considerably, as a matter of precaution such processing should be generally considered incompatible with security policy, independent of the further use of its results.

124

As special cases, use of visibility-restricted information gained from web services of case 3 in the activities wait (with respect to duration), throw (with respect to exception thrown), exit (with respect to condition for termination), switch (with respect to definition of cases), while (with respect to loop control), and pick (with respect to timeout interval) also turns out to be security-relevant as shown in Tables II and III. The reason for this is, that defining any of the terms indicated in parenthesis dependent on visibility-restricted information could be exploited to circumvent restrictions implied by security policy. For instance, if the visibility-restricted information *l* is used to control the amount of loop cycles in a while activity, for some externally observable behaviour such as sending a message to an external web service from within the loop body could be used to circumvent the visibility restriction on *l*. In this way, an external observer would be able to count the numbers of such messages and to deduce the value of *l* from this observation. However, revealing *l* to an external observer in whatever manner would violate the security policy restricting this information from being disclosed outside the domain. Therefore, use of visibility-restricted information for flow control purposes also needs special attention during compliance assessment of BPEL.

Research prototype

Using the results of the analysis presented here in conjunction with a schema for defining security policies in terms of allowed and disallowed semantic patterns identified above as security-relevant, a research prototype has been implemented as proof of concept. This schema has been described in detail in another paper of the authors (Fischer *et al.*, 2007). The BPEL script to be checked and the security policies defined using this schema are input to the prototype. Furthermore, the WSDL definitions (Chinnici *et al.*, 2006) of all web services addressed in the BPEL script under consideration have to be made available to the prototype. Without executing the BPEL script, the prototype inspects it step by step to ensure, that the restrictions specified by the security policies are obeyed. If any violation is detected, the program stops its analysis and returns a fail verdict. It also indicates the location in the BPEL script giving rise to this verdict together with the security policy implied restriction violated at that location. If the inspection is completed without detecting any violation of the security policy, then the prototype assigns a pass verdict to the BPEL script.

Before the checks with respect to the different kind of restrictions as indicated in Tables II and III can be performed, the declaration part of the BPEL script being checked is analysed to get information about web services potentially invoked during execution, the message types used in such invocations (as defined in the corresponding WSDL scripts for the particular web service), and the variables and their respective types used for storing results from and passing values to web service invocations. Furthermore, the security policy defined using the aforementioned schema is parsed and the information contained in it is stored as an internal representation of the security policy for further processing.

After completion of this initial step and storing the information gained during this stage, the prototype starts to analyse the activities of the BPEL script. Each activity encountered is treated separately by the prototype, performing the specific checks and actions associated with each type of BPEL activity. While stepping through the process part of the BPEL script, the prototype simultaneously performs forward and backward information flow analysis as required for the semantic patterns encountered during the analysis. Further details of the processing performed for the different BPEL activities are described in the above mentioned paper (Fischer *et al.*, 2007).

Security-relevant
semantics of
BPEL

125

Since, this prototype is intended as a proof of concept, only small BPEL scripts including comparatively simple business logic have been used to show that the architecture and algorithms used are suitable to detect possible violations of the security policy. Though, in principle, the viability of automatic compliance assessment could be approved this way, before using these algorithms for real-world applications, more thorough tests with larger BPEL scripts comprising more complex business logic would have to be performed.

Conclusions and further work

Our analysis of security-relevant semantics of business processes defined by BPEL scripts has identified security risks associated with particular constructs of BPEL in conjunction with various types of security policy-implied restrictions on the use of web services, herein called semantic patterns. The results of this analysis can be used to specify security policies applicable to cross-domain defined BPEL scripts in terms of such patterns. This way, assessment of compliance with local security policies of business processes defined and executed in a distributed manner can be facilitated. Since, assessment become suitable for automatic processing as has been shown by implementing a research prototype described briefly above and in more detail in another paper of the authors (Fischer *et al.*, 2007), security issues arising from applying BPEL for cross-organisational development of business processes may be treated satisfactorily thereby fostering acceptance of exploiting multi-platform capability of BPEL this way in practical applications.

Further work will be dedicated to improving the research prototype and expanding the field of application of the results from this research to other areas beyond business process management where similar circumstances with executing scripts written in a standardized process definition language prevail. One such area could be grid computing where BPEL can be used for orchestration and choreography of grid services (Tuecke *et al.*, 2003) in order to define grid processes.

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IMCS
15.2

126

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Security-relevant
semantics of
BPEL

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127

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Security Policy Enforcement in BPEL-Defined Collaborative Business Processes

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Abstract

This paper presents an approach to security policy enforcement with collaborative business processes defined using BPEL and deployed across enterprise domain boundaries for execution. The assessment of compliance with security policies at the location where a BPEL script is to be executed is facilitated by re-formulating the security policies with respect to the potential of violation inherent in BPEL. The results of an analysis of the security-relevant semantics of BPEL-defined business processes conducted for this purpose indicate the paramount role of information flow analysis in business processes. Based on these results, the paper proposes an XML-based schema for specifying security policies for cross-organisational business processes that allows for automatic checking of BPEL scripts for compliance to these security policies. The paper also introduces a prototype implementation of an automatic compliance check that approves the feasibility of the method for practical application in security policy enforcement.

Keywords

Collaborative Business Processes, Business Process Execution Language (BPEL), Security Policy Enforcement, Information Flow Analysis, Semantic Analysis, Web Services, Service Oriented Computing (SOC)

1. Introduction

Defining business processes on top of Web services has evolved as a promising approach to cope with requirements for high flexibility and short time-to-market in current business process environments [19]. Web Services Business Process Execution Language (WS-BPEL) [2], usually abbreviated BPEL, is considered to be the emerging de-facto standard for Web service composition [18,30] in order to define business processes. The nature of being a standardized definition language for business processes, being able to be executed on several platforms, is particularly useful when collaborative business processes spanning several enterprise domains are specified.

One aspect of BPEL being multi-platform enabled seems not to have found its way into practical application: Employing the fact that business processes defined this way are able to perform on several platforms makes it feasible to define cross-organisational business processes at one location, for instance one enterprise, and execute them at a different location, for instance a second enterprise.

However, security issues involved in this way of using BPEL-defined business processes impede practical application of this approach. In particular, the uncertainty about the semantics of remotely defined BPEL scripts, particularly with respect to their compatibility with local security policies, gets in the way of executing them at a foreign location. Being able to assess (in an easy, and preferably automatic, way) that the semantics of such

scripts comply to local security policies, could foster further exploitation of BPEL as a standard by allowing remotely defined scripts being executed without jeopardizing security requirements.

In this paper, we propose a method of defining security policies in terms of security-relevant semantics inherent in BPEL. This way, the comparison between security policies and BPEL scripts is facilitated such that an assessment of compliance with these policies is enabled to be conducted automatically. It should be noted that the term “compliance” is always used in this sense here. The paper also describes a research prototype that has been developed for approving the feasibility of automatic assessment of BPEL scripts based on this approach. Since the assessment can be performed prior to execution of the BPEL scripts, the method appears to be well-suited to support effective security policy enforcement in the context of BPEL-defined collaborative business processes.

2. An SCM Example for a Collaborative Business Process

In Figure 1, an example from the area of supply chain management (SCM) is shown that will be used to illustrate the security issues arising when remotely defined BPEL scripts are being deployed across enterprise domain boundaries.

The application context of the distributed business process depicted in Figure 1 is the order processing of a car manufacturer ordering gearboxes or components thereof from a gearbox manufacturer who, in turn, orders components for gearboxes from different sub-suppliers, two in this example.

