AUTOMATIC COMPOSITION OF SEMANTIC WEB SERVICES WITH THE ABDUCTIVE EVENT CALCULUS

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WITH THE ABDUCTIVE EVENT CALCULUS

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ABSTRACT

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In today's world, composite web services are widely used in service oriented computing, web mashups and B2B Applications etc. Most of these services are composed manually. However, the complexity of manually composing web services increase exponentially with the increase in the number of available web services, the need for dynamically created/updated/discovered services and the necessity for higher amount of data bindings and type mappings in longer compositions. Therefore, current highly manual web service composition techniques are far from being the answer to web service composition problem. Automatic web service composition methods are recent research efforts to tackle the issues with manual techniques. Broadly, these methods fall into two groups: (i) workflow based methods and (ii) methods using AI planning. This thesis investigates the application of AI planning techniques to the web service composition problem and in particular, it proposes the use of the abductive event calculus in this domain. Web service compositions are defined as templates using OWL-S ("OWL for Services"). These generic composition definitions are converted to Prolog language as axioms for the abductive event calculus planner and solutions found by the planner constitute the specific result plans for the generic composition plan. In this thesis it is shown that abductive planning capabilities of the event calculus can be used to generate the web service composition plans that realize the generic procedure.

Keywords: Automatic Web Service Composition, OWL-S, Abductive Event Calculus, Semantic Web Services

ÖZ

ANLAMSAL ÖRÜN SERVİSLERİNİN ÇIKARIMSAL OLAY CEBİRİ İLE OTOMATİK BİRLEŞİMİ

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Günümüzde servis odaklı mimarinin, örün mashup'ları ve B2B uygulamaların artmasıyla örün ağı servisleri birleşimleri de geniş bir kullanım alanına sahip olmuştur. Bu örün ağı servis birleşimlerinin büyük bir çoğunluğu el ile yapılmaktadır. Ancak bu işlemin karmaşıklığı uygun örün servislerinin sayısındaki artış, devingen olarak oluşturulmuş/güncellenmiş/bulunmuş örün servislerine olan gereksinim ve daha yüksek oranda veri bağlama ve tür eşleme ihtiyacı sebepleriyle gün geçtikçe artmaktadır. Dolayısıyla günümüzde kullanılan el ile örün servisi birleştirme yöntemleri bu problemin cevabı olmaktan çok uzaktır. Bu sebeple son yıllarda otomatik örün servisi birleştirme metodlarının geliştirilmesi için araştırmalar sürdürülmektedir. Bu metodlar genel olarak iki ana sınıfta toplanabilir: (i) iş akışı temelli metodlar ve (ii) yapay zeka ile planlama içeren metodlar. Bu tezde yapay zeka planlama tekniklerinin örün servisi birleşimi problemine nasıl uygulanabileceği araştırılmış ve özellikle çıkarımsal olay cebirinin bu alandaki kullanılabilirliği irdelenmiştir. Örün servisi birleşimleri OWL-S ("Servisler için OWL") dili ile şablonlar halinde tanımlanmış ve bu tanımlar Prolog dilinde çıkarımsal olay cebiri planlayıcısının kullanabileceği aksiyomlara çevrilmiştir. Bu aksiyomları kullanan planlayıcının bulduğu çözümler, genel örün servisi birleşimi planının özel çözümlerini içeren kümeyi oluşturmaktadır. Bu tezde olay cebirinin çıkarımsal planlama yeteneklerinin genel örün servisi birleşimi yordamı için çözüm teşkil edecek planları oluşturma amacıyla kullanılabileceği gösterilmiştir.

Anahtar Kelimeler: Otomatik Örün Servisi Birleşimi, OWL-S, Çıkarımsal Olay Cebiri, Anlamsal Örün Ağları

To My Parents

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CHAPTER 1

INTRODUCTION

In the early days of computing, organizations were monolithic and focused on static and centralized applications. Changes were perceived as problems disrupting the normal flow, schedule, budget etc, and they should be avoided. But nowadays the world is much more dynamic and fast organizational responses to rapidly changing intra and extra organizational requirements are needed. The need for changing the systems quickly according to the context gives rise to the usage of off-the-shelf components. Web service technology gains importance in this context as one of the most prominent paradigms for building complex web based applications.

According to the IBM web service tutorial [67] the definition of web services is as follows: “Web services are a new breed of web application. They are self-contained, self-describing, modular applications that can be published, located, and invoked across the web. Web services perform functions, which can be anything from simple requests to complicated business processes. … Once a Web service is deployed, other applications (and other web services) can discover and invoke the deployed service.” Web services architecture is loosely coupled and service oriented. The Web Service Description

Language (WSDL) [13] is used to describe the interface of the service. It uses the XML format to describe the methods provided by a web service, including input and output parameters, data types and the transport protocol, which is typically HTTP, to be used. The Universal Description Discovery and Integration standard (UDDI) [74] is used to publish details about a service provider, the services that are stored and the opportunity for service consumers to find service providers and web service details. The Simple Object Access Protocol (SOAP) [24] is used for XML formatted information exchange among the entities involved in the web service model.

One drawback of WSDL is that, it does not supply the specification of what happens when a web service is used in a machine interpretable way. To make use of a web service, a software agent needs a computer-interpretable description of the service, and the means by which it is accessed. Semantic web provides some answers to this problem. The semantic web is a set of technologies for representing, and publishing computer-interpretable structured information on the web. Standard languages including the resource description framework (RDF), RDF schemas (RDFS), and the web ontology language (OWL) have been developed for enabling the creation of ontologies for any domain and the instantiation of these ontologies in the description of specific web components. In an environment of semantically annotated services, users who need to achieve certain goals could be assisted by software agents which automatically identify and, if necessary, dynamically compose services in order to accomplish the user's goals, which may be either explicitly stated or derived from the situation the user is in. In order to use semantic web techniques to automate dealings with web services, OWL-S have been developed. OWL-S [34] is an ontology of service concepts that supplies a web service designer with a core set of markup language constructs for describing the properties and capabilities of a web service in an unambiguous, computer-interpretable form. OWL-S allows for the description of a web service in terms of a Profile, which tells "what the service does", a Process Model, which tells "how the service works", and a Grounding, which tells "how to access the service". These semantically rich descriptions enable automated machine reasoning over service and domain descriptions, thus supporting automation of service discovery, composition, and execution, and reducing manual configuration and programming efforts.

Moving onto the web service composition problem, sometimes no single web service can satisfy the user’s requirement. In this case, there arises a need to combine existing services so that the combination would fulfill the user’s requirement. The service oriented architecture is based on this idea. It is possible to create applications by combining the convenient web services together. Recursive compositions can be created by using a composite service as an individual service contained in the composition. To define such an application, a flow specification is needed to describe in which order messages have to be exchanged between the services. There are many flow specification languages for web services like BPEL4WS [15] and WSCI [3].

The composition should be defined manually using these languages, but there are some problems about it. First, the amount of available web services is too much, and they can be created and updated on the fly. Thus the composition system needs to detect the updating at runtime and the decision should be made based on the up-to-date information. In addition, the web services are usually developed by different organizations that use different models for presenting the properties of the services. This requires the processing of semantic information about the services, for finding the suitable service and composing it. Handling these issues manually in a short time with human intervention is beyond the human capability. Thus the ability to efficiently select and compose web services seamlessly and dynamically in runtime becomes an important issue, which is the so called problem of *automated web services composition*. Given a repository of service descriptions and a service request, the *web service composition problem* involves finding multiple web services that can be put together in correct order of execution to obtain the desired service [14]. Finding a web service that can fulfill the request alone is referred to as *web service discovery problem* [42]. When it is impossible for one web service to fully satisfy the request, one has to compose multiple web services, in sequential or parallel, preferably in an automated fashion [14].

The web service composition problem is similar to the AI planning problem in many ways, which for over three decades, has investigated the problem of how to synthesize complex behaviors given an initial state, an explicit goal representation, and a set of possible state transitions. It is often assumed that a business process or application is associated with some explicit business goal definition that can guide a planning-based composition tool to select the right service [37]. Both the planning problem and composition problem seek a (possibly partially) ordered set of operations that would lead to the goal starting from an initial state (or situation). Also, like actions in planning domain, compositions have web services which have parameters, preconditions, results and effects. Hence AI planning is a very suitable and attractive method for the web service composition problem.

There is a considerable amount of work on automated web service composition with AI planning techniques. Viewing the composition problem as an AI planning problem, different planners are employed for the solution [32, 36, 37,42, 44, 46]. The techniques introduced so far are using the situation calculus, the Planning Domain Definition Language (PDDL), rule-based planning, the theorem proving and others. For instance, the STRIPS [19] is the first major AI planning system to describe actions in terms of their preconditions and effects. The Graphplan [10] is a general-purpose planner for STRIPS-style domains using graph algorithms. Given a problem statement, Graphplan uses a backward search to extract a plan and allows for partial ordering among actions. As the satisfiability approach for the planning problems, the SATPlan algorithm [29] is a greedy local search method that translates a planning problem into propositional axioms and finds a model that corresponds to a valid plan [42].

In this thesis, it is shown that the abductive planning capabilities of the event calculus [50] has the necessary features to be used for the solution of web service composition problem. Our tool constitutes a proof of concept showing this. It is shown that the composition problem can be represented and solved completely in a logical framework, taking the advantage of its declarative behaviour and clear semantics, which enables the easy development and solution of the problem. When the composition is represented as event calculus axioms, it is possible to apply planning methods of the event calculus given the initial state and goal state. Abduction is used in planning, and the necessary steps for reaching the goal state are found by the planner. The generic web service composition template is to be provided by the user, and our tool generates a set of possible execution plans which would satisfy the goal on execution. The generic composition definitions are represented in OWL-S, which enables the definition of semantic information of the composite service and the individual services included in the composite service. The inputs, outputs, preconditions and effects of the services are provided by the OWL-S and the composition is translated to event calculus framework. In the planning process, web service discovery is needed to guide the plans and also, after the user selects one of the generated plans for execution, the composite service is to be executed. Both of the discovery and execution parts are out of the scope of this thesis, so the role of these parts are simulated.

The rest of the thesis is organized as follows. Chapter 2 gives insight information about web services, OWL-S and the event calculus. Also current technologies and techniques for the solution of web service discovery and composition problems are presented. Chapter 3 presents the abductive implementation of the event calculus and the usage of it in web service composition problem to generate the composition plans automatically. In Chapter 4, methods to translate service descriptions in OWL-S to event calculus axioms are presented. The implementation of our solution is described in Chapter 5. Finally, conclusions and possible future work are presented in Chapter 6.

CHAPTER 2

RELATED WORK

In this chapter, some background information on Web services, Web service discovery/composition methods, OWL-S and Event Calculus is provided. The purpose of this chapter is to describe the basic concepts, introduce the necessary terminology, and present relevant definitions.

2.1 Web Services

2.1.1 Introduction to Web Services Model

According to W3C (World Wide Web Consortium) definition in the Web Services Architecture document [11], Web services are software systems designed to support interoperable machine-to-machine interaction over a network. They are considered as self-contained, self-describing, modular applications that can be published, located, and invoked across the Web [58]. As the current Web enables users to connect to applications, the web services enable applications to connect to other applications in a way that it provides an interface for applications to publish their functions or messages to the rest of the world so that other applications can use them across the

Web. Web services are therefore a key technology in enabling business models to move from B2C (Business to Consumer) to B2B (Business to Business) [21].

There are three roles in the Web service model to accomplish the above task, namely the service provider, the service requestor and the service registry. The service provider publishes the service description to the service registry. This description includes the format for requests and responses for the service. The service requester then finds the service description via the service registry. The description of the service in the registry contains sufficient information for the service requestor to bind to the service provider to use the service. So after the requestor finds the service it needs, the service registry fullfills its task and the remaining interaction is carried over between the service requestor and the service provider themselves. vFigure 2.1 shows a graphical representation of this traditional web service model.

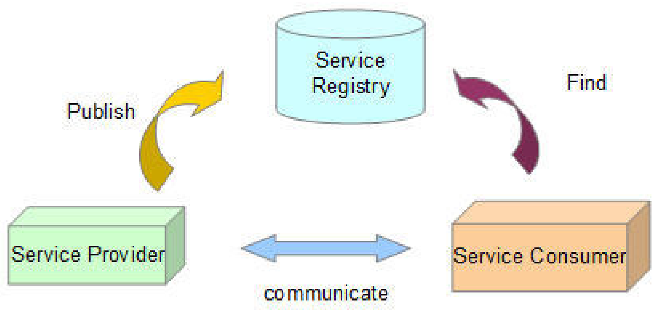


Figure 1.1 Web Service Framework

2.1.2 Types of Web Services

Web services can be categorized in three groups according to their uses:

1. **Web services as reusable application components**: There are common patterns that are used by different applications. Web services can be used for those common parts so that each application would not need to contain the common job, instead they can use the Web service fulfilling that functionality. The ideal case is that, there will only be one type of each application component, and anyone can use it in their application.
2. **Web services for connecting existing software**: Web services help solve the interoperability problem by giving different applications a way to link their data. Using Web services one can exchange data between different applications and different platforms.
3. **Web services as parts of a bigger Web service**: Usually Web services should be connected to each other as a workflow to meet the user's needs. This is known as the Web service composition problem and will be investigated in Section 2.3.

Web services can also be categorized according to the task performed inside them. There are two categories falling into this group:

1. **Information-Providing Web services**: These services can be defined as services that return information only about the initial state, and do not have any world-altering effects. Most services of this kind are stateless, i.e they only provide information about the current state of the world, but do not change that state. Services such as flight information providers, map services, temperature sensors, and cameras can be given as examples of this kind.

2. **World-Altering Web services**: If a Web service has an effect on its domain after the execution, it is accepted to be a World-Altering Web Service [5]. Services such as flight-booking programs, sensor controllers, and a variety of e-commerce and business-to-business services can be given as examples of this kind.

2.1.3 Web Services Standards

Web services may be defined and running on diverse environments. They can be mapped to any implementation language, platform, object model, or messaging system. In order to provide interoperability among applications and Web services, some standards are defined. Firstly, Web services have an interface described in a machine-processable format (specifically WSDL). Other systems interact with the Web service in a manner defined by its description using SOAP messages, typically conveyed using HTTP with an XML serialization in conjunction with other Web-related standards [25]. These standards have lowered costs and shortened development timelines. The following sections provide more detailed descriptions of these standards.

2.1.3.1 WSDL (Web Services Description Language)

The web services description language (WSDL) [13] has been developed for the necessity of a standard way of defining services. It is an XML-based language for describing Web services and methods of interacting with them along with the message format and protocol details. A WSDL document defines “services” as collections of network endpoints, or “ports” [13], and defines “binding” as a common mechanism used to attach a specific protocol or data format or structure to an abstract message, operation, or endpoint, which allows the reuse of abstract definitions. This “binding” mechanism is in practice likely to be another XML-based standard, SOAP [24].

There are two different kinds of users for WSDL documents:

- The developer: During development of an application that will use a web service, the developer needs to know the interface to the service that the application will bind to.
- The application: When the application is running it needs details of a specific implementation of that service so that it can bind to it.

WSDL describes four critical pieces of data in the definition of Web services [28]:

- Datatype information for all message requests and message responses.
- Interface information describing all publicly available functions.
- Binding information about the transport protocol to be used.
- Address information for locating the specified service.

It uses the following elements for these definitions [13]:

- Types: A container for data type definitions using some type system (such as XSD).
- Message: An abstract, typed definition of the data being communicated.
- Operation: An abstract description of an action supported by the service.
- Port Type: An abstract set of operations supported by one or more endpoints.
- Binding: A concrete protocol and data format specification for a particular port type.
- Port: A single endpoint defined as a combination of a binding and a network address.

- Service: A collection of related endpoints.

2.1.3.2 SOAP

SOAP [24] is a standard communication protocol for XML-based information exchange between distributed applications. The acronym “SOAP” once stood for “Simple Object Access Protocol” but SOAP Version 1.2 [24] doesn't define "SOAP" as an acronym anymore since it is considered to be misleading. SOAP specifies the format of the request and response XML documents and provides a platform for a distributed processing model where communication is between applications or Web services via Internet. This distributed processing model can support many message exchange patterns such as one-way messages, request/response interactions and peer-to-peer conversations.

SOAP is based on XML and consists of three parts: a SOAP envelope (describing what's in the message and how to process it); a set of encoding rules, and a convention for representing RPCs (Remote Procedure Calls) and responses. SOAP messages can be carried by a variety of network protocols; such as HTTP, SMTP, FTP, RMI/IIOP, or a proprietary messaging protocol, but mainly HTTP is used for message exchange. There is a standard way of encoding WSDL messages in SOAP to achieve interoperability. By definition, SOAP is a stateless, one-way message exchange paradigm; but applications can create more complex interaction patterns by combining such one-way exchanges.

According to the SOAP Version 1.2 specification, SOAP messaging framework consists of the following items:

- The SOAP processing model defining the rules for processing a SOAP
- The SOAP Extensibility model defining the concepts of SOAP features and SOAP modules
- The SOAP underlying protocol binding framework describing the rules for defining a binding to an underlying protocol that can be used for exchanging SOAP messages between SOAP nodes.
- The SOAP message construct defining the structure of a SOAP message.

The details of these items can be found in [24].

SOAP has an extensibility mechanism which can be used to add capabilities found in richer messaging environments. Some example features with which SOAP may be extended may be "reliability", "security", "correlation" and “routing". Also SOAP may be extended with some message exchange patterns such as request/response, one-way, and peer-to-peer conversations.

The following example from [24] shows a sample notification message expressed in SOAP.

```
<env:Envelope xmlns:env="http://www.w3.org/2003/05/soap-envelope">
 <env:Header>
  <n:alertcontrol xmlns:n="http://example.org/alertcontrol">
   <n:priority>1</n:priority>
   <n:expires>2001-06-22T14:00:00-05:00</n:expires>
  </n:alertcontrol>
 </env:Header>
 <env:Body>
  <m:alert xmlns:m="http://example.org/alert">
   <m:msg>Pick up Mary at school at 2pm</m:msg>
  </m:alert>
 </env:Body>
</env:Envelope>
```

Figure 1.2 SOAP message containing a header block and a body

2.1.3.3 UDDI (Universal Description, Discovery and Integration)

UDDI [74] is a platform independent registry system that provides a standardized way for publishing and discovering services over the Internet. It is an open industry initiative, sponsored by OASIS [72]. UDDI is itself a web service which uses World Wide Web Consortium (W3C) and Internet Engineering Task Force (IETF) internet standards such as XML, HTTP, and DNS protocols; and can be accessed via SOAP from an application that wishes to discover web services. UDDI specifies interfaces for applications to publish and discover web services. WSDL can be considered as the main interface but a UDDI entry actually contains more than just a WSDL interface and implementation, it can also include further metadata such as quality of service parameters, payment mechanisms, security and keywords for resource discovery. UDDI discovery mechanisms can be classified as both keyword and table-based.

There are three main parts of UDDI:

- White Pages: Contact information about the businesses that developed the Web services is listed.
- Yellow Pages: Web services are organized according to their categories.
- Green Pages: Technical details of offered services (WSDL descriptions) are given.

With these standards we have the infrastructure to publish (WSDL, UDDI), find (WSDL, UDDI) and bind (WSDL, SOAP) web services in an interoperable manner.

2.2 Web Service Discovery

Web service discovery is "the act of locating a machine processable description of a Web service that may have been previously unknown and that meets certain functional criteria" [11]. Generally speaking, the need for web service discovery could emerge in two phases: development phase and execution phase [22].

In the development phase the designer of the composition or an intelligent software agent discovers the services that will be necessary to build a composition. In the execution phase, instances of services matching a specific interface will be discovered, to replace or assist services already in a composition.

The challanges in service discovery are the heterogenity of the descriptions, ontological and vocabulary related disagreements and the scattered distribution of service providers.

There are several approaches to web service discovery, these are: centralized Universal Description, Discovery and Integration (UDDI) registries, specialized portals, search engines and peer to peer methods [6].

2.2.1 UDDI Registries

UDDI is an open industry initiative supervised by OASIS [72] and has been proposed as a core web service standard in 2000. UDDI specification includes APIs to allow querying and publishing information to the registry, the data model for services to be stored on the registry. Being a centralized and

XML based corporate information repository, UDDI registries were planned to be the key indexes for publicly available web services.

Since 2006, most of the publicly available UDDI registries have been discontinued and UDDI has been mostly used as an internal repository within the company networks [6]. The main reasons for the less than expected popularity of UDDI are: (i) the need for keywords, service name and manual selection of discovered services, (ii) lack of coverage of the web services available publicly (iii) the simplicity of the available search tools (iv) lack of correlations between web services and quality of service information.

There are several approaches trying to incorporate the semanticity of OWL-S with the keyword based capabilities and centralized indexing of UDDI by adding OWL-S descriptions to UDDI registries [56].

2.2.2 Specialized Portals and Search Engines

There are specialized portals and search engines for web services discovery like XMethods, BindingPoint, Web Service List and StrikeIron [6]. Most of these web sites allow the manual registration of services, and some of them also have intelligent crawlers for web service indexing themselves. Search engines such as Google also index web service descriptor documents. Using text search methods an agent can search through WSDL and OWL-S documents to find services required.

Even though the traditional search engines have a much larger database of service descriptions in contrast to specialized portals, there are no specialized query methods for the service description documents. To improve the performance of search engines in web service discovery, web service providers can use standardized vocabularies such as eClass [66] and search engine providers can implement different searching and processing routines for WSDL/OWL-S files.

2.2.3 Peer to Peer (P2P) Methods

P2P overlay networks provide infrastructures for routing information between the nodes of a decentralized environment. In a P2P web service discovery environment, the nodes of the network may also be the publishers of the services they index. Proposed P2P systems for web service discovery include CAN [47], Pastry [49] and Chord [57].

In the P2P overlay systems nodes are assigned id numbers from a global address space. Each peer in the network stores information about the network to appropriately route queries. Peers consult their lookup tables when a query is received and route the query to an appropriate peer that stores the queried key [22].

The advantage of P2P service discovery is that the users can access more up-to-date web services, since the hosts in the P2P network can publish and update their web services dynamically.

2.3 Web Service Composition

Recently, many companies and organizations prefer to implement just their core business, and outsource other applications they use by making use of web services over the Internet. So it has become an important issue finding/selecting the right web services to fulfill the given goal and integrating them easily and efficiently. But this task has become more difficult because of the poliferation of web services. It becomes even more difficult when there is no web service capable of satisfying the functionality required by the user, but there should be a combination of existing web services in order to fulfill the request. The problem of combining multiple web services to satisfy a single task is called *web services composition problem*, and a considerable amount of research has been done on it in academia and in industry [46]. Manual, semi-automated and automated solutions are proposed to the problem. In manual solutions, the user generates the workflow, finds the services and sends them to the execution engine. However due to the increase on the number of services it becomes more and more diffucult for users to deal with locating the exact services and integrating them. Semi-automated techniques facilitates user tasks by making suggestions for service selection, however the user is still responsible for constructing the workflow and making service selection from a short list [28]. Automatic techniques aim to select, combine, integrate and execute web services to achieve a user's objective automatically.

Service composition in general can be differentiated into *synthesis* and *orchestration* [31]. *Synthesis* refers to *generating a plan* how to achieve a desired behavior by combining the abilities of multiple services. In contrast, *orchestration* refers to *coordinating the control and data flow among the various components* when executing that plan [31]. Orchestration is an important problem that is complementary to synthesis. Examples of "service composition" approaches referring to orchestration include [45, 8]. In this thesis, focus is on automatic synthesis.

2.3.1 Illustrative Examples

The following is a motivating example for web service composition problem from [42]: Suppose there are two web services available: (1) *findRestaurant*: returns a name, phone number, and address of the closest restaurant provided a zip code and food preference; and (2) *findDirection* returns driving direction and a map image provided a start and destination addresses. "Sylvie" visits "State College, PA" on a business trip and stays in the "Atherton" hotel at "100 Atherton Ave, 16801, PA." Now, she wants to find a Thai restaurant near the hotel along with a driving direction. We can see that neither of two web services can satisfy the request alone. *findRestaurant* can find a Thai restaurant near the hotel, but cannot provide a driving direction. On the other hand, the web service *findDirection* can give a direction from one location to another, but cannot locate a restaurant. Therefore, one has to combine both web services to jointly satisfy the request as follows: (1) invoke findRestaurant("16801", "Thai") to get the address of the closest restaurant, say "410 S. Allen St. 16802, PA"; and (2) invoke the web service findDirection("100 Atherton Ave, 16801, PA", "410 S. Allen St. 16802, PA") to get the driving direction.

Some other examples posed to be solved with the help of automatic web service composition techniques are [5]:

- **Traveling Domain**: It is the domain of trip planning systems that offer to query and book transportation and accommodation according to user-defined constraints [27]. A typical problem of this domain is to plan a trip for a conference attendance with constraints like the date and place of the conference, preferences for certain hotels or airlines [37].

- **Appointment Scheduling Domain**: It is the domain of schedule organizing systems that offer multiple appointments according to user constraints. A typical instance is arranging a schedule after a visit to a doctor that involves tasks of prescription filling in pharmacy, diagnostic tests in different medical test centers and a final follow-up meeting with the doctor [9].
- **Commercial Sale Domain**: It is the domain of electronic sale system that offers purchasing of items according to customer constraints or quality of service (QoS) [60] parameters. For instance a customer wants to buy a microprocessor but s/he does not want to know where or how to buy the item [36].