The business process is set up in a service-oriented computing (SOC) environment where all functions used for the application are provided as Web services and the composition of Web services is accomplished using BPEL for the definition of the controlling workflow. In such a context, BPEL scripts do not need to perform any kind of data manipulation or data processing on their own. Since BPEL does not provide any language constructs for performing data manipulations, constructs of other languages such as XPath [4] would have to be imported for these purpose anyway. Since in a service oriented application context all data processing can be kept outside the controlling BPEL scripts, it is assumed that the BPEL scripts considered here only make use of elements imported from XPath, if any, in expressions specifying conditions for flow control purposes not implying any data manipulation.

2.1. Description of Example Business Process

In this example, a controlling BPEL script is executed in a system of the gearbox manufacturer defining a controlling business process denoted by *control* in Figure 1. An *order* process of the car manufacturer that may itself be a Web service or a BPEL-defined business process invokes the Web service offered by the *control* process at the gearbox manufacturer providing a list of gearbox components to be ordered by the car manufacturer. Before placing an order, the car manufacturer expects a price offer accompanied by a commitment with respect to the delivery date.

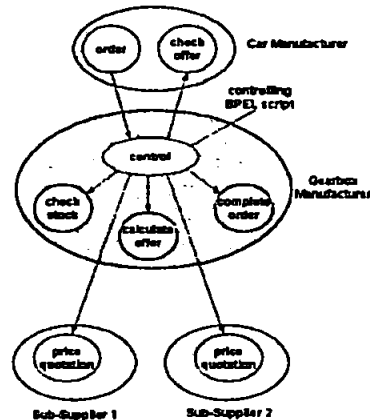


Figure 1: Collaborative business process example

The *control* process invokes a *check stock* Web service for checking the availability of the ordered items in stock. For this purpose, the list of items to be ordered is passed to this Web service. After checking availability in stock, the *check stock* Web service returns two lists of items that are to be ordered from sub-supplier 1 and sub-supplier 2, respectively. Together with these lists, a transaction ID for the order in progress and the credentials required to invoke the respective Web services of the two sub-suppliers are returned by *check stock*.

Upon receiving the response of *check stock*, the *control* process invokes the *price quotation* Web services of the sub-suppliers and provides the respective list of items to each of them. To get access to these Web services, the credentials returned by *check stock* are used by the *control* process. Of course, each Web service of

the sub-suppliers requires its own set of credentials. Therefore, the *control* process has to provide the proper instance of credentials to each of them.

After checking availability of the items on the respective list, each *price quotation* Web service returns a list augmented by prices and availability on stock or dates of delivery. The *control* process then invokes a *calculate offer* Web service of the gearbox manufacturer to prepare an offer for the car manufacturer. For this purpose, the *control* process passes the augmented lists returned from both sub-suppliers to the *calculate offer* Web service together with the transaction ID that was returned to it before by the *check stock* Web service.

The *calculate offer* Web service uses the transaction ID to identify the proper order request of the car manufacturer and to find the information relating to this order in the data base of the gearbox manufacturer provided there by the *check stock* Web service. For instance, information about items found to be available in stock and potentially reserved for this order by the *check stock* Web service could be identified by the *calculate offer* Web service in the course of its processing. Finally, the offer is returned to the *control* process and will be passed to a *check offer* Web service of the car manufacturer. This Web service will return an 'OK' or 'Reject' response to the *control* process after having checked whether the offer would be acceptable to the car manufacturer.

The response from the *check offer* Web service is passed to an *order completion* Web service by the *control* process. Depending on the type of response, this Web service either completes the order processing within the gearbox manufacturer if the response was 'OK' or discards all intermediate information such as items reserved for this transaction ID if the response was 'Reject'.

After the *order completion* Web service has terminated its task, it returns a corresponding result to the *control* process that, in turn, provides this result to the *order* Web service of the car manufacturer as a response to its own invocation, thereby completing the workflow of this business process.

For the purpose of our discussion we suppose that the *control* process could be specified by the car manufacturer as a BPEL script and sent to the gearbox manufacturer for execution. Reasons for doing so could be the ability to better adapt the order processing with respect to communication requirements between the car manufacturer and the gearbox manufacturer and to react faster to changing requests concerning the workflow on the side of the car manufacturer. However, unless the security issues related with this approach as discussed in the next section could be solved satisfactorily, the gearbox manufacturer would not accept this remotely defined BPEL script for execution. It should be noted that the deployment of the BPEL script for remote execution and the required assessment

for compliance with local security policies constitutes a workflow of its own not depicted in Figure 1.

2.2. Security Policy-Induced Restrictions in Cross-Organisational Business Process Execution

When the controlling BPEL script is brought in from the car manufacturer for execution in the domain of the gearbox manufacturer, the processing performed by the controlling business process will be subject to several restrictions derived from the security policies of the gearbox manufacturer.

These security policies may mandate that the list of items that are not in stock and, therefore, have to be ordered from the sub-suppliers may not be disclosed to the car manufacturer and the respective competing sub-supplier for strategic reasons. The same will hold for the credentials required for granting access to the price quotation Web services of the sub-suppliers. This information may only be passed to the respective sub-supplier, but neither to the competing sub-supplier nor to the car manufacturer for obvious security reasons.

Other restrictions in the example of Figure 1 may require that the list containing prices and delivery dates for the items to be ordered returned by each of the sub-suppliers has to be passed unmodified to the *calculate offer* Web service, the respective source of the lists may not be confused in order to allow for proper calculation of an offer to the car manufacturer, and, finally, this information may also not be disclosed to the car manufacturer or the competing sub-supplier. Furthermore, it may be required that the offer containing prices and delivery dates returned from the *calculation* Web service is passed to the *check order* Web service of the car manufacturer without any modification in order to prevent manipulation of this offer.

3. Security Issues with Remotely Defined BPEL Scripts

As can be seen from the foregoing discussion, many restrictions refer to non-disclosure of information passed between Web services within the *control* process to destinations outside the domain of the gearbox manufacturer, in particular to the car manufacturer. The latter restriction is of special interest given the fact that in our example this very process is defined by exactly the car manufacturer who is restricted to get some of the information handled by this process. Other restrictions mandate that the values passed to a Web service originate from a particular other Web service.

Access control to Web services (e.g., [1,7]) and in particular role-based access control (RBAC) [10,21] may

only cover part of these restrictions. When addressed by access control means alone, enforcement of non-disclosure of information outside the local domain would imply that access to the particular information would not be granted to any principal outside the local domain. In our example, the car manufacturer residing outside the local domain of the gearbox manufacturer and, as a consequence, also the BPEL script defined and invoked by the car manufacturer, would not be granted access to visibility restricted information thus preventing the *control* process of our example being remotely defined and deployed by the car manufacturer.

Relaxation of access restrictions such as granting access provided the values passed to a Web service come from a particular source, for instance values returned from a specific Web service, require information flow (in backwards direction) to be considered for making decisions upon granting access or not. Thus, information flow analysis has to be applied in addition to purely access control-oriented approaches, in order to cope with this kind of restrictions.

Restrictions with respect to visibility of values returned from a Web service are also not covered by access control measures alone. For this purpose, information flow (in forward direction) has to be analysed, which means the future use of the values returned has to be taken into consideration.

With the approach proposed in this paper, these restrictions derived from the security policies at the location where a remotely defined BPEL script will be executed can be enforced using the methods proposed, including the restriction that the author of the BPEL script is precluded from getting knowledge about information handled by the business process he has specified. At first sight, this may seem to be a restriction contradictory to itself.