2.3.2 Techniques for Web Service Composition

As the need for the web services composition is grown, several techniques have been risen up for this area. There are several composition languages that have been proposed for defining the web services composition, such as BPML [2], IBM's WSFL [26, 33], Microsoft's draft of XLANG [59], and Business Process Execution Language for Web Services (BPEL4WS) [1]. Almost all of these flow languages use/extend WSDL as the web service definition language.

XLANG models the entities as services and specifes interaction among their operations using *contract* construct. The details of how a service performs its work are given in the *behaviour* section using any of sequential, concurrent, conditional, loop and non-deterministic constructs. The main differences between XLANG and WSFL are that XLANG does not provide for separate control and data link specification, and it has support for delay and rollback-recovery (called compensation) of operations.

BPEL descriptions are XML documents, which describe the roles involved in the message exchange, supported port types and orchestration, and correlation information as aspects of a process. BPEL4WS is a service composition model, which supports both, composition and coordination protocols. It also consists of an activity-based component model, an orchestration model that allows the definition of structured activities, XML schema data types, a service selection model and a mechanism for exception, event and compensation handling. BPEL4WS has become a standard for defining the business process for the Web services composition later.

Despite all these efforts, web service composition is still a very complex and challenging task, and dealing with it manually is beyond the human capability. The problems with it can be listed as follows [46]: First, the number of services available over the web increases dramatically during the recent years, and one can expect to have a huge web service repository to be searched. Second, web services can be created and updated on the fly, thus the composition system needs to detect the updating at runtime and the decision should be made based on the up to date information. Third, web services can be developed by different organizations, which use different models to describe the services, but, there does not exist a universal language to define and evaluate the web services in an identical means. Therefore, building composite web services with an automated or semiautomated tool is a very critical issue.

Before performing a web service composition, some basics to enable service composition have to be performed. Six different issues that have a large impact on service composition have been identified: Coordination, transaction, context, conversation modelling, execution monitoring, infrastructure. Details can be found in [17].

Web service composition methods can be grouped according to the following categories of composition strategies:

- Static or dynamic composition strategies
- Model driven service composition
- Business rule driven service composition
- Declarative service composition
- Automated or manual service composition
- Small or large scale composition
- Compositions using simple or complex operator
- Template-based, interface-based, and logic-based systems

We will investigate the automated service composition methods in the following section. Details about the other categories can be found in [42], [17] and [20].

2.3.3 Automated Web Service Composition

Automated web service composition allows service consumers to generate and change the composition structure on the fly and adapt it to changing conditions. Despite its difficulties, dynamic service composition provides several benefits to the emerging applications, namely, flexibility, adaptability, and availability. It accelerates rapid application development, service reuse, and complex service creation.

2.3.3.1 Web Services Composition Framework

A general framework for automated web services composition is proposed in [46] and depicted in Figure 2.3.

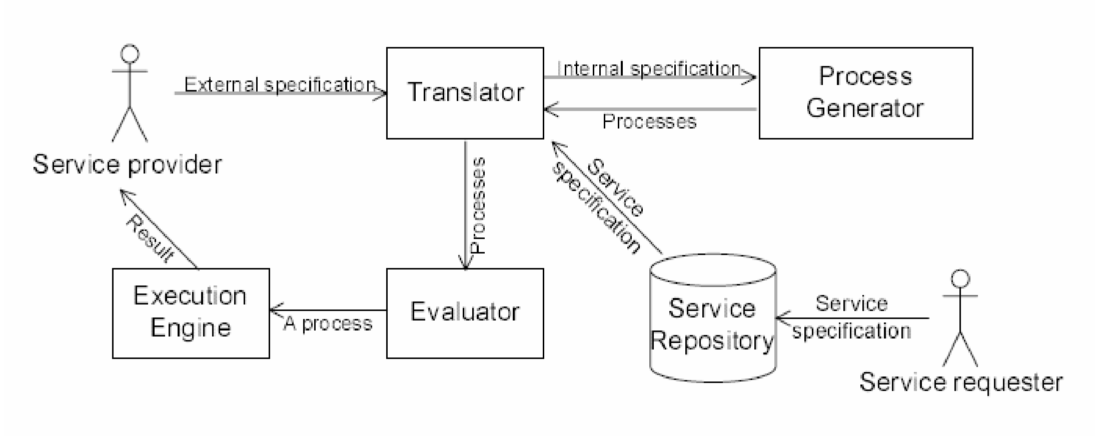


Figure 1.3 The Framework of the Service Composition System

This composition system has two kinds of participants, service provider and service requester. The service providers propose Web services for use. The service requesters consume information or services offered by service providers. The translator translates between the external languages used by the participants and the internal languages used by the process generator. For each request, the process generator tries to generate a plan that composes the available services in the service repository to fulfill the request. If more than one plan is found, the evaluator evaluates all plans and proposes the best one for execution. The execution engine executes the plan and returns the result to the service provider. Then the provider sends the result to the requestor.

2.3.3.2 Automatic Web Service Composition Methods

For automatic composition of web services, several techniques have been proposed, which define how the process generator in Figure 2.3 generates the process. The automation in this context means that either the method can generate the process model automatically, or the method can locate the correct services if an abstract process model is given [46]. These methods can be grouped under two categories: Workflow based and AI planning based methods. These categories will be explained in the following sections with example methods for each group.

2.3.3.2.1 Workflow Based Composition Techniques

When composing web services, the business logic of the client is implemented by several services. The definition of the service composition includes a set of atomic services with the control/data flow information among them. This is analogous to workflow management, where the application logic is realised by composing autonomous applications. The current achievements on flexible workflow, automatic process adaption and cross-enterprise integration provide the means for automated web services composition as well. In addition, the dynamic workflow methods provide the means to bind the abstract nodes with the concrete resources or services automatically [46].

There are two kinds of workflow generation techniques [46]:

- **Static Workflow Generation**: With this technique, the abstract process model should be provided by the client prior to planning. The abstract process model includes a set of tasks and their data dependency. Each task contains a query clause that is used to search the real atomic web service to achieve the task. In this technique, only the selection and binding of atomic web service is done automatically. Most commonly, the process model is provided to the tool as a graph, but methods are also included using a language to represent the model. This language may be a commonly used standard or may be specifically defined for the tool in question.

EFlow [12] uses static workflow generation methods where a composite process is modelled as a graph manually and may be updated dynamically. The graph may include service, decision and event nodes. The tasks in the workflow are however not semantically annotated. Automatic discovery of web services is based on a definition contained in each service node in the graph.

- **Dynamic Workflow Generation**: With this technique the process model is also created automatically in addition to the selection and binding of atomic services. In this case, the client should specify the constraints of the composition. More information on this technique can be found in [40] and [16]. These research are based on homogenous environments and require no mediation amongst services.

2.3.3.2.2 AI Planning Based Composition Techniques

Given a set of goals and a set of process specifications, it is possible to derive a sequence of process instances which can accomplish those goals using AI planning methods. AI planning methods are widely used for the web service composition problem. The reason for this is the great similarity between these two fields, and the high maturity level of the AI planning methods. Both the planning problem and composition problem seek a (possibly partially) ordered set of operations that would lead to the goal starting from an initial state (or situation). Operations of the planning domain are actions (or events) and operations of the composition domain are the web services [1414]. To apply AI planning methods to automatic web service composition problem, services are represented as actions having parameters, preconditions, results and effects; and service composition is treated like a planning problem. With this approach each web service is first translated to a planning operator, the objective is expressed as a logical condition, and the planner generates a plan which is essentially a sequence of web service instances; that is, a sequential composition that causes the goal condition to be true upon execution [54]. The AI planning methods are used when the requester has no process model but has a set of constraints and preferences; hence the process model can be generated automatically by the program [46].

Using AI planning techniques for web services composition introduces some challenges which are defined in [32] as follows: The traditional planning systems assume that the planner begins with complete information about the world. However, in web service composition problem, most of the information (if it is available) must be acquired from the web services, or may require prior use of such information-providing services. In many cases, however, it is not feasible or practical to execute all the information-providing services up front to form a complete initial state of the world. Some other challenges can be found in [54].

Viewing the composition problem as an AI planning problem, different planners are employed for the solution. Here, some of the existing work are highlighted.

- **Situation Calculus:** In [37], McIlraith and others presented a method to compose web services by applying logical inferencing techniques on predefined plan templates. This technique focuses on the process-centric description of services as actions that are applicable in states. The states of the world and the world-altering actions are modeled as Golog programs, and the information-providing services are modeled as external functions calls made within those programs. Golog is a logic programming language built on top of the situation calculus and it supports specification and execution of complex actions in dynamical systems. Semantic representations of state, actions, goals are needed for composing services. The service capabilities are annotated in DAML-S/RDF and then manually translated into Prolog. The goal is stated as a Prolog-like query and the answer to that query is a sequence of world-altering actions that achieves the goal, when executed in the initial state of the world. During the composition process, however, it is assumed that no world-altering services are executed. Instead, their effects are simulated in order to keep track of the state transitions that will occur when they are actually executed.

- **Hierarchical Task Network Planning**: An approach using HTN planning was proposed in [55], facilitating the SHOP2 system [41]. This approach is based on the relationship between OWL-S used for describing web services and *Hierarchical Task Networks* as in HTN Planning. OWL-S processes are translated into tasks to be achieved by the SHOP2 planner, and SHOP2 generates a collection of atomic process instances that achieves the desired functionality. The advantage of the approach is its ability to deal with very large problem domains [44], and authors claim that the HTN planner is more efficient than other planning languages, such as Golog.

- **PDDL**: PDDL, the “Planning Domain Definition Language" [23], is a widely accepted language for expressing planning problems and domains. It allows to describe the requirements of planning domains and the capabilities of planners in a uniform way. This enables to easily select the best suited planner for a particular composition task. The structure of it is also very similar to DAML-S. For web service composition, DAML-S descriptions could be translated to PDDL format, so that different planners could be exploited for further service synthesis. A PDDL based tool for automatic web service composition is presented in [43]. The tool transforms web service composition problems into AI planning problems and delegates them to the planners most suitable for the particular planning task.

- **Graph Based Planning**: Generally, the graph based planning consists of two interleaved phases: extending the planning graph, and searching for plans. A planning graph is a directed leveled graph as in Figure 2.4 [62].

  Graphplan [10] is the first planning algorithm using a planning graph. It consists of two kinds of alternating levels, state levels and service levels. The first level consists of initial states. The second level consists of services whose preconditions are present in the first level. The third level consists of the states appearing in the first level and the states brought by the services in the second level as their effects. In this way the graph is extended by state levels and service levels alternatively.

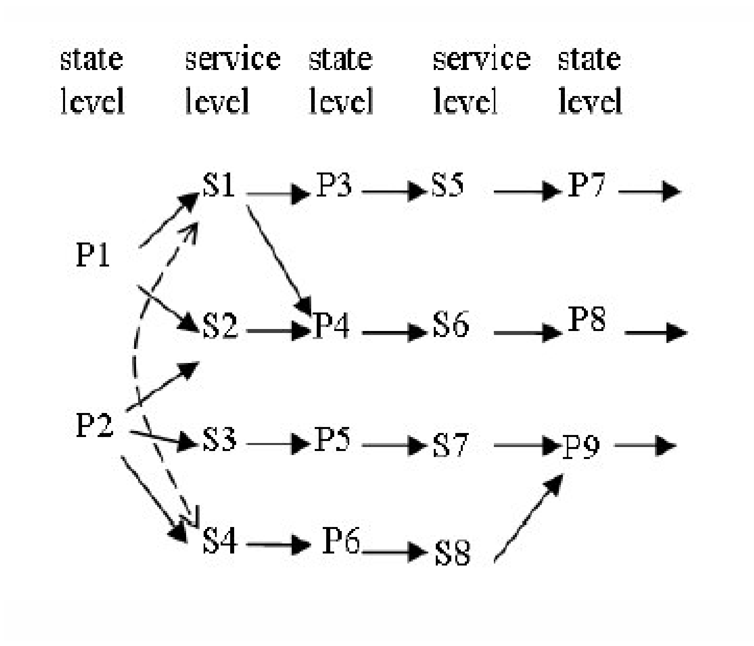


Figure 1.4 Planning Graph

When the graph reaches a level where all goal states are present, the algorithm searches for plans. Graphplan uses a backward search to extract a plan and allows for partial ordering among actions. A valid plan is a subgraph satisfying some conditions [10].

- **Estimated Regression Planning:** Estimated-Regression is a planning technique in which the situation space is searched with the guide of a heuristic that makes use of backward chaining in a relaxed problem space [36]. A regression planner starts with a state satisfying the goal and searches for action instances that bring the planner closer to the initial state. To apply this method to composition domain, the *estimatedregression* planner called Optop [36] translates the composition problem to a PDDL planning problem and tries to solve it. As an instance of the General-WSC procedure, a state is a *situation* in Optop, which is essentially a partial plan. The solution function checks whether the current situation satisfies the conjunction of the goal literals given to the planner as input, and the children-of function computes a regression-match graph and returns the successors of the current situation [4].