The security issues arising when remotely defined BPEL scripts are to be executed can be condensed into the following questions:

- Will the business process defined by the remotely defined BPEL script comply with the local security policies of the executing domain?
- Which access privileges are required in order to grant access to the business process defined by the BPEL script (to possess the proper privileges for accessing the resources, in particular the Web services, encountered in the course of its execution)?

The second question is addressed by research considering access control [16,20], even though not necessarily in the context of BPEL script execution [14]. The first question, however, is comparatively novel since execution of remotely defined BPEL scripts is not currently in widespread practical use and, therefore, security aspects inherent in this way of using BPEL have not received significant attention in prior research [11,12].

4. Related Work

In the context of security considerations of Web services, access control related aspects play a central role and, therefore, are well studied (e.g. [3]). Research has also been dedicated to access control with respect to business processes. In related work, Koshutanski and Massacci [16] address access control issues of business processes defined by BPEL scripts, in particular the problem of providing the required evidence of possessing the proper access privileges at the right time to the right place during execution of a business process.

Peng and Chen [21] propose an extension to conventional RBAC models called WS-RBAC, in order to incorporate Web services and business processes on top of them. In their approach, Web services are subject to access control in place of common system resources in conventional approaches. Business processes and enterprises are elements in their WS-RBAC model making it suitable for application to collaborative business processes.

In other related work, Mendling *et al.* [20] investigate access control requirements of BPEL script-defined business processes. By extracting RBAC models from BPEL scripts, and converting BPEL language constructs in a format suitable for a particular RBAC software component, they provide an automated link of access control enforcement into business processes defined by the BPEL scripts.

Algebraic and language-based approaches, not dedicated specifically to Web services, address the relation of programs and programming languages with security policies [8,13,17,22,29,31]. From their point of view, these papers are comparable with the scope of our research, albeit from a theoretical view. Approaches requiring for analysis purposes, that all programming logic is expressed by algebraic formulations such as λ -calculus (e.g., [17]) may be of limited use in the field of business processes considering the program size of the platform running such business processes. However, some insights from these theory-oriented papers might be of interest also in this field. For instance, Sabelfeld and Myers [22] point out that with respect to information flow, static analysis being superior to dynamic analysis as it considers all possible execution paths of a program while dynamic analysis considers only one instance of program execution. They also explicate the potential existence of so-called covert channels and emphasise the difficulty to detect them during information flow analysis. Covert channels denote means of information transfer that exploit mechanisms not primarily intended for information transfer such as the number of iterations in a loop to leak information via externally observable program behaviour.

Other related work proposes runtime monitoring as a concept for security policy enforcement [23,28] in mobile or untrusted code. Since these approaches require access to Java byte code [28] or the program code at system level [24,27], they might also be of only limited use for being applied for analysing BPEL scripts and the business process defined by them (since neither Java byte code nor program code at system level is available for instrumentation or monitoring at the level a business process is executed on a BPEL-enabled platform).

Our approach, as described in [11,12], tries to keep the assessment of compliance and the methods for analysing security-relevant semantics of BPEL scripts as simple as possible, without requiring profound skills in special formalisms such as algebraic formulation of programming logic. The methods proposed are based on technology and methods well-known to developers of Web services and business processes in order to be comparatively easy to be applied and, therefore, could be attractive to be adopted by practitioners in this field.

5. Schema for Security Policies Adapted to BPEL Script Execution

One basic idea of our approach to enforcing security policies with remotely defined business processes is expressing the restrictions resulting from them in such a way that checking of a BPEL script for compliance to the security policies is reduced to searching a BPEL script for particular patterns that have been identified beforehand to be security-critical. This approach is aiming to allow as much functionality as possible for remotely defined business processes without jeopardizing the security policy of the domain executing these processes.

Based on the results of an analysis of BPEL as a specification language for its potential to define security-critical behaviour, set out in a former paper of the authors [12], security policies can be specified in terms of presence or absence of such patterns in a BPEL script [11]. It turns out that combinations of Web service invocations having special kinds of access restrictions imposed on their parameters with certain language constructs of BPEL form the patterns that have to be looked for when assessing a BPEL script for compliance with security policies.

To allow for better understanding of the schema for security policies presented here, we summarize some insights from our former papers [11,12]. We have identified six classes of access restrictions to Web services as a whole or to their parameters induced by security policies that are described in Table 1. Unrestricted access to a Web service (class 1) is included for completeness though it does not represent any actual restriction. In the example of Figure 1, several parameters returned by the Web services

involved turned out to be subject to visibility restrictions (class 3) as discussed above. Also, input parameters of Web services restricted to their values coming from specific sources (class 6) were found in this example, e.g., the list of items passed to the *price quotation* Web services of both sub-suppliers had to be the lists destined for the respective sub-supplier returned by the *check stock* Web service. Web service parameters of class 4 and 5 did not occur in this example, but situations when such restrictions may occur are easy to imagine. For instance, the Web service *calculate offer* could be augmented to comprise one or several further input parameters that force price reduction in order to provide special offers. Such input parameters could be of class 4 when a BPEL script sent from the car manufacturer would be allowed to invoke this augmented Web service. One of these new input parameters could indicate a scale of discount, for instance, ranging from 1 to 5, with 5 leading to the highest rebate. A BPEL script from the car manufacturer could be restricted to use only one of these values (e.g., value 2), thereby obviously representing an example of a class 5 type of restriction.

Class	Description of Restriction
1	Web service with unrestricted access to all parts of resources or information offered
2	Web service with completely restricted access, i.e., Web service that is not to be invoked at all
3	Web service parameters with restricted visibility of read values: information made accessible via these parameters is not allowed to be carried outside current domain
4	Web service parameters with restricted write access: these input parameters are not allowed to be used at all
5	Web service parameters with restricted set of values allowed in write access: these input parameters may only be used with particular values
6	Web service parameters with values in write access restricted to specific sources; for these input parameters only values from particular origins may be used

Table 1: Classes of Web service access restrictions [12]

In order to make the specification of security policies better suited for the assessment of compliance, the security policy will be expressed in terms of Web services allowed to be invoked at all by such a BPEL script and the restrictions induced by this security policy [11]. The result of re-specifying security policies this way is called a security policy statement (SPS). For each of the Web services indicated in an SPS, the restrictions with respect to its input and output parameters will be stated in terms of the classes 3 through 6 of Table 1.

```
<?xml>
<domain-ref remoteDomain="foreignDomain"
             localDomain="localDomain"
             localAppContext="context" />
<twrs> ... </twrs>
<swrs> ... </swrs>
<unrestrictInternalWs> ... </unrestrictInternalWs>
<unrestrictExternalWs> ... </unrestrictExternalWs>
</sp>
```

Listing 1: Overall XML structure of SPS

As already proposed in [11], the SPS should be specified in a machine-processible form. As also being used for BPEL scripts and WSDL [6] specifications of the Web services invoked by them, XML seems to be a good choice for also specifying SPSs.

For our prototype implementation of the assessment procedure, the XML schema in Listing 1 has been used for specifying an SPS [15]. For better readability (and because of lack of space), the schema is depicted here in an BNF-like format instead of using XML-Schema [5,9,25] in the listings. Therefore, an asterisk sign (*) behind an XML element indicates that zero, one or more occurrences of that element being allowed at this place. Similarly, a plus sign (+) behind an XML element means that one or more occurrences are allowed. Finally, a question mark (?) behind an XML element identifies an optional element that may occur once or may be absent.

The element <domain-ref> indicates the domain defining the BPEL script and the domain where it is to be executed in the attributes remoteDomain and localDomain, respectively. The application context the SPS relates to can be specified in the attribute <localAppContext>. For instance, for the car manufacturer in Figure 1 a different set of security policy derived restrictions could apply if he would also be entitled to remotely define business processes in the context of communicating construction plans for new gearboxes with the gearbox manufacturer.