2.4 OWL-S

OWL -short for Web Ontology Language- is a semantic markup language for publishing and sharing ontologies on the World Wide Web according to W3C [7]. It is used as the language for defining compositions in this thesis.

OWL-S -formerly DAML-S- is built on OWL, and is used for describing semantic web services. OWL-S has been developed within the DARPA/DAML program and currently is a W3C recommendation. OWL-S is serialized using RDF/XML syntax.

The need for OWL-S arose with the emergence of semantic web. With semantic web, software agents will be able to access content on the web easily. Software agents should also be able to discover, invoke, compose and monitor services on the Web easily, with a high level of automation [34].

This need can be fulfilled by OWL-S, which provides constructs for defining semantic web services that can be interpreted easily by computers.

An OWL-S specification for a web service can be formed of three main parts, which are:

- **Profile**: for service advertisement and discovery
- **Process**: for describing service's operation model in detail
- **Grounding**: for disclosing technical details on how to communicate with the service.

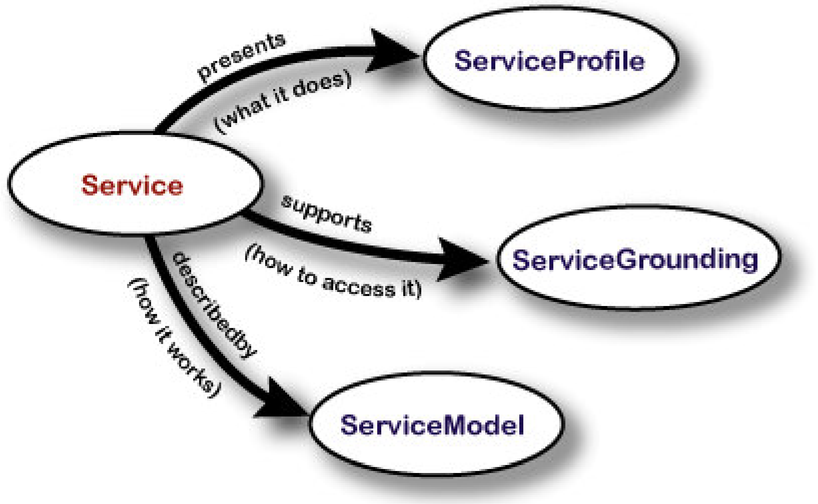


Figure 1.5 OWL-S Model

2.4.1 Service Profile

Service profile section of an OWL-S documents is aimed for both human reading and service seeking agents, and includes service name, description and contact information about the publisher. This part does not directly contribute to the semantics of the service description, unless software agents use text mining techniques.

A service-seeking agent or a matchmaking agent assisting a service-seeking agent can use the service profile to see whether the service meets its needs [34].

Service profile includes a “serviceCategory” section, which refers to an ontology of services that are offered. High level services can include classification on top of industry taxonomies (i.e. NAICS [71]). A sample profile specification for an airline company is provided below:

```
<profile:serviceCategory>
     <addParam:UNSPSC rdf:ID="UNSPSC-category">
          <profile:value>Travel Agent</profile:value>
          <profile:code>90121500</profile:code>
     </addParam:UNSPSC>
</profile:serviceCategory>
```

Using process ontology, service profiles can model inputs, outputs, preconditions and effects (hereafter called IOPEs) of the related process. These IOPEs, just like the profile itself are useful until the service selection is made, because once the service is selected the client will use the Process Model of the service to interact with it, thus the Process Model in a way subsumes the information contained in the Service Profile.

2.4.2 Process Model

Process model of the service describes how a software agent can interact with the service. An atomic process is a service which responds with a set of outputs when provided a set of inputs in a single step. A composite process is a set of services in which the client advances its state by communicating with sub-processes step by step.

There are two main types of services: information providing and world altering services, as defined in Section 2.1.2. While inputs and outputs are used to model information providing services, preconditions and effects are used to model world altering services.

The process model includes the set of inputs and outputs of each service. For composite service definitions, the input-output bindings are also provided to describe the data flow of the composition (i.e. where a service's output is the input of another service). Input/output bindings carry an important role in service composition since all the connectivity relies on them. A sample output binding is provided below:

```
<process:OutputBinding>
     <process:toParam rdf:resource="#PreferredFlightItinerary"/>
     <process:valueSource>
          <process:ValueOf>
             <process:theVar
             rdf:resource="#BookFlight_PreferredFlightItinerary"/>
          <process:fromProcess rdf:resource="#PerformBookFlight"/>
          </process:ValueOf>
     </process:valueSource>
</process:OutputBinding>
```

In the above example, *BookFlight_PreferredFlightItinerary* output from the atomic *PerformBookFlight* process is bind to *PreferredFlightItinerary* output of the current composite process.

Process model also contains the preconditions and outputs for the included services. These constructs can be described in logical languages such as

DRS (Discourse Representation Structures), SWRL (Semantic Web Rule Language) or KIF (Knowledge Interchange Format) [73]. A sample precondition with SWRL is provided below:

```
<expr:expressionBody rdf:parseType="Literal">
     <swrl:AtomList>
          <rdf:first>
               <swrl:ClassAtom>
               <swrl:classPredicate rdf:resource="#LoggedIn"/>
               <swrl:argument1 rdf:resource="#AcctName"/>
               </swrl:ClassAtom>
          </rdf:first>
          <rdf:rest rdf:resource="&rdf;#nil"/>
     </swrl:AtomList>
</expr:expressionBody>
```

In the above example, the condition examines whether the given account name variable is logged in, by checking its class.

Preconditions are meant to be evaluated in the client side, and limit the range of inputs and states that are to be used while invoking a service. When the preconditions of a process are met and inputs are provided, the associated outputs and effects (as a couple called “results”) in the process should occur.

Composite processes and control constructs are also specified in the process model, which are examined in detail in Section 2.4.4 below.

2.4.3 Service Grounding

The grounding part of the OWL-S description contains the wiring information for the given service. Communication protocols, message formats, url addresses and port numbers are specified in this part.

Since OWL-S 1.1, grounding specification targets WSDL 1.1. The grounding specifications are made in *WsdlGrounding* element, which is just a collection of *WsdlAtomicProcessGrounding* elements. Each instance of *WsdlAtomicProcessGrounding* denotes a one to one correspondence between an atomic process defined in OWL-S and a WSDL operation.

2.4.4 Service Composition with OWL-S

There are three types of processes in OWL-S: atomic processes, simple processes and composite processes. The atomic processes are services that can be directly invoked with groundings, and they do not contain any sub-processes. They execute at a single step.

A simple process is an abstraction of a process, atomic or composite. It does not contain a grounding, therefore it is not executable. The reason for a simple process is to enable easier planning for software agents. In the OWL-S description, a simple process can be realized by an atomic process or expanded to a composite process.

Composite processes are composed of atomic or other composite processes, via control constructs such as Sequence, If-Then-Else, Split-Join etc. These control constructs are defined in OWL-S process ontology. A composite process is not a program that gets automatically invoked by itself once the inputs for the initial process are provided, rather the client can follow the steps described by the composition with the specified inputs to get the expected outputs. The types of compositions available in OWL-S are examined in the next section.

2.4.4.1 Sequence

A Sequence construct lists a series of atomic or composite processes to be executed in the specified order. A sample process with Sequence structure is provided below:

```
<process:composedOf>
   <process:Sequence>
      <process:components>
         <process:ControlConstructList>
           <list:first>
             <process:Perform rdf:ID="PerformProcess1">
               <process:process rdf:resource="#Process1" />
             </process:Perform>
           </list:first>
           <list:rest>
             <process:ControlConstructList>
               <list:first>
                 <process:Perform rdf:ID="PerformProcess2">
                   <process:process rdf:resource="#Process2" />
                 </process:Perform>
               </list:first>
               <list:rest rdf:resource="&shadow-rdf;#nil" />
             </process:ControlConstructList>
           </list:rest>
         </process:ControlConstructList>
      </process:components>
   </process:Sequence>
</process:composedOf>
```

In the above example, a composite process with a Sequence of two processes is decribed (data flow is intentionally left out). The client is expected to invoke Process1 and Process2 in the given order.

2.4.4.2 If-Then-Else

The If-Then-Else construct has an *if* condition, *then* case and *else* case. The *if* condition can be represented in one of the aforementioned logical languages. A sample If-Then-Else construct is provided below. In this example, the TestVariable is tested whether it is of the TestClassPredicate class, and if it is, *Then* process, if not the *Else* process is executed by the client.

```
<process:If-Then-Else>
  <process:ifCondition>
   <expr:SWRL-Condition>
      <rdfs:label>IfCondition</rdfs:label>
      <rdfs:comment>This condition is an if condition</rdfs:comment>
      <expr:expressionBody rdf:parseType="Literal">
         <swrl:AtomList>
         <rdf:first>
         <swrl:ClassAtom>
         <swrl:classPredicate rdf:resource="#TestClassPredicate"/>
         <swrl:argument1 rdf:resource="#TestVariable" />
         </swrl:ClassAtom>
         </rdf:first>
      <rdf:rest rdf:resource="&rdf;#nil" />
         </swrl:AtomList>
      </expr:expressionBody>
   </expr:SWRL-Condition>
  </process:ifCondition>
  <process:then>
   <process:Perform rdf:ID="PerformThen">
      <process:process rdf:resource="#Then" />
   </process:Perform>
  </process:then>
  <process:else>
   <process:Perform rdf:ID="PerformElse">
      <process:process rdf:resource="#Else" />
   </process:Perform>
  </process:else>
</process:If-Then-Else>
```

2.4.4.3 Split

Split, is an asynchronous construct, which contains a bag of processes instead of a list of processes to be executed. When a Split composition is invoked, all the processes in the construct are scheduled for execution at the same time and the composite process is completed right after the scheduling. The responses of the individual processes in the Split bag are not waited.

2.4.4.4 Split+Join

Split+Join is a similar construct to a Split construct in the sense that it contains a bag of processes, and does not have an ordering amongst the processes it contains, but unlike the Split construct it carries a synchronous nature. The Split+Join composite process returns response when each and every individual process returns response.

2.4.4.5 Any-Order

In an Any-Order composition, an unspecified ordering is made within a bag of processes that are defined by the composition, and all the responses of the child processes are awaited by the composite processes. This construct is different than a Split+Join construct since the execution of the individual services can not be concurrent, they can not overlap, and different from the Sequence construct since the ordering of the bag of services is not specified explicitly, they can be executed in any order the client requests.

```
<process:composedOf>
  <process:Any-Order>
   <process:components>
      <process:ControlConstructBag>
         <list:first>
            <process:Perform rdf:nodeID="Perform1" />
         </list:first>
         <list:rest>
            <process:ControlConstructBag>
               <list:first>
                  <process:Perform rdf:nodeID="Perform2" />
               </list:first>
               <list:rest rdf:resource="&list;#nil" />
            </process:ControlConstructBag>
         </list:rest>
      </process:ControlConstructBag>
   </process:components>
  </process:Any-Order>
</process:composedOf>
```

In the above example, the processes contained in Perform1 and Perform2 are executed in any order the client requests.

2.4.4.6 Choice

The Choice construct specifies a bag of services, from which the client should select one and execute. This construct is useful in the cases where identical services are replicated and defined for backup or redundancy purposes.

2.4.4.7 Repeat-Until and Repeat-While

Both of these iterable constructs provide a way to re-initiate service calls until a condition becomes true or false. Repeat-While tests the condition and proceeds with the operation and stops if the condition becomes false. Repeat-Until does the operation, tests the condition and stops if the condition becomes true. Since the condition test is made after the operation in the Repeat-Until construct, the related service is invoked at least once.

2.5 Event Calculus

2.5.1 The Formalism, Predicates and Axioms of the Event Calculus

In situation calculus [35], a changing world is represented by a discrete and strictly ordered sequence of "snapshots", each representing the complete state of the world at a given instant. It is hard to represent partially ordered or simultaneous events, or continuous change in situation calculus because of this structure. To overcome this problem, several new formalisms were developed. The introduction of the event calculus from Kowalski and Sergot [30] is one such formalism. It is a logic programming paradigm for representing events (or actions) and their effects, especially in database applications [53]. Here, actions/events mean the activities which have an effect on the fluents in the world around them, and fluents are properties that can hold or not hold. A number of alternative formulations, implementations and applications of the Event Calculus have sprung up, aiming to accommodate constructs intended to enhance the expressiveness of event calculus. These new dialects have been developed in a number of logic programming forms; in classical logic , in modal logic and as an "action description language". In these forms, event calculus is extended in the context of many different areas including planning, abductive reasoning, etc [38]. One such extension is introduced by Murray Shanahan in [52, 53]. In the event calculus described by Kowalski and Sergot, all change is discrete. But it needs to be extended to be able to represent continuously changing quantities. [52] presents such an extension and the event calculus version discussed here will be this version. It is based on first-order predicate calculus with circumscription, and is capable of representing a variety of phenomena, including actions with indirect effects, actions with non-deterministic effects, compound actions, concurrent actions, and continuous change. This version also presents a straightforward solution to the frame problem.

The event calculus can be defined as a logical mechanism that infers what's true when given what happens when and what actions do. The "what happens when" part is the plan (temporal ordering, sequence of *Happens(…)* and a description of the initial state); and the "what actions do" part is the domain dependent sentences and information about the effects of actions. The "what actions do" part describes the effects of events described in "what happens when" part. Figure 2.6 from [53] shows this graphically.

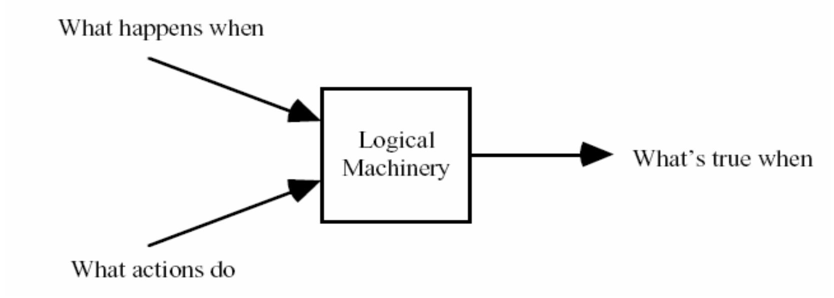


Figure 1.6 How the Event Calculus Functions

In the event calculus, some predicates are used in order to define the theory of a specific problem domain, i.e for saying what happens when, for describing the initial situation, for describing the effects of actions, and for saying which fluents hold at what times. Figure 2.7 [5] lists some of these predicates.

Predicate	Meaning
$T_1<T_2$	Time point T_1 precedes time point T_2 in the time line.
Happens(E, T_1, T_2)	Event E happens during time frame between T_1 and T_2 where $T_1<T_2$.
Happens(E, T)	Instantaneous Event E happened at T defined as Happens(E, T, T).
HoldsAt(F, T)	Fluent F holds at time T.
Initially(F)	HoldsAt(F, T_0) where T_0 is the time of the initial state.
Initiates(E, F, T)	HoldsAt(F, T) when Happens(E, T, T_A).
Terminates(E, F, T)	HoldsAt($\neg$F, T) when Happens(E, T, T_A).
Releases(E, F, T)	Valuation of Fluent F is released, removing the inertial constraints on it.
Clipped(T_1, F , T_2)	HoldsAt(F, T) where $T_1< T <T_2$
Declipped(T_1, F , T_2)	HoldsAt($\neg$F, T) where $T_1< T <T_2$

Figure 1.7 Event Calculus Predicates

The “what happens when” part in Figure 2.6 corresponds to the predicates “Initially” and “Happens”; the “what actions do” part corresponds to the “Initiates” and “Terminates” predicates; and “what’s true when” part corresponds to the “HoldsAt” predicate.

Event Calculus representations consist fundamentally of the following constructs [61]:

1. **Domain dependent sentences**: Sentences which explain the effects of actions and provide information about initial states:
   Initiates(α,β,τ): Action α initiates fluent β at some time point τ
   Terminates(α,β,τ): Action α terminates fluent β at some time point τ

2. **Domain independent axioms**: These axioms are the heart of the event calculus. They define which fluents hold and do not hold at specific time points. The definitions of these axioms are as follows.

   - The predicates *Clipped/Declipped* define a time frame for a fluent that is overlapping with the time frame of an event which initiates/terminates or releases this fluent respectively [5]. Relevant axioms are:
     $Clipped(t1,f,t4) \leftrightarrow \exists a,t2,t3\ [\ Happens(a,t2,t3) \wedge t1 < t3 \wedge t2 < t4 \wedge$
     $[\ Terminates(a,f,t2) \vee Releases(a,f,t2)]\ ]$
     $Declipped(t1,f,t4) \leftrightarrow \exists a,t2,t3\ [\ Happens(a,t2,t3) \wedge t1 < t3 \wedge t2 < t4$
     $\wedge\ [\ Initiates(a,f,t2) \wedge Releases(a,f,t2)]\ ]$

- The axioms that define whether a fluent holds since the initial state are as follows. A fluent holds at some time t if it was initially true and has not been terminated (clipped):
  $HoldsAt(f,t) \leftarrow Initially(f) \wedge \neg Clipped(0,f\ t)$

  A fluent does not hold at some time t if it was initially held but was terminated (declipped):
  $\neg HoldsAt(f,t) \leftarrow Initially(f) \wedge Declipped(0,f,t)$

- The axioms that define whether a fluent holds or not at a specific time are as follows. A fluent holds at some time t3 if an event happens before t3 which initiates the fluent and the fluent is not terminated during the event (clipped):
  $HoldsAt(f,t3) \leftarrow Happens(a,t1,t2) \wedge Initiates(a,f,t1) \wedge t2 < t3 \wedge$
  $\neg Clipped(t1,f,t3)$
  A fluent does not hold at some time t3 if an event happens before t3 which terminates the fluent and the fluent is not initiated during the event (declipped):
  $\neg HoldsAt(f,t3) \leftarrow Happens(a,t1,t2) \wedge Terminates(a,f,t1) \wedge t2 <t3 \wedge$
  $\neg \mathrm{Declipped(t1,f,t3)}$

3. **Goal:** Goals indicate specific times when certain events occurred. They are a finite conjunction of *HoldsAt(…)* predicates and optionally *Happens(…)* clauses.
4. **Narrative:** A finite sequence of *Happens(…)* predicates and temporal orderings, such as "*t1<t2*" meaning that t1 occurs before t2.
5. **Initial situation**: It is used to describe the state of fluents at the initial time. The initial situation is not mandatory.

Initallyp(β): Fluent β initially holds at the start time point.

6. **Uniqueness of names**: This defines a common sense rule that actions are unique and are not identical to other actions.

2.6 Planning with the Event Calculus

2.6.1 Basic Concepts

A plan is a sequence of actions that allows you to achieve a desired goal. There are two kinds of plans:

1. **Total ordered plans**: The sequence of actions in the plan are totally ordered, so no parallel execution is possible.
2. **Partial ordered plans**: They consist of a partially ordered list of actions, that are either ordered before or after another and some actions are unordered, so parallelism is supported.

Figure 2.8 illustrates graphical representations of these kinds of plans.

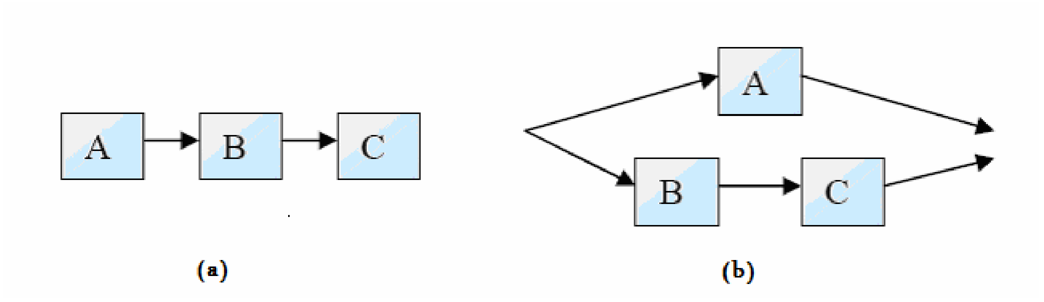


Figure 1.8 (a) Total order plan (b) Partial order plan

The event calculus supplies a logical foundation for *deductive, abductive,* and *inductive* reasoning in the following ways [53]:

- **Deduction**: In a deductive task, “what happens when” and “what actions do” are given and “what’s true when” are required. Deductive tasks include temporal *projection* or *prediction*, where the outcome of a known sequence of actions is sought.
- **Abduction**: In an abductive task, “what actions do” and “what’s true when” are supplied, and “what happens when” is required. In other words, a sequence of actions is sought that leads to a given outcome. Examples of such tasks include temporal *explanation* or *postdiction*, certain kinds of *diagnosis*, and *planning*.
- **Induction**: In an inductive task, “what’s true when” and “what happens when” are supplied, and “what actions do” is required. In this case, we’re seeking a set of general rules, a theory of the effects of actions, that accounts for observed data. Inductive tasks include certain kinds of *learning, scientific discovery*, and *theory formation*.

2.6.2 The Abductive Theorem Prover (ATP)

The event calculus has been used mainly for deductive reasoning in database applications. Developing a notation to represent actions and change is the fundamental issue with AI planning. The event calculus representation is suitable for this, and Kave Eshghi was the first to show that the event calculus could be used for planning using abduction instead of deduction [18]. Shanahan further improved this by encoding the event calculus axioms in meta-level and presented this meta-interpreter planning system written in Prolog language in [50] as an abductive theorem prover (ATP) which is a second order logical prover. Several other abductive event calculus planners were developed. In this thesis the one Shanahan described in [50], and extended in [5] to cover issues related with service composition will be used since it goes beyond the work of its predecessors.

For the plan generation phase, the initial state and the goal clause are defined and provided to the planner and abduction is used for finding out the plans as web service compositions to reach the goal. The abductive theorem prover (ATP) returns a set of time stamped events that would lead the plan from the initial state to the goal. Multiple plans are found with the help of backtracking mechanism of Prolog. The generated plans are sets of events represented by *happens* predicates and the temporal relationship between them represented by *before* predicates.

2.6.2.1 Generation of Plans

ATP takes a list of goal clauses and tries to find out a plan that contains the narrative. It tries to solve the goal list proving the elements one by one. Abductive planning continues until all axioms which are unified with goal clauses are proved.

During the resolution, abducible predicates, which are *before* and *happens*, are stored in a residue to keep the record of the narrative. This process is depicted in Figure 2.9 [5].

The axioms for the process are not directly written as implications but they are defined inside the predicate *axiom* in order to gain control of the abduction process. By adding a meta-level predicate this way, normal flow of Prolog is altered and an extra degree of control is added which makes it possible to adjust the order in which the subgoals of *holds_at* are solved. For example, although the *initiates* predicate is resolved immediately, further work on the sub-goals of *initiates* is postponed until the resolution on *happens* and *before* to prevent looping. Also, the predicate *Ab* is used to denote the theorem prover. During the process, axiom bodies are resolved by the *Ab* and this technique allows *Ab* to reach bodies of the axioms.

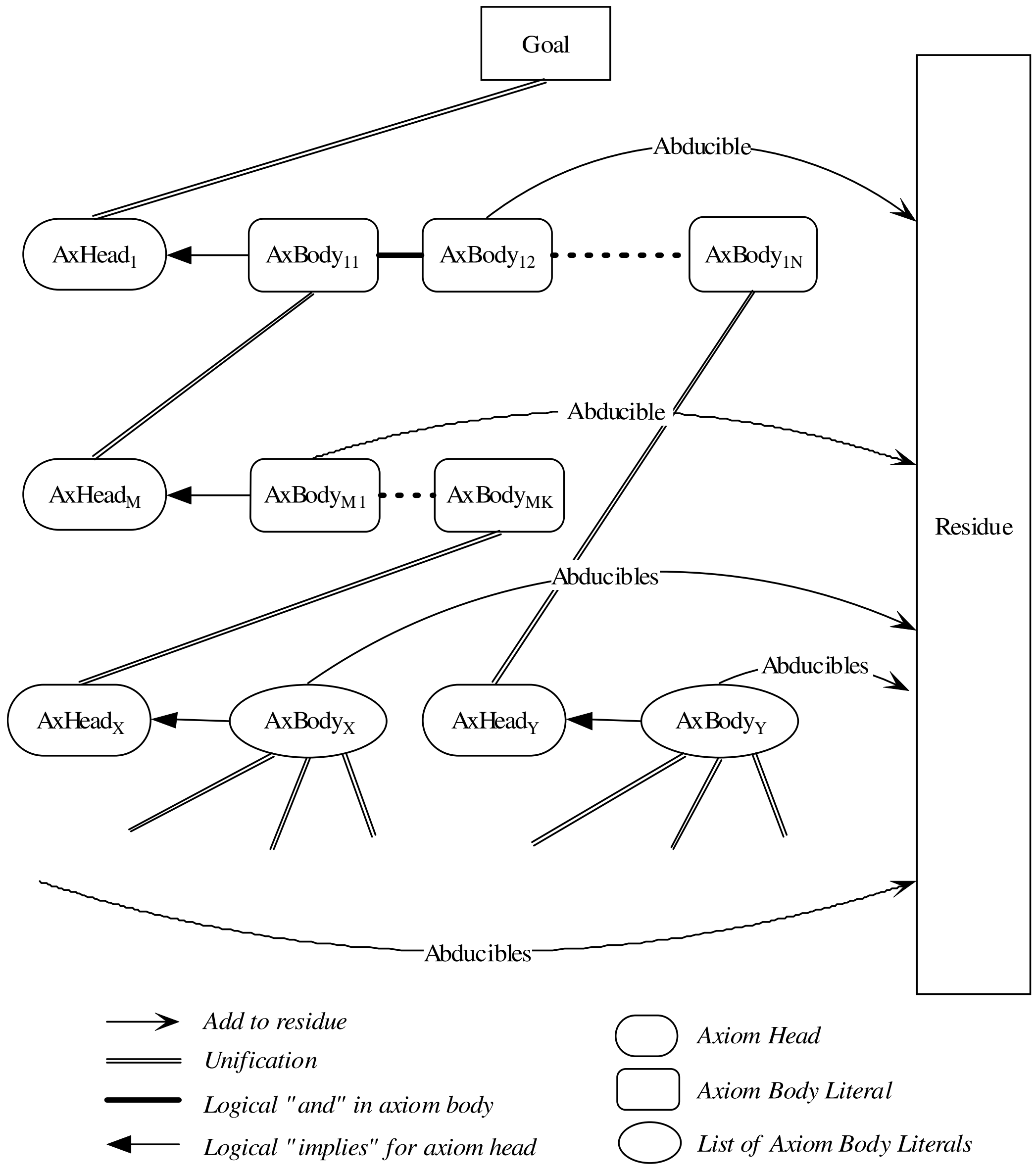


Figure 1.9 Abductive Theorem Proving

The goal of the ATP is to find out a residue containing the narrative, given a list of goal clauses. For each specific object level axiom of the event calculus, a meta-level Ab solver rule is written. The following examples of this are taken from [5].