The elements <swrs> and <twrs> denote restrictions with respect to external and internal Web services, one element for each Web service indicated. Similarly, the elements <unrestrictInternalWs> and <unrestrictExternalWs> denote unrestricted external and internal Web services (class 1), respectively.

In Listing 2, the structure of the element <swrs> is depicted. The element <twrs> has a similar internal structure. The element <operation> denotes the name of a Web service operation and indicates the corresponding port type by a URI. The <input> and <output> elements indicate restrictions to the corresponding type of Web service parameters, one for each type of message a Web service operation is able to receive or send, respectively.

```
<swrs>
  <operation name="operationName"
             portType="URIofPortType" ... </operation>
  <input> ... </input>
  <output> ... </output>
</swrs>
```

Listing 2: External WS restriction statement

From Listing 3, the structure of the element <input> can be seen. It contains indications whether all input parameters or only particular ones are source restricted (class 6). If so, the required originating Web service(s) for a value to be allowed is indicated in one or more <service> element(s) contained in the <sourceRestriction> element. More than one such originating Web service may be indicated to allow for alternative sources.

If not all, but only specific input parameters are restricted, this is indicated in the <part> element contained in an <input> element. Again, it may be indicated whether an input parameter contained in the message representing the union of all input parameters of a Web service is source restricted or not (class 6). If so, the <part> element in turn contains an element <sourceRestriction> (not indicated in Listing 3) with the same internal structure as discussed above for the message level.

```
<input message="messageName"
       sourceRestricted="true|false"?
       <sourceRestriction?
       <service portType="URIofPortType"
                 operation="operationName" />
       </sourceRestriction?
       <part name="partName"
             sourceRestricted="true|false"?
             disallowed="true|false"?
             valueRestricted="true|false"?
             ...
             <valueRestriction?
             <permitsValue> ... </permitsValue>
             </valueRestriction?
       </part>
</input>
```

Listing 3: Input restrictions of Web service

In addition, at the part level there is an optional indication (via attribute disallowed) whether a specific input parameter may not be used (class 4). This information is not provided on the message level, that is, for all input parameters at once. Such a shortcut for indicating class 4 restrictions for all input parameters has not been recognized as being required in the schema. It should be noted that having class 4 restrictions for all input parameters is not equivalent to a class 2 restriction for the Web service as a whole. There may be cases, where it is forbidden to pass any value with a Web service invocation, but still the Web service is allowed to be invoked (without passing any value to it).

Furthermore, via the attribute `valueRestricted` it can be indicated at the part level that a specific input parameter may only be used with certain values (class 5). The permitted values are specified in one or more `<permittedValue>` elements contained in the element `<part>`. Obviously, the indication of value restriction is only sensible at the part level, since the permitted values have to be specified separately for each input parameter affected by a class 5 restriction.

To conclude the discussion of the XML schema for SPS, the structure of the element `<output>` is depicted in Listing 4. Similar to the indication of source restriction in the `<input>` element, visibility restriction may be indicated on the message level and on the part level via attribute `visibilityRestricted`. As a special case, visibility restriction may be relaxed to cope with the situation, in which one or several domains are allowed to see an otherwise visibility-restricted value.

An example for such a relaxation is the lists of items to be ordered from the sub-suppliers in Figure 1. These lists have their visibility restriction relaxed, since they are visibility restricted to all external domains except the specific sub-supplier the list is intended for.

```
<output message="messageName"
  visibilityRestricted="true|false">
  <targetRelaxation?
    <domain name="domainURI" />
  </targetRelaxation>
  <part name="partName"
    visibilityRestricted="true|false">
    ...
  </part>
</output>
```

Listing 4: Output restrictions of Web service

The relaxation of visibility restriction is indicated by the element `<targetRelaxation>` contained within the `<output>` element and contains one or more `<domain>` elements to indicate the domain(s) to which the output parameter may exceptionally be passed. Similar to the `<input>` element, separate parts of the output message, that is, specific output parameters, could be indicated as being visibility restricted in one or more elements `<part>` contained in the `<output>` element. If target relaxation applies to specific parts, this is indicated by `<targetRelaxation>` elements contained within the `<part>` elements and specifying the domain(s) to which the parameter may be passed. The structures of `<targetRelaxation>` elements are the same at message level and at part level. Therefore, the optional `<targetRelaxation>` element included at part level is not shown in Listing 4. It should be noted that visibility restriction does not apply to the local security domain where the BPEL script is to be executed. Therefore, this domain will never be indicated

in a `<domain>` element within the element `<targetRelaxation>`.

Once the security policy has been specified in such a manner, the process of assessing compliance to the restrictions imposed by the security policy for a particular partner domain can be performed automatically by parsing the BPEL script and the SPS in parallel. This is described in more detail in the next section.

6. Security Policy Enforcement Based on SPS

As already mentioned, the procedure of assessing the compliance of a remotely defined BPEL script with the security policies will be performed prior to the execution of such a BPEL script. This procedure can be considered a check point in the sense of security patterns [32]. An analysis performed for this purpose has shown that none of the activities (i.e., the language constructs of BPEL for specifying the logic of a business process) is on its own of any relevance with respect to potential violations of security policies [12]. Only the combination of BPEL activities with Web services and the values passed to and received from them can exhibit any behaviour that might be in conflict with security policies.

Therefore, the analysis considers the restriction classes of Web services invoked by a BPEL script in conjunction with particular language constructs of BPEL occurring in a BPEL script.

Aspects of security policies resulting in completely restricted access (class 2) for one or several Web services can easily be enforced by looking for invocations of these Web services in a BPEL script. If no such invocation is present in a BPEL script, then the script is compliant with the security policies from which these restrictions resulted.

If a restriction with respect to the use of particular input parameters (class 4) are to be enforced, this can be achieved by checking that in invocations of Web services comprising such parameters, the specific parameters of class 4 are not used.

The remaining classes 3, 5, and 6 require more detailed analysis of a BPEL script in order to enforce security policies resulting in such restrictions. If restricted visibility of some Web service parameters (class 3) is to be enforced, then information flow analysis as to the further use of these parameters after the invocation of Web services is required. In order to avoid information leakage, the information returned by class 3 parameters must not be used in messages destined to targets outside its permitted visibility domain. As a minimum, the visibility domain comprises the security domain where the BPEL script will be executed.

Our analysis of security-relevant semantics of BPEL [12] further has shown that in order to avoid covert

channels [22] as explained above it has to be ensured, that visibility restricted information is not used in certain language constructs of BPEL, for instance to define the duration in a wait activity or for loop control in a while activity.

Restrictions as to a set of permitted values for input parameters are either comparatively easy to be assessed or can not be assessed at all during an analysis prior to execution. If constant values are used for those parameters, compliance assessment is possible and may be readily performed since the values of the constants used are known in the BPEL script. Otherwise, if values returned from Web service invocations are used for input parameters of this class, it is, in general, not possible to decide in a pre-execution analysis which values will be returned. Therefore, assessment of compliance with class 5 restrictions in combination with dynamic values returned from Web service invocations can only be accomplished if these parameters are treated as class 4 parameters in this situation.

In order to enforce security policies resulting in restrictions of the allowed sources of values used as input parameters (class 6), information flow analysis considering the history of a variable used for this purpose is required. This means, the source of a value used as input parameter of class 6 has to be determined by analysing the information flow from the point of invocation backwards. In this analysis, all sources that the current value at the time of invocation could come from have to be taken into consideration. Therefore, all actual parallel flows as specified by the flow activity as well as all potential parallel flows as in the switch and pick activities have to be considered in backward information flow analysis in order to determine where a value could come from.