In the object level axiom below, AH is the head of the axiom and AB_1 to AB_N is the body definition of the axiom:

$$AH \leftarrow AB_1 \wedge AB_2 \wedge \ldots \wedge AB_3$$

This axiom is translated to the following predicate form for the ATP:

$$\text{Axiom } (AH, \{AB_1, AB_2, \ldots, AB_N\})$$

Axiom bodies are resolved by *Ab* but not Prolog itself since *Ab* populates the *abducibles* inside the residue [5]. A simple version of *Ab* solver which solves general axioms is as follows, such that *RL*:residue list, *GL:* goal list, *A*: axiom head and *AL:* axiom body:

$$Ab(GL, RL) \leftarrow GL = \varnothing$$

$$Ab(\{A\} \text{ U } GL, RL) \leftarrow Abducible(A) \wedge Ab(GL, \{A\} \text{ U } RL)$$

$$Ab(\{A\} \text{ U } GL, RL) \leftarrow Axiom(A, AL) \wedge Ab(AL \text{ U } G, RL)$$

Abducible literals are declared via the *Abducible* predicate, and are added to the residue. The axioms which are not abducible are inserted into the goal list to be resolved with other axioms.

When negative axioms are to be proven, a technique called *negation-as-failure* is used to prove it. When literals added to the residue, previously proved negated goals may no longer be provable. This is because the negations of axioms are proven according to the absence of contradicting evidence, but the new members of residue might change it by proving the axioms positive. So negated goals have to be recorded and rechecked each time the residue is modified. An Ab version handling negated axioms is as follows [50]:

$$
\begin{aligned}
&Ab(GL, RL, NL) \leftarrow GL = \varnothing \\
&Ab(\{A\} \cup GL, RL, NL) \leftarrow Abducible(A) \wedge \\
&\qquad Consistent(NL, \{A\} \cup RL) \wedge Ab(GL, \{A\} \cup RL, NL) \\
&Ab(\{A\} \cup GL, RL, NL) \leftarrow Axiom(A, AL) \wedge Ab(AL \cup G, RL, NL) \\
&Ab(\{\neg A\} \cup GL, RL, NL) \leftarrow Irresolvable(\{A\}, RL) \wedge \\
&\qquad Ab(AL \cup G, RL, \{A\} \cup NL)
\end{aligned}
$$

The last argument of the Ab predicate (NL) is a list of negated goals, which is recorded for subsequent checking.

In this chapter, introductory information about the technologies and concepts used in this work has been given. OWL-S is used as the language for web service composition definitions in our work. For generating the steps leading an application from an initial state to a goal state, AI planning methods are used. Specifically, an abductive event calculus planner is employed for resolving the intervening steps constituting the actions which are the solutions to the composition problem.

CHAPTER 3

EVENT CALCULUS AND WEB SERVICE COMPOSITION

The event calculus, described in the previous chapter, serves as the framework for representing the web service compositions and applying abductive theorem proving techniques. In this chapter, methods for achieving these issues will be investigated.

3.1 Architecture of the System

In our system, generic web service composition definitions are taken, and they are translated to event calculus domain for finding the possible plan set with the abductive planner. A subset of OWL-S ontology is used as the language for the generic composition definition. The generic composition definition is translated to event calculus axioms in Prolog language as compound events. The abductive planner in event calculus generates the plans which would lead the user to the desired goal on execution. Figure 3.1 shows the architecture of our system graphically

In the planning process, the planner is in a continuous interaction with the real world to get the available services which can be used in the plan in order to achieve the goal. The plan acquires its structure step by step with this information on the discovered services. In a single step of planning, a separate plan is generated for each discovered service for the step in question. The list of generated plans is then presented to the user in an interactive graphical user interface for selection of the preferred plan for execution. The preferred plan is then executed with the parameters provided by the user, and the goal is reached.

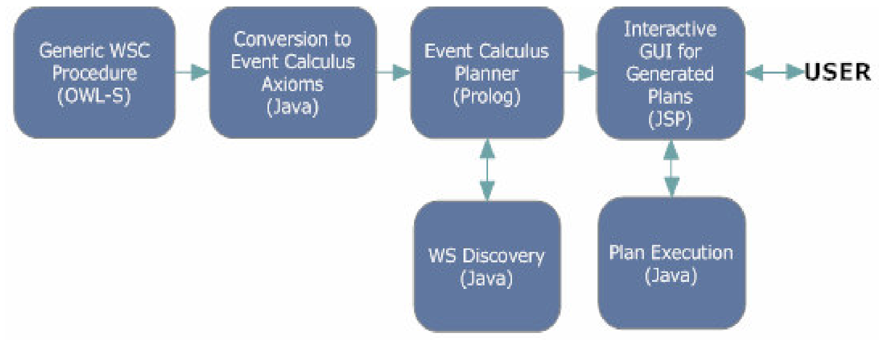

Generic WSC Procedure (OWL-S)
Conversion to Event Calculus Axioms (Java)
Event Calculus Planner (Prolog)
Interactive GUI for Generated Plans (JSP)
USER
WS Discovery (Java)
Plan Execution (Java)

Figure 3.1 The System Architecture

The web service discovery and execution parts are out of the scope of this thesis, so only primitive structures are implemented for them in this thesis. The translation from OWL-S to event calculus will be explained in Chapter IV, and the implementation details of this architecture are explained in Chapter V. In this chapter, it will be shown how abductive planning capabilities of the event calculus can be used to solve the web service composition problem.

3.2 Advantages of Using Event Calculus

The planning problem in the event calculus is formulated in simple terms as follows [14]: Given the domain knowledge containing possible events in that domain and how the fluents are affected from those events (i.e. a conjunction of specific axioms *happens, initiates, terminates* for that domain), the event calculus axioms (i.e. *holdsAt, clipped, declipped*) and a goal state (e.g. *holdsAt(f,t)*), the abductive theorem prover generates the plan which is a conjunction of (i.e. abducible literals) time stamped *happens* predicates and temporal ordering predicates. The event calculus provides an elegant way to represent the changes of the world through actions. The choice of event calculus as the domain for planning is motivated by both practical and formal needs, and gives several advantages. The primary advantage is that, the event calculus ontology has the necessary properties and components to represent a generic composition description, making it possible to map the description to the logical representation in its domain. The event calculus ontology includes an explicit time structure that enables it to express the temporal ordering of the events included in the composition. It is possible to represent totally ordered or partially ordered sets of events with the capability to express concurrency, or sequential ordering of events. Another advantage is that, the semantics of non-functional requirements can be represented in event calculus enabling the transfer of preconditions/effects of web services involved in the composition. Also, it is possible to define conditional constructs for the representation of conditional components belonging to the generic composition definition. So, in this thesis the abductive event calculus planner (ATP) described in [50], and extended in [5] will be used for representing the generic composition definition and generating a composite process as the output of planning.

3.3 Representation of Web Service Composition in Event Calculus

In order to use abductive event calculus, first of all the web service composition definition should be translated to the domain of planning namely the event calculus axioms described in Section 2.5, so that the properties of the composite service are specified in the form of a logical sequent to be proven. The following sections describe how the generic web service composition definition, the web services involved in the composition and the data/control flow are represented in event calculus.

3.3.1 Representation of Web Services

In general, semantic web services have the properties input, output, precondition and effect. In the event calculus, they are modeled as events with parameters for inputs and outputs. Figure 3.2 illustrates a generic representation of a web service in the event calculus.

```
axiom(happens(serviceName([InputList], [OutputList]), T1, T2),
[
      [preconditions],
      jpl_webServiceName([InputList], [OutputList])
]).
```

Figure 3.2 Representation of a Single Web Service

In this figure, the name of the web service should begin with a lower-case letter and input/output parameters should begin with upper-case letters. An example definition would be:

```
axiom(happens(pCurrencyCon(Price,Currency,OutputPrice),T1,TN),
[
      jpl_pPrecondition(Currency,IsValidCurrency),
      jpl_pCurrencyCon(Price,Currency,OutputPrice)
]).
```

The name of the above web service is "*CurrencyCon*". It takes "*Price*" and "*Currency*" as inputs and returns the price in the provided currency as the output "*OutputPrice*" if it is a valid currency. This service runs in the time interval [T_1, T_N]. The jpl method definitions constitute the interface between the planner and the real world. Interaction with the web service discovery module is carried on by these methods. The details of jpl methods will be investigated in Section 3.4.3 and Chapter V.

The preconditions, if there are any, are modeled inside the definition of the web service. If they are not satisfied, the event fails and no plan containing this event is generated.

The effects can also be modeled similary. Only world-altering web services can generate effects, but in the planning phase no world altering services are executed. They are executed via the web service execution module only when the user selects the preferred plan.

3.3.2 Representation of Composition

The compositions are modeled as sets of events accompanied with the necessary data and control flow information provided to represent the structure of the generic composition definition. Control flow information reveals the sequence of the services' execution; and data flow reveals the message bindings among the parameters of the services.

Two kinds of composition types are defined according to the approaches for translating them to the event calculus: simple compositions and recursive compositions:

3.3.2.1 Simple Compositions

If a composite process is constructed only with atomic processes, this composition is called a simple composition. In a simple composition there is only one composition construct and a single level of composition. Only atomic web services can be included in a simple composition. To be more specific, if the composition type is one of Sequence, Split-Join, Choice…etc. and all the contained sub-processes are atomic processes, the composition is said to be a simple composition. The graphical representation of an example simple composite process, with a Sequence control construct can be seen in Figure 3.3.

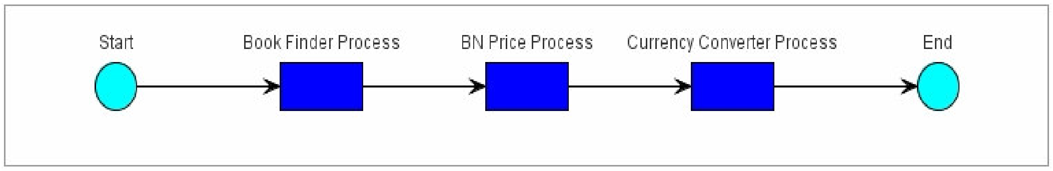


Figure 3.3 Graphical Representation of a Simple Composite Process

In Figure3.3, the simple composite web service is named “*BookPrice”* and it gives the price of a book in the desired currency. It is composed of three atomic web services which are supposed to run sequentially. The first service finds the ISBN of the book whose name is provided by the user, the second service finds the price of the book with the provided ISBN from the first service, and the third service converts the found price to the desired currency.

In the event calculus, a simple composite process is modeled as a compound event which contains the declarations of the participating atomic web services as simple events. The atomic web services are declared in a timely fashion for expressing control flow according to the type of composition. The definitions of atomic web services should also be added to the model as individual events as described in the previous section.

An example axiom for a simple process definition in the event calculus is as follows:

```
axiom(happens(pBookPrice(Currency, BookName), T1, TN),
[
    happens(pBookFinder(BookName, BookInfo), T2, T2),
    happens(pBNPrice(BookInfo, Price), T3, T3),
    happens(pCurrencyCon(Price, Currency, OutPrice),T4, T4),
    before(T1, T2),
    before(T2, T3),
    before(T3, T4),
    before(T4, TN)
]).
```

Figure 3.4 Representation of A Simple Composition

The events for individual services, i.e "*pBookFinder", "pBNPrice"* and *"pCurrencyCon"* and relevant jpl methods should also be defined as in Figure 3.2.

3.3.2.2 Recursive Compositions

If a composite process includes another composite process as one of its subprocesses, then this composition is called a recursive composition. In recursive compositions, there are multiple levels of composite processes in contrast to simple compositions. The graphical representation of an example recursive composite process can be seen in Figure 3.5.