The prototype performing such a process of assessing compliance of a BPEL script with security policies has been implemented using Java [15]. The BPEL script to be checked and the SPS defining the security policies are input to the prototype. Furthermore, the WSDL definitions [6] of all Web services addressed in the BPEL script under consideration have to be made available to the prototype. Without executing the BPEL script, the prototype inspects it step by step to ensure, that the restrictions specified in the SPS are obeyed. If any violation is detected, the program stops its analysis and returns a fail verdict. It also indicates the location in the BPEL script giving rise to this verdict together with the restriction in the SPS violated at that location. If the inspection is completed without detecting any violation of the SPS, then the prototype assigns a pass verdict to the BPEL script.

Before the checks with respect to the different kind of restrictions described above can be performed, the declaration part of the BPEL script being checked is analysed to get information about Web services poten-

tially invoked during execution, the message types used in such invocations (as defined in the corresponding WSDL scripts for the particular Web service), and the variables and their respective types used for storing results from and passing values to Web service invocations. Furthermore, the SPS is parsed and the information contained in it will be stored in instances of Java classes thus forming an internal representation of the SPS for further processing.

After completion of this initial step and storing the information gained during this stage in instances of Java classes defined for this purpose, the prototype starts to analyse the activities of the BPEL script. Each activity encountered is treated separately, performing the specific checks and actions associated with each type of BPEL activity.

As an example, the treatment of a Web service invocation will be described in further detail. As this treatment is the most complex one in the assessment since all types of restrictions may apply, describing the steps performed here gives an overview of the actions performed by the prototype with any BPEL activity.

Upon encountering an invoke activity, the prototype determines the Web service invoked and looks up the internal representation of the SPS for the information present therein for the specific Web service.

If the Web service is not found in the SPS, the processing stops because invocation of a Web service not defined in SPS as being allowed represents a violation of the security policy. It should be noted that for every Web service that is allowed to be invoked an entry in the SPS has to exist.

If the Web service is found in SPS, the restrictions defined there are copied for further use. Since the output parameters of a Web service invocation are stored in a variable defined in the BPEL script, the restrictions contained in the <output> element corresponding to the particular Web service are stored in the instance of the Java class representing this variable. Along with the restrictions, the URI of the Web service invoked is stored in this variable for potential later use in validating potential source restrictions (class 6).

Usually, this process of storing the restrictions for the output part of a Web service in the variable receiving this output will override the information stored there with former uses of this variable in Web service invocations. However, if the Web service invocation was found in a (actual or potential) parallel flow (i.e., within a flow, switch, or pick activity), then the information does not override the information already stored there. Instead, the information to be stored in the variable is labelled with a hierarchical flow identifier enabling simultaneous collection of information related to all potential parallel information flows. This way, the backward information flow

analysis can use the restrictions from all former parallel information flows. When information from parallel flows is present and the same variable is re-used as container for the output of a Web service, the hierarchical flow identifiers stored with the information has to be considered to decide which part of the information to override and which to keep.

The variable used as input message to the Web service invoked is analysed with respect to the accumulated restrictions already stored in it. This way it is checked whether visibility restricted (class 3) information is contained in the variable to determine whether conflicts with those restrictions would occur by passing this information to the current Web service.

In the case, class 6 restrictions are present for the input parameters of a Web service, the origin of the information contained in the variable will be used to assess compliance or detect potential non-compliance with these class 6 restrictions.

Similar processing as with the input and output parameters in an *invoke* activity applies to the *reply* and *receive* activities (and the receiving parts in a *pick* activity), respectively.

In order to prevent covert channels [22], the prototype takes a rigorous approach in disallowing any visibility restricted information to be used for flow control purposes (in the activities *exit*, *throw*, *wait*, *while*, *switch* and the *timeout* part of *pick*).

7. Conclusion and Further Research

We have proposed a method for specifying security policies in such a manner that assessment of compliance of BPEL-defined business processes will be facilitated. The method is based on an analysis of security-relevant patterns that can occur in BPEL scripts [12]. Assessment of compliance, particularly the required information flow analysis can be performed automatically as has been shown by the realisation of a research prototype. This method of security policy enforcement usually is applied prior to execution of remotely defined BPEL scripts since neither testing nor monitoring of the business processes defined by these scripts is involved.

Therefore, shortcomings of approaches requiring execution of a script in order to observe its behaviour, namely the risk that upon detecting a violation of security policy, the activity causing violation could already have passed a point of no return such that interception would have been exercised too late to stop the activity and to prevent security violations from being committed, are securely avoided in our approach.

However, though the proposed methods may foster security policy enforcement for BPEL-defined business processes, they are not intended as a replacement of other

security related mechanisms addressing complementary purposes such as safeguarding external communication flows or protection against accidental or malicious tampering of the execution environment or BPEL scripts and Web services involved.

Further work will elaborate more sophisticated algorithms for detecting covert channels than the current one in the prototype. This aims at weakening the restrictions implied to the use of visibility restricted information for flow control purposes thereby permitting even more processing diversity for remotely defined business processes.

Another direction of further work will be dedicated to expanding the field of application of the methods proposed to other areas beyond business process management where similar circumstances with respect to the execution of controlling scripts written in a standardized definition language prevail. One of such an area could be grid computing where grid services [26] are being employed and BPEL be used for orchestration and choreography of grid services in order to define grid processes.

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Pre-execution Security Policy Assessment of Remotely Defined BPEL-Based Grid Processes

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Abstract. In this paper results from research on security policy enforcement for cross-domain defined business processes specified in BPEL are transferred to the field of Grid computing, where BPEL is used to define Grid processes. In order to facilitate the assessment of remotely defined BPEL-based Grid processes for compliance with security policies prior to execution, a method for specifying security policies with respect to security-relevant semantic patterns in BPEL is applied. The paper shows the extent to which transfer of the former results was successful and indicates limitations and areas of further research. Where the situation is similar to cooperative business processes, such as in forming dynamic virtual organizations using Grid technology, the results turned out to be transferable with minor modifications, whereas for a transfer to the Grid context in general further investigation is required (in particular with respect to formal specification of security-relevant semantics of Grid services).

Keywords: Business Process Execution Language (BPEL), Grid Processes, Security Policy Enforcement, Information Flow Analysis, Virtual Organizations, Grid Services.

1 Introduction

For the purpose of defining business processes on top of Web services, Business Process Execution Language (WS-BPEL) [1], usually abbreviated BPEL, has emerged as the de-facto standard for Web service composition [26]. In the field of Grid computing, Grid services [24] play a role similar to Web services in the field of business processes. Due to this similarity, BPEL has been found its way to application in Grid context for the specification of long-running processes modeled with BPEL invoking Grid services (e.g., [2,14]). Because of its analogy to using BPEL in collaborative business process (CBP) context, this paper proposes to transfer results of research on security policy enforcement for remotely defined business processes [9,10,11] to a Grid process context.

In a CBP context, availability of BPEL-enabled platforms at every site involved in such a business process could be assumed, since this already is or soon will be

common practice in enterprises engaging in CBPs. Therefore, gaining access to a BPEL-enabled node was not considered a motivation for remotely defining BPEL scripts. Instead, location-dependent access restrictions gave rise to defining business processes displaced from the intended location of execution [9,11]. In a Grid context, however, the lack of access to a BPEL-enabled platform could very well motivate definition of BPEL scripts for remote execution since not every location having the need for defining Grid processes may be assumed to have local access to a BPEL-enabled platform. In particular, having (local) access to such a platform may not be considered a standard situation in small or medium-sized organizations. Therefore, defining BPEL scripts for remote execution might be an interesting amendment of current state of the art of using BPEL in a Grid context.

As indicated in our earlier works [10,11], security issues involved in this way of using BPEL-defined business processes (the same holds for BPEL-defined Grid processes) may impede practical application of this approach. When execution of remotely defined BPEL scripts is requested, there is first of all the uncertainty about the semantics of the process defined with respect to their compatibility with local security policies that gets in the way of executing them without reservation.

Making otherwise inaccessible Web services available to a controlling business process while still observing the security policy with respect to non-disclosure of information gained or access to resources granted by invoking such Web services was discussed in [11]. Since the conditions to be observed with respect to access control could be much more diverse in a Grid context [5], the investigation of generally granting access to otherwise restricted Grid services as the reason for executing remotely defined BPEL scripts is left to further study.

However, the transfer of our results from the CBP context to the Grid context seems to be most obvious for situations where Grid technology is used for forming virtual organizations (VOs) [13]. In this context, the number of partners are limited and controlled by regulations for joining a VO, particularly with respect to authentication and authorization. When remotely defined BPEL scripts are used for controlling Grid processes in VOs, there are many analogies to business processes defined by remotely defined BPEL scripts in the CBP context. As with CBPs, local security policies of an organization offering resources for being used in a VO usually determine access to these resources. These policies will result in restrictions to allowed semantics of remotely defined BPEL scripts that may be accepted for execution from a member of the VO. Such restrictions on allowed semantics may further restrict access to Grid services than access would be restricted by security policies of the sites offering these services alone. Reasons for this could be that allowing invocation of a Grid service in a particular context of a Grid process would violate a security policy such as prevention of generating or relaying mass e-mail from within the domain executing the BPEL script.

In this paper, the method of defining security policies in terms of security-relevant semantics inherent in BPEL in order to facilitate the assessment of compliance with such policies will be transferred from the field of business processes to the Grid context. It will be shown to what extent this attempt is successful and where limitations and issues for further study exist.

A further aspect discussed in this paper is the possibility to delegate the task of assessing compliance of BPEL-defined Grid processes with local security policies. An

180 K. -P. Fischer, U. Bleimann, and S. Furnell

infrastructure supporting the delegation of this task to one or several dedicated nodes in a network or to specific assessment centers has also been introduced for the CBP context [9]. This possibility may be of even more interest in the Grid context where typically many small to medium size computers, spread over different locations, are involved, not necessarily belonging to a larger organization (as typically encountered in a CBP context) that can afford or provide the effort required for the task of performing the security policy assessment as proposed in this paper.

2 Related Work

Since security in the Grid context plays a paramount role, much research has been dedicated to this field on Grid computing. In particular, research concerned with expressing security policies in the context of VOs are related to our approach presented herein. In [7], for example, a security architecture for peer-to-peer-based Grid computing is proposed where a security layer offering security-related functionality resides between the Grid application layer and the communication infrastructure. This way, applications do not need to implement such functionality on their own. Security requirements may be stated by each member of a VO on a peer-by-peer basis or for groups of peers.

In [27], it is investigated how security functionality can be made available to Grid services, in particular in the context of VOs. A security model for Open Grid Services Architecture (OGSA) [12] specifying security services to provide different security functionality is proposed for this purpose. The authors show how security-related specifications from the field of Web services can be used in the context of this security architecture. In their paper, expressing security policies for using a Web service in terms of WS-Policy [3] specifications and publishing these policies together with the WSDL [6] specification of the service is also addressed.

It should be noted that security policy expressed in terms of WS-Policy deals with the requirements for security mechanisms to be applied or provided for using a Grid service (such as certificates to be required for accessing a service, or encryption methods to be applied when communicating input and output parameters of a service). In a layered architecture for composing new services from existing ones, or for executing processes based on existing services as proposed in [16], these mechanisms are to be provided in layers below the business process layer, since in the business process layer (and particularly in BPEL) there are no means for providing communication security and for exchanging or checking security certificates. The security policies expressed in the two approaches above, therefore, address aspects of policies complementary to those that have to be obeyed in the business process layer when remotely defined BPEL scripts are to be executed (as addressed in our former research [10,11] and in this paper).

Process algebra and language-based research, not dedicated specifically to Web services or Grid services, addressing the relation of programs and programming languages with security policies [8,21] are comparable with the scope of our approach, albeit from a theoretical perspective. Approaches requiring for analysis purposes, that all programming logic is expressed by algebraic formulations such as λ -calculus (e.g., [17]) may be of limited use in the field of Grid processes considering the program size

of the execution environment running such processes. However, some insights from these theory-oriented papers might be of interest also in the context of Grid processes. With respect to information flow, for instance, Sabelfeld and Myers [21] emphasize the advantage of static analysis considering all possible execution paths of a program compared to dynamic analysis considering only one instance of program execution. They also explicate the potential existence of so-called covert channels (*i.e.*, means of information transfer exploiting mechanisms not primarily intended for information transfer such as the number of iterations in a loop to leak information via externally observable program behavior) and emphasize the difficulty to detect them during information flow analysis.

Our approach, as described in [9,10,11], tries to keep the assessment of compliance and the methods for analyzing security-relevant semantics of BPEL scripts as simple as possible without requiring profound skills in special formalisms such as algebraic formulation of programming logic. The methods proposed are based on technologies and methods well-known to developers of Web services and business processes as well as of Grid services and Grid processes in order to be comparatively easy to be applied and, therefore, could be attractive to be adopted by practitioners in this fields. The insights from theory-oriented research with respect to information flow analysis and consequences of the considerations with respect to covert channels mentioned above, however, have been taken into account in our approach.

Other related work proposing runtime monitoring as a concept for security policy enforcement in mobile or untrusted code requires access to Java byte code as in [25] or to program code at system level as in [22]. These approaches might also be of only limited use to be applied for analyzing BPEL scripts and the Grid process defined by them for compliance with security policies (since neither Java byte code nor program code at system level is available for instrumentation or monitoring at the level a Grid process is executed on a BPEL-enabled platform).

Since the approach taken in our research allows for assessing compliance of BPEL scripts with security policies prior to execution, the shortcomings of approaches requiring execution of a Grid (or any other) process in order to observe its behavior and to check it for possible violations during execution are neatly avoided. One of these shortcomings is the risk that upon detecting a violation of security policy, the activity causing violation could already have passed a point of no return such that interception would have been exercised too late to prevent security violations from being committed, which can be securely avoided by pre-execution assessment.

3 Security-Relevant Semantic Patterns in BPEL-Based Grid Processes

Based on the results of an analysis of BPEL as a specification language for its potential to define security-critical behavior, security-relevant semantic patterns in BPEL have been identified as combinations of BPEL activities and Web services subject to access or information flow restrictions to and from their parameters as derived from security policies [10]. In order to transfer this concept to the Grid context, the classes of security policy-induced access restrictions found in [10] are converted with respect to Grid services (GS) as shown in Table 1.

Table 1. Classification of access restrictions to Grid services (adapted from [10])

Class	Description of Restriction
1	GS with unrestricted access to all parts of resources or information offered
2	GS with completely restricted access (i.e., GS that are not allowed to be invoked)
3	GS parameters with restricted visibility of output values with respect to specific targets: information returned by these parameters is not allowed to be carried to specific targets (i.e., to specific other GS or to particular parameters of specific GS)
4	GS with restricted write access: some of the input parameters of the GS are not allowed to be used at all
5	GS parameters with restricted set of values allowed in write access: such input parameters of a GS may only be used with particular values
6	GS parameters with values in write access restricted to specific sources: for such input parameters of a GS only values from particular origins may be used, that is, only values returned by a particular GS or a specific parameter of a particular GS
7	GS particularly prone to overload if invoked excessively. For these GS, maximum invocation rates or maximum amount of data passed to it that prevent overloading will have to be observed

Whereas the term 'Web service' had to be replaced by 'Grid service' throughout Table 1, most descriptions could be transferred otherwise unchanged (classes 1, 2, 4, and 5) or nearly unchanged (class 6). Only the description of class 3 was modified to better fit in the Grid context and a new class 7 was introduced.