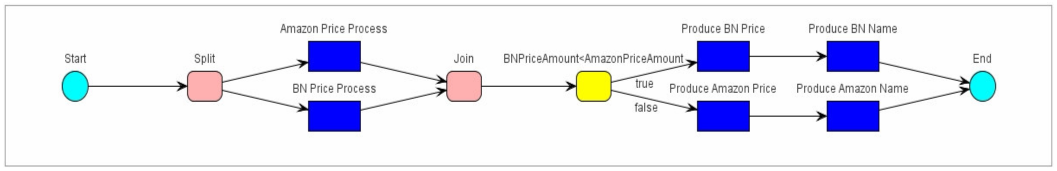


Figure 3.5 Graphical Representation of a Recursive Composite Process

In Figure 3.5, the main, or the outermost composition is the recursive composition structured according to the composition control construct *Sequence* containing four more compositions: one *Split-Join* (marked with pink), one *If-Then-Else* (marked with yellow), and two other *Sequence* (marked with arrows) types. The blue recktangles represent the atomic services.

In a simple composition there is only one composite axiom representing the composite event, whereas in the recursive composition there are as many composite axioms as the composite process count. Each composite process should be axiomatized according to its type and the indvidual processes contained in it. The axiom for the recursive composition includes the declarations of the contained atomic and/or composite web services. Each contained composite process should also be axiomatized in a recursive fashion until there remain only atomic web services to be represented as individual events.

The structure of the axioms for recursive compositions is the same as the simple one's depicted in Figure 3.4. The only difference between the representations is that, for the recursive compositions, the contained axioms corresponding to the contained composite web services also need to be defined as the main recursive composition axiom. The details and examples will be provided in Chapter V.

3.3.3 Representation of Control Flow

In the event calculus, the temporal relationships between the web services defining the flow of control of the generic composition definition are represented by the predicate *before*. As the name implies, *"before (T_1, T_2)"* means that T_1 is a former timestamp in timeline than $T_{2.}$ It is possible to model sequential and concurrent activities with this predicate. This enables the total and partial ordering of events for the planning process. Also it is possible to represent conjunctions, disjunctions and temporal iterations as well [48].

There are two types of events according to their durations. First group contains events occuring in an instant and do not have a significant duration. They are represented as:

```
happens(E1, T1) or
happens(E1, T1, T1)
```

Second group contains the events having a duration bounded by start and finish times of the event, and are represented as:

```
happens(E1, T1, T2).
```

For the second group the predicate *before* (T_1, T_2) is included implicitly. There is no need to define it again.

3.3.3.1 Modelling Sequential Activities

The sequential activity is modeled as follows for the first and second groups. For the first group:

```
happens(E1, T1),
happens(E2, T2),
before(T1, T2)
```

For the second group:

```
happens(E1, T1, T2),
happens(E2, T3, T4),
before(T2, T3)
```

3.3.3.2 Modelling Concurrent Activities

Obviously, if the timestamps of the events are equal, then those events are said to be concurrent. For the following examples, E1 and E2 are concurrent events.

```
happens(E1, T1),
happens(E2, T1)
```

Or,

```
happens(E1, T1, T2),
happens(E2, T1, T2),
```

Also, when there is no relative ordering between the timestamps of events, then those events are assumed to be concurrent. The following example from [14] illustrates this. In this example there is no time relationship between E2 and E3, so they are assumed to be concurrent. The example for the second group is similar.

```
happens(E1, T1),
happens(E2, T2),
happens(E3, T3),
happens(E4, T4),
before(T1, T2), before(T2, T4),
before(T1, T3), before(T3, T4)
```

3.3.4 Representation of Data Flow Between Web Services

As a result of web service compositions' nature, outputs of atomic or composite processes can be the inputs of other processes in the composition. The individual web services comprised in the composition operate as autonomous and separate entities being executed on the servers they are hosted and they are not subject to a form of centralized monitoring. But the composition itself is supposed to be executed by the client owning the composition. As a result, the wiring of the input/output parameters between the atomic or composite web services should be handled also in the side owning the composition.This is necessary in order not to lose the path for the flow of data between the services and invoke the services with the inputs dynamically obtained in the runtime.

In the event calculus, this data flow is handled via parameter names of the events. In a specific axiom, all the variable names which point to a certain value should have the same name. For example, in Figure 3.4, the second input parameter *"BookName"* of the composite service "*pBookPrice"* is used also as the input for "*pBookFinder"* process. The same naming of the parameter ensures that the input of the composite process "*pBookPrice"* will be provided to the process "*pBookFinder"* as its input. Also, the parameter "*BookInfo"* is declared both in "*pBookFinder"* and "*pBNPrice"* processes. This means the output of the first process "*BookInfo"* will be the input of the second process.

Using the techniques described in this section, a comprehensive representation of the generic composition definition in the event calculus can be maintained. Having this representation in hand, it is possible to apply the abductive planning techniques for generating the list of possible plans for the generic composition. The following section describes how the planning is accomplished for a composition defined in event calculus.

3.4 Plan Generation with Abductive Theorem Prover (ATP)

In this thesis, the Abductive Theorem Prover is used as a planner in the event calculus framework in the planning phase. The theoretical grounding of planning with ATP has been given in Section 2.6. In this section, the advantages of using ATP and an example illustrating how the plans are generated with it will be presented in addition to some issues about planning in our tool.

3.4.1 Advantages of ATP

The advantages of ATP can be summarized as follows [51]: It supports reasonably complex event calculus plans. It tackles the issue of hierarchical planning. The event calculus formalism used is not just a logic program, but is specified in first-order predicate calculus augmented with circumscription. It can handle actions with context-dependent effects; and since it uses abduction to solve initiates and terminates goals, the planner is both sound and complete.

3.4.2 Plan Generation Example

A simple example showing how abduction can be used in planning will be shown here. With the use of abduction, the planner generates a sequence of actions leading from an initial state to a final state.

In the example from [39], given that Nathan was not awake and then he was awake, it is possible to abduce that he woke up with ATP. In order to perform abduction with ATP, first a file containing the relevant event calculus axioms are created. In our case the file, named sleep.pl contains the following:

```
axiom(initiates(wake_up(X),awake(X),T),[]).
axiom(terminates(fall_asleep(X),awake(X),T),[]).
axiom(initially(neg(awake(nathan))),[]). abducible(dummy).
executable(wake_up(X)). executable(fall_asleep(X)).
```

Then Prolog is started and event calculus planner and sleep.pl files are consulted (loaded) to it. Then the following query is issued to Prolog:

```
abdemo([holds_at(awake(nathan),t)],R).
```

Given the above axioms and goal, the event calculus planner produces the following plan:

```
R = [[happens(wake_up(nathan), t1, t1)], [before(t1, t)]]
```

It is found out by abduction that, Nathan should perform the action “wake_up” before time t in order to satisfy the situation that he was awake at time t.

3.4.3 Communication with the Real World

In the planning process, the planner is in a continuous interaction with the real world to get the available services which can be used in the plan in order to achieve the goal. Since the plan generation is a dynamic process, in every step of the planning process where an atomic web service is to be processed, there needs to be an interaction with the real world to get the information about the discovered services. The interaction is with the web service discovery module, which, in theory, takes the semantic descriptions of atomic web services included in the generic composition definition, and returns the set of convenient and available web services as a result of its internal discovery mechanism. This communication is achieved through jpl method definitions, that provide an interface between the planning process and the discovery module. There is a single jpl method for each event representing an atomic web service. That single jpl method manages all the necessary data transfers and transformations. It provides the semantic information of the services needed by the planner, provided the inputs are taken from the user. The plans are generated and listed with this gathered information including service name and parameters.

Once the user selects the preferred plan, the next phase of planning begins. In this phase, the information providing services included in the selected plan are executed, and the results are shown to the user. This execution is also handled via jpl calls. The jpl method definitions handle the case where there is more than one output of the atomic service description, and also there is more than one web service found by the discovery module for the event in question. This dynamic structure will presented in Chapter V.

3.4.4 Service Execution During Planning

In the plan generation phase, the inputs defined in the generic composition definition are provided by the user and the outputs of the individual atomic services are taken after the execution of the found services provided by the discovery module. The services executed in the planning phase and guiding the plan generation process are only information-providing web services. The world-altering services are not executed, because changing the state of the world would result in unwanted harm unless the plan in question is not selected by the user for execution. For example, it may be desired querying the price of a book from a set of web services in order to find the cheapest one, but buying the book, which has a world-altering effect, needs confirmation from the user. The plan containing the step for buying the book should be selected by the user explicitly and confirmed for execution.

When there are multiple services found by the discovery engine, a separate plan for each of them is generated. Also, for multiple steps having multiple discovered services, combinations of the found services are taken. Consider the following generic composition definition given in Figure 3.7. This composition is a simple composition having “Any-*Order*” structure as the control construct. In this service, the execution order of the services does not matter, so plans including the found services in any order are valid.

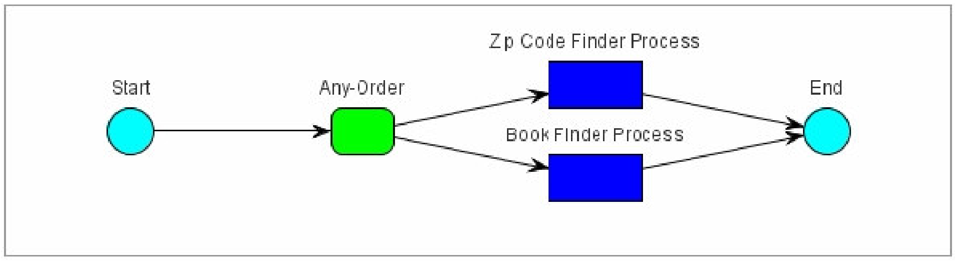


Figure 3.6 Simple Composition with Any-Order Control Construct

For this composition, assume that there are two services found for the “Zip Code Finder Process” Z_1, Z_2; and one service for the “Book Finder Process”

B_1. In this case, ATP will generate plans including Z_1 and B in any order, and also including Z_2 and B in any order. There will be four plans as folows:

Plan 1 - Step 1: B, Step 2: Z_1

Plan 2 - Step 1: B, Step 2: Z_2

Plan 3 - Step 1: Z_1, Step 2: B

Plan 4 - Step 1: Z_2, Step 2: B

In this chapter, the plan generation phase with the generic composition definition provided in event calculus has been explained. But in our system, generic compositions are defined in OWL-S. The composition structure as well as the user constraints should be declared in OWL-S files and provided to our system. Next chapter presents the methods for translating generic compositions in OWL-S to the event calculus domain.

CHAPTER 4

OWL-S TO EVENT CALCULUS TRANSLATION

In our system, a subset of OWL-S ontology is used as the language for generic composition definitions, which are the specifications for how to compose a sequence of atomic process executions. It is possible to define the composition abstractly using the process model part of OWL-S. The grounding information is not needed in our system, since the exact services will be discovered and provided by the service discovery module. The profile part is not needed either, but it would be beneficial for the discovery module. The abstraction mechanism of OWL-S helps service discovery engines to easily understand the properties of the composition. The advantage of using OWL-S is that, it is possible to express the composition structure and the interaction scenarios of the services (data/control flow) as well as the necessary information for the discovery of the composite service and the atomic services included in the composition. The generic composite services are translated to event calculus axioms automatically with our tool. In this chapter, we will show how to encode a composite process composition problem as an abductive event calculus planning problem, so that our tool can be used with OWL-S web services descriptions to automatically generate a composition of web services calls.

4.1 Translation of the Goal State

A plan is a set of events resulting in the goal state on execution. The plans are returned by the planner as answers to the query declaring the goal state. The query for the abductive theorem prover, stating the goal situation is defined as an event calculus axiom as follows.

```
abdemo([holds_at(pCompositeProcessPlanned(InputList), t)], R).
```

Here, the lower-case letter "p" is added as a prefix to the name since the predicates should begin with a lower-case letter. Also, the word "Planned" is attached to the name of the composite process as a suffix. It could be another word either; the point here is that the name should be different from the original process name.

This query reveals the set of plans which satisfy the "pCompositeProcessPlanned" predicate at time t with the input list (InputList) of the composite process provided by the user. An actual query example would be as follows.

```
abdemo([holds_at(pBookPriceProcessPlanned('YTL',
                    'Madam Bovary'),t)],R).
```

The predicate "pCompositeProcessPlanned" is a construct for linking the goal state to the main process axiom. It is used as follows:

```
initiates(pCompositeProcess(InputList),
        pCompositeProcessPlanned(InputList), T).
```

Here “pCompositeProcess” is the name of the main composite process. The predicate “pCompositeProcessPlanned” is initiated by “pCompositeProcess”. Since the goal state is the satisfaction of pCompositeProcessPlanned, it is possible only if “pCompositeProcess” is satisfied. So by this way the planner is guided to prove “pCompositeProcess”, which is the main composite process axiom. An example initiates axiom is as follows.

```
initiates(pBookPriceProcess(OutputCurrency,BookName),
      pBookPriceProcessPlanned(OutputCurrency, BookName), T).
```

In this example, the main composite process is “BookPriceProcess”, having the input parameters “OutputCurrency” and “BookName”. The OWL-S description of an example having a Sequence control construct, and its translation to event calculus can be found in Appendix A.