While in the CBP context the restriction in class 3 was specified in terms of restricted visibility to targets outside the domain executing a BPEL script, this distinction does not always play an important role in the Grid context. Therefore, the definition of class 3 was abstracted from the location where a target resides to generally express restricted information flow to dedicated targets irrespective of their location. Hence, restrictions will be specified in terms of specific Grid services or particular input parameters thereof that are forbidden to receive the values returned from these parameters. In order, for instance, to prevent a list of e-mail addresses returned by a particular Grid service to be used for generating mass e-mail, this output parameter could be restricted not to be used as input parameter of particular other Grid services known to generate an e-mail to each address passed to it. Obviously, the location of the second Grid service (inside or outside the executing site) does not matter in this case.

Unlike in the CBP context, where effective runtime mechanisms for prevention of overloading a Web services could be deemed to be in place (in layers below the business layer) at a platform running these services, this might not, in general, be expected from sites running Grid services. Therefore, a security policy of a site accepting remotely defined BPEL scripts in a Grid context could require that a process running on resources of this site shall not cause overload (running the risk to result in an intentional or unintentional denial of service attack) to specific Grid services known to be prone to overload when invoked in a particular manner. Since, in a Grid context, effective runtime prevention of overloading a Grid service shall not be expected to take place at all sites running these services, semantic patterns of BPEL potentially causing such overload have to be identified and looked for in pre-execution compliance assessment to prevent BPEL scripts including such patterns from being executed.

Table 2. Security relevance of semantic patterns with primitive activities (adapted from [10])

Primitive Activities		Class 3	Class 4	Classes 5/6	Class 7
invoke	invocation of a Grid service	IFA(v)	w	IFA(w/s)	IFA(a)
receive	waiting for a message to arrive	IFA(v)	-	-	-
reply	sending a reply to a message received	-	w	IFA(w/s)	-
assign	assignment of values between two different locations	(relevant in IFA only)			
wait	waiting for a specified amount of time	time(v)	-	-	-
throw	indication of exceptions such as failures during execution	except(v)	-	-	-
empty	no operation	-	-	-	-
exit	termination of a process instance	exit(v)	-	-	-

w = observance of restricted use of input parameters in write access to GS.

IFA = information flow analysis, (v) with respect to visibility of values read from GS, (w) with respect to values written to GS,

(s) with respect to sources of values written to GS, (a) with respect to amount of data written.

There are two types of overload that may be caused to a Grid service: One type is sending more data in an invocation of a Grid service than can be handled. The other type is invoking a Grid service at a higher rate than this service can cope with. Therefore, performance-related restrictions related to these types of overload may be indicated for a Grid service falling in this new class 7 in the Grid context.

Table 3. Security relevance of semantic patterns with structured activities (adapted from [10])

Structured Activities		Class 3	Class 4	Classes 5/6	Class 7
sequence	definition of a fixed execution order	-	-	-	FQ
flow	parallel execution of activities	-	-	-	FQ
switch	branching between several alternate activities depending on conditions	switch cond(v)	-	-	-
while	iterative execution, i.e., looping	loop cond(v)	-	-	FQ
pick	waiting simultaneously for several events to occur and proceeding with the event that occurs first (see note)	IFA(v)	-	-	-
		time(v)	-	-	-

Note: Typically, one of the events is a timeout event, while the other events are messages to arrive.

IFA(v) = information flow analysis with respect to visibility of values read from GS.

FQ = invocation frequency to be checked against maximum.

The security-relevant semantic patterns were adapted from [10] in Tables 2 and 3. For reasons discussed in [10], no such patterns exist for classes 1 and 2. While all semantic patterns identified in [10] are also relevant in the Grid context and, therefore, could be transferred by simply substituting the term "Grid service" for "Web service", some new semantic patterns were added as combinations of BPEL activities and the new restriction class 7 in the last column of Tables 2 and 3, respectively. Hence, attention has to be paid during compliance assessment to semantic patterns identified as being capable of generating high invocation frequencies of Grid services (in **while**, **sequence**, or **flow** activities, marked 'FQ' in Table 3) or passing large amount of

data to Grid services not designed for coping with such data volumes (in **invoke** activities, marked 'IFA(a)' in Table 2).

From Tables 2 and 3, it can be seen that information flow analysis is required for most of the semantic patterns identified as security-relevant in [10]. It should be noted that the security relevance of the patterns in Table 2 related to restriction class 3 denoted by 'time(v)' (i.e., duration of wait dependent on visibility-restricted value), 'except(v)' (i.e., type of exception thrown dependent on visibility-restricted value), and 'exit(v)' (i.e., termination dependent on visibility-restricted value) as well as in the same column of Table 3 denoted by 'switch cond(v)' (i.e., branching dependent on visibility-restricted value), 'loop cond(v)' (i.e., number of iterations dependent on visibility-restricted value), and again 'time(v)' is a consequence of the requirement to prevent covert channels as mentioned above.

Making, for instance, the condition for choosing alternative flows in a **switch** activity dependent on visibility-restricted information, constitutes a covert channel since this could enable an external observer of the executing process to draw conclusions on the values of such visibility-restricted information from the observation which alternative flow actually is being taken thereby violating the security policy of non-disclosure of this information.

4 Rewriting Security Policies to Support Pre-execution Security Policy Assessment

In [9,10], rewriting security policies in terms of security-relevant semantics has been proposed to support compliance assessment of remotely defined BPEL-based business processes with these policies. An informal checklist for stating allowed and disallowed semantic patterns was introduced in [9] leading to a so-called security policy statement (SPS) when filled in to reflect the security policies of a specific domain. In the CBP context, such an SPS was defined domain-specific with respect to two domains, namely the domain where the security policy is in effect (i.e., domain executing BPEL scripts) and the domain defining and sending BPEL scripts for execution. An XML-based schema for specifying an SPS in machine-readable form which has been the basis for implementing an automatic assessment of BPEL scripts for compliance with security policies expressed by such an SPS has been introduced in [11].

In the Grid context, rewriting security policies in such a way may also prove useful for assessing BPEL scripts with respect to compliance with these policies. Since semantic patterns have been modified (definition of restriction class 3) and supplemented (patterns involving new restriction class 7) compared with those found in [10], the check list as basis of an SPS as well as the XML-based SPS schema for machine-readable versions thereof have to be modified accordingly in order to accommodate this new set of security-relevant semantic patterns.

Unlike in the CBP context, an SPS may not be sensibly defined for a specific foreign domain, since Grid computing is concerned with a potentially large amount of foreign domains that are essentially indistinguishable from the point of view of the domain executing the BPEL-defined Grid processes. Only in a VO environment, when the identities of members and their privileges to execute Grid services are

known in advance, defining an SPS for each other member in the VO that is allowed to send BPEL scripts for execution could make sense.

Therefore, with the exception of the latter situation, only one or a few SPSs without any relation to a specific external domain will make sense in the Grid context. If more than one SPS will be specified for a domain, they are expected to be differentiated with respect to different application contexts for which they apply (e.g., computational simulation in a particular field, collection of field-specific data such as in meteorology). Although details of application context-dependent SPSs are left to further study, it is anticipated that such SPSs will be tightly bound to access privileges or roles classifying the sender of a BPEL script.

Specifying security policies in terms of security-relevant semantic patterns identified in section 3 requires an exhaustive list of all Grid services allowed to be invoked by a remotely defined BPEL script. Furthermore, for every Grid service mentioned in this list, the security-relevant semantics of the service and its parameters has to be known in order to determine the access restriction classes appropriate for each of them (cf., Table 1). This requirement may cause additional effort since specification of security-relevant semantics may not be available for Grid services in the first place.

It should be noted that unavailability of semantic specification (at least as far as security-relevant semantics is concerned) may prevent the approach proposed herein from being applied. However, unavailability of such specification may also prevent the application of any other pre-execution approach to assessing compliance of Grid processes with security policies. This holds independently of both the location where a Grid process is being defined and executed, and also the manner in which the process is being specified (i.e., independent of using BPEL or any other means for specifying Grid processes). In case of unavailable semantic specifications, the only way of enforcing security policies is monitoring the execution of a Grid process and interfering in cases when violations of security policy have been detected involving the known shortcomings of such approaches mentioned above.

However, much current research is concerned with describing the semantics of Grid services in order to support identification of matching Grid services for automatic Grid process orchestration (e.g., [18,20]). Bringing the results of this research together with the approach proposed in this paper in order to define a framework for formally specifying security-relevant semantics of Grid services in terms of well-defined (maybe even standardized) categories is expected to be an interesting field of further study.

A further motivation for research in this direction could be the endeavor to facilitate specification of information flow restrictions of output parameters and value or source restrictions for input parameters with respect to particular characteristics of a Grid service by denoting particular semantics bound to this Grid service instead of particular Grid services themselves. Such semantic characteristics could be "returning lists of e-mail addresses" or "causes sending e-mails to addresses passed". Means to specify restrictions this way would eliminate the need to analyze every potentially allowed Grid service for falling into a specific restriction class if, in parallel, Grid services and their parameters would have been specified in terms of such characteristics with respect to their (security-relevant) semantics.

If such classification of Grid services would be available, then, for instance, in order to enforce a security policy of avoiding the generation of Spam emails at a Grid

node, one could require that any output parameter with the semantic characteristic "returning a (potentially large) list of email addresses" must not be input to any parameter with the characteristic "causes sending e-mails to addresses passed". Specifying allowed and disallowed semantic patterns with respect to such categories instead of individual Grid services and their parameters obviously would help to shorten the content of an SPS considerably. How far this idea of categorizing Grid parameter semantics for this purpose can be successfully based on or linked with research such as work on semantic Grid services [15], semantic matchmaking of Grid service composition [18], or workflow ontology of Grid services [4] requires further investigation.

Such amendments of addressing semantic characteristics of Grid service parameters in an SPS are expected to involve increased complexity of the assessment task because of required matching of SPS and semantic characteristics of the Grid services actually used in a BPEL script. Even before such amendments are available, it is not obvious and actually will require further investigation whether the assessment of compliance with security policies specified in an SPS is similarly straightforward as it has been shown for the CBP context by implementing a research prototype [11]. In particular, it is expected that covering semantic patterns involving class 7 restrictions in automatic compliance assessment prior to execution will turn out to be complex or even impossible to a certain extent since this class of restrictions addresses dynamic aspects of a BPEL script that obviously are not easy to be analyzed in a static pre-execution assessment.

5 Delegation of Security Policy Assessment

Since, as indicated above, the assessment of compliance with security policies may be more complex in a Grid context requiring specific skills or use of dedicated tools, the motivation to delegate this task to a specific node or an assessment center may be higher in the Grid context than it already was in the CBP context. Delegation of compliance assessment can occur in a variety of ways, as described in the specification of a security infrastructure enabling such delegation [9]. This infrastructure can be transferred to the Grid context in a straightforward manner and some amendments specific for the Grid context are made.

Assessment can be performed against locally or remotely defined SPSs. Such remotely defined SPS may be sent together with the BPEL script as a kind of assertion what the Grid process defined by the BPEL script is going to do or not to do with respect to security-relevant semantics inherent in BPEL and the Grid services involved.

When this approach is taken, means for checking the proper relation and integrity of the SPS and the BPEL script may be provided based on appropriate certificates added to both the BPEL script and the SPS.

A remotely defined SPS provided with a BPEL script may be checked against local security policy requirements. After positive assessment of compliance with these requirements, the local site:

- may decide to trust in the assertion provided by the remote site and, after checking integrity of BPEL script and SPS, execute the BPEL script without any further compliance assessment, or
- may initiate an assessment of compliance in any ways mentioned below.

Besides local or remote definition of SPSs, there is the third alternative that an SPS may be defined centrally (*e.g.*, defined by a central organization within a Grid environment or agreed upon as a standard relevant to a Grid context). In any of these cases, assessment of compliance with security policies expressed in an SPS may be performed in different ways:

- Locally at the executing site itself. The potential problem with this approach as already indicated above could be that performing security policy assessment locally might be too elaborate a task to be conducted by small footprint computers (*e.g.*, stand-alone personal computers) or small organizations that cannot afford specific checking tools or acquire specific skill required for this task.
- Remotely (in an assessment center) on behalf of the site executing the BPEL script. The SPS will be sent together with the BPEL script to the trusted assessment center for checking compliance of BPEL script and SPS-defined security policies. In case of a centrally defined SPS, a reference to this SPS may be sent instead of the SPS itself. The results will be returned to the executing site as certified verdicts (*i.e.*, passed or failed, the latter possibly accompanied by the reason(s) for this verdict).
- (Not applicable for locally defined SPS) Remotely (in an assessment center) on behalf of the site defining the BPEL script with respect to an SPS defined by the remote site or centrally defined. BPEL script and SPS are sent to the assessment center as in the previous case. The results of the assessment may be certified by the assessment center and sent back to the defining site together with the certified (with respect to integrity and identity) BPEL script and SPS. The defining site may then pass the certified BPEL script and SPS to the executing site possibly accompanied by the certified results from the assessment center. If an assessment center adheres to a published policy to only certify BPEL scripts and SPSs that received a passed verdict when checked for compliance, then sending the result from the defining site to the executing site can be abandoned since, in this case, having a certificate from such an assessment center implies the passed verdict for the BPEL script.

From the current point of view, these alternatives seem to be versatile enough to cover the requirements in the Grid context and, therefore, there seems to be no particular need for further research in this area.

6 Conclusions and Further Research

In this paper, the results arising from research into collaborative business processes, defined using BPEL scripts at one site and brought to another side for execution, with respect to assessing their compliance with the security policies effective at the executing site have been transferred to Grid processes. The discussion has identified the extent to which such a transfer can succeed, with or without requiring modifications of the former results and the limitations and areas needing further study.

The insights with respect to compliance with security policies could also be beneficial for security policy enforcement of Grid processes in strictly local environments (*i.e.*, when definition and execution of BPEL scripts occur at the same location in a Grid environment), since reformulating security policies such that the process of

compliance assessment is facilitated thereby possibly enabling automatic performance of assessment could also be useful there.

In the attempt to transfer the results from the CBP to Grid context, several issues for further research have been encountered. Amongst them the classification of security-relevant semantics of Grid services and their parameters is deemed to be the most challenging as well as the most promising field for further study.

Investigating how the approaches proposed in this paper could be applied based on Grid environments or Grid middleware such as Globus Toolkit [23] or OurGrid [19], and what adaptation would be required in order to be successful in doing this, is another interesting direction of further research.

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