4.2 Translation of Atomic Services

Atomic services are translated into simple events of the event calculus. An atomic service in OWL-S can be seen in Figure 4.1. This atomic service named "AtomicProcess1" has 2 inputs, "Input1" and “Input2" and an output, “Output1”. Some constructs of OWL-S such as comments, bindings, etc. are not included for simplicity throughout this chapter. Also, there are so many alternatives for representation of processes in OWL-S which are all valid. Some of them are shown here. For other alternatives ontology description [73] can be used.

This atomic process is translated to an event calculus axiom as an event with the same name as the atomic process with the lower-case letter “p” attached as a prefix. The inputs and outputs of the process are the parameters of the event with upper-case letters.

```
<process:AtomicProcess rdf:ID="AtomicProcess1">
<rdfs:label> AtomicProcess1 </rdfs:label>
<process:hasInput>
      <process:Input rdf:ID="Input1">
      <process:parameterType
                  rdf:datatype="&xsd;#anyURI">&xsd;#string
      </process:parameterType>
      </process:Input>
</process:hasInput>
<process:hasInput>
      <process:Input rdf:ID="Input2">
      <process:parameterType
                  rdf:datatype="&xsd;#anyURI">&xsd;#string
      </process:parameterType>
      </process:Input>
</process:hasInput>
<process:hasOutput>
      <process:Output rdf:ID="Output1 ">
      <process:parameterType
                  rdf:datatype="&xsd;#anyURI">&xsd;#string
      </process:parameterType>
      </process:Output>
</process:hasOutput>
</process:AtomicProcess>
```

Figure 4.1 OWL-S Representation of an Atomic Service

The inputs of the event are instantiated with the inputs provided by the user, and outputs are the results of the execution of the actual information-providing services. The time interval in which the service is active is described by the time tags “T1, TN” which are the last two parameters. They are used to cache results for operations. If operations are not cached according to their time points then different effect axioms of the same atomic process would be associated with different outputs which might result conflicting effects when the world altering web service operations are invoked to collect outputs [14]. The translation of the atomic process in Figure 4.1 can be seen in Figure 4.2.

```
axiom(happens(pAtomicProcess1(Input1,Input2,Output1),T1, TN),
[
      jpl_pAtomicProcess1(Input1,Input2,Output1)
]).
```

Figure 4.2 Event Calculus Representation of an Atomic Service

4.3 Translation of Composite Services

Composite processes are composed of subprocesses, and specify constraints on the ordering and conditional execution of the subprocesses. The constraints are captured by the “composedOf" property in OWL-S, which is required for a composite process [73], and they are similar to standard workflow structures. Composite processes are constructed using control constructs and references to processes are called “Perform”s in OWL-S ontology. Performs may be references to atomic or composite processes, and they are composed using other “ControlConstruct”s. The minimal initial set of control constructs according to [73] includes *Sequence, Split, Split + Join, Any-Order, Condition, If-Then-Else, Iterate, Repeat-While* and *Repeat-Until*. These constructs are translated into compound events in the event calculus framework. The subprocesses in a composition can be either atomic or composite processes. So, the translation of the control constructs is recursively applied to the processes until all composite processes are replaced with the corresponding axioms that contain atomic processes as stated in [14]. The translation of some of the flow control constructs into the event calculus axioms is presented in the following sections. The *Repeat-While* and *Repeat-Until* constructs are not within the scope of this thesis, so their translations are not included. The abstract and more generic formulations for the translations can be found in [5].

4.3.1 Translation of the Sequence Control Construct

When the *Sequence* construct is used, all the sub-processes contained in it are to be executed sequentially in order. An example composite process definition containing a *Sequence* control construct can be seen in Figure 4.3. There two sub-processes in this definition. The inputs, outputs, bindings and some other OWL-S constructs are omitted for simplicity. A real composition including most of the control constructs with their comprehensive definitions can be found in Appendix B.

The translation is accomplished through the use of compound events in the event calculus which contain sub-events [14]. The sequence of events is triggered from the body of the compound event and the ordering between them is ensured with the “before” predicate, satisfying the ordering in the OWL-S definition. The event calculus axiom which is the translation of the composition in Figure 4.3 is given in Figure 4.4.

```
<process:CompositeProcess rdf:ID="SequenceExample">
<process:composedOf>
      <process:Sequence>
      <process:components>
         <process:ControlConstructList>
         <list:first>
              <process:Perform rdf:ID="PerformProcess1">
                   <process:process rdf:resource="#Process1" />
              </process:Perform>
         </list:first>
         <list:rest>
              <process:ControlConstructList>
              <list:first>
                   <process:Perform rdf:ID="PerformProcess2">
                   <process:process rdf:resource="#Process2" />
                   </process:Perform>
              </list:first>
              <list:rest rdf:resource="&list;#nil" />
                   </process:ControlConstructList>
              </list:rest>
         </process:ControlConstructList>
      </process:components>
      </process:Sequence>
</process:composedOf>
</process:CompositeProcess>
```

Figure 4.3 A Composition with the *Sequence* Construct in OWL-S

```
axiom(happens(pSequenceExample([InputList],[OutputList]),T1, TN),
[
      happens(pProcess1([InputList], [OutputList]), T2, T3),
      happens(pProcess2([InputList], [OutputList]), T4, T5),
      before(T1, T2),
      before(T3, T4),
      before(T5, TN)
]).
```

Figure 4.4 Translation of Sequence to Event Calculus

4.3.2 Translation of the Any-Order Control Construct

According to the OWL-S process ontology, *Any-Order* control construct allows the sub-processes contained in it to be executed in some unspecified order but not concurrently. The sub-processes are specified in a structure named “ControlConstructBag”. Execution and completion of all components is required. The execution of processes in an Any-Order construct cannot overlap, i.e. atomic processes cannot be executed concurrently and composite processes cannot be interleaved. An example composition with Any-Order construct can be seen in Figure 4.5.

```
<process:CompositeProcess rdf:ID="AnyOrderExample">
<process:composedOf>
      <process:Any-Order>
      <process:components>
          <process:ControlConstructBag>
          <list:first>
                  <process:Perform rdf:ID="PerformProcess1">
                  <process:process rdf:resource="#Process1" />
                  </process:Perform>
            </list:first>
            <list:rest>
                  <process:ControlConstructList>
              <list:first>
                  <process:Perform rdf:ID="PerformProcess2">
                      <process:process rdf:resource="#Process2" />
                      </process:Perform>
                 </list:first>
                  <list:rest rdf:resource="&list;#nil" />
                  </process:ControlConstructList>
            </list:rest>
            </process:ControlConstructBag>
      </process:components>
      </process:Any-Order>
```

```
</process:composedOf>
</process:CompositeProcess>
```

Figure 4.5 A Composition with the *Any-Order* Construct in OWL-S

The ordering of the sub-processes can be any permutation of them. So, a permutation predicate is needed for the translation, which is as follows.

```
jpl_permutation([A, B], [A1, B2]):-
                        permutation([A, B], [A1, B2]),
                        true.
```

The definition of the permutation method includes the permutation method from Prolog library, and extends it by returning the value “true”. This is necessary because this permutation method is used in the compound event calculus axiom representing the Any-Order composite process, and if it does not return “true”, then the whole event would fail. The translation of the composition in Figure 4.5 can be seen in Figure 4.6 below. In this translation, the plans are generated for all permutations of the processes.

```
axiom(happens(pAnyOrderExample([InputList],[OutputList]),T1,TN),
[
      jpl_permutation([pProcess1([InputList], [OutputList]),
                       pProcess2([InputList], [OutputList])],
                   L1, L2]),
      happens(L1, T2, T2),
      happens(L2, T3, T3),
      before(T1, T2),
      before(T2, T3),
      before(T3, TN)
]).
```

Figure 4.6 Translation of Any-Order to Event Calculus

4.3.3 Translation of the Choice Control Construct

The *Choice* construct calls for the execution of one of the sub-processes from a given bag of control constructs containing them. Any of the given control constructs may be chosen for execution. OWL-S representation of Choice control construct is the same as the Any-Order representation in Figure 4.5, except the construct name is “Choice” instead of “Any-Order”.

For the translation of the Choice, an event is created for each sub-process included in the Choice construct. By this way, different plans, each having one of the sub-processes can be generated. The translation of a composite process having two sub-processes can be seen in Figure 4.7.

```
axiom(happens(pChoiceExample([InputList],[OutputList]),T1,TN),
[
      happens(pProcess1([InputList], [OutputList]), T2, T3),
      before(T1, T2),
      before(T3, TN)
]).

axiom(happens(pChoiceExample([InputList],[OutputList]),T1,TN),
[
      happens(pProcess2([InputList], [OutputList]), T2, T3),
      before(T1, T2),
      before(T3, TN)
]).
```

Figure 4.7 Translation of Choice to Event Calculus

With the above translation, there will be two plans generated, since there are two possible orderings of two processes. One plan will include just the Process1 and the other plan will include just the Process2.

4.3.4 Translation of the Split Control Construct

When the *Split* control construct is used, the composite process consists of concurrent execution of a bunch of sub-processes. No further specification about waiting, synchronization, etc. are given. It is similar to the usage of "Concurrent" or "Parallel" structures in other ontologies. It terminates when all of its sub-processes are scheduled to be executed.

The OWL-S representation of Split construct is similar to Any-Order construct in Figure 4.5, except the “<process:Any-Order>” should be replaced with “ <process:Split>”. The translation of it is given in Figure 4.8.

```
axiom(happens(pSplitExample([InputList],[OutputList]),T1,TN),
[
      happens(pProcess1([InputList],[OutputList]),T2,T3),
      happens(pProcess2([InputList],[OutputList]),T4,T5),
      before(T1,T2),
      before(T1,T4),
      before(T1,TN)
]).
```

Figure 4.8 Translation of Split to Event Calculus

As seen in the translation, a Split process immediately completes when the sub-processes are scheduled, but not already executed. The completion of executions of them is not waited and it is not checked whether the sub-processes execute and terminate successfully. Split is somewhat similar to an asynchronous method call.

4.3.5 Translation of the Split-Join Control Construct

Compositions with the *Split-Join* construct consist of concurrent execution of a bunch of sub-processes. Unlike Split construct, it is used for ensuring that the component processes are completed within the time segment of the composite process. A Split-Join process waits until all its sub-processes are completed their executions.

The OWL-S description is similar to the one for Any-Order in Figure 4.5. The translation of it is given in Figure 4.9.

```
axiom(happens(pSplitJoinExample([InputList],[OutputList]),T1,TN),
[
      happens(pProcess1([InputList],[OutputList]),T2,T3),
      happens(pProcess2([InputList],[OutputList]),T4,T5),
      before(T1,T2),
      before(T1,T4),
      before(T3,TN),
      before(T5,TN),
]).
```

Figure 4.9 Translation of Split-Join to Event Calculus

The completion of sub-processes within the main axiom's time interval is ensured by the last two “before” predicates in Figure 4.9.

4.3.6 Translation of the If-Then-Else Control Construct

The *If-Then-Else* control construct consists of a condition, a “then” and an optional “else” process. Its semantics is to test the condition, if it is true, do the then process, if it is false, do the else process if it exists. The OWL-S description including the if-condition definition defined in SWRL can be seen in Figure 4.10 and its translation can be seen in Figure 4.11.

```
<process:CompositeProcess rdf:ID="IfThenElseExample">
<process:composedOf>
<process:If-Then-Else>
  <process:ifCondition>
      <expr:SWRL-Condition rdf:resource="#SWRLCondition1"/>
  </process:ifCondition>
  <process:then rdf:resource="#ThenProcess"/>
  <process:else rdf:resource="#ElseProcess"/>
</process:If-Then-Else>
</process:composedOf>

<expr:SWRL-Condition rdf:ID="SWRLCondition1">
  <expr:expressionBody rdf:parseType="Literal">
  <swrl:AtomList>
      <rdf:first>
          <swrl:BuiltinAtom>
          <swrl:builtin rdf:resource="&swrlb;#lessThan" />
               <swrl:arguments>
                    <rdf:List>
                    <rdf:first rdf:resource="#Input1" />
                    <rdf:rest>
                    <rdf:List>
                         <rdf:first rdf:resource="#Input2" />
                         <rdf:rest rdf:resource="&rdf;#nil" />
                    </rdf:List>
               </swrl:arguments>
               </swrl:BuiltinAtom>
          </rdf:first>
          <rdf:rest rdf:resource="&rdf;#nil" />
  </swrl:AtomList>
  </expr:expressionBody>
</expr:SWRL-Condition>
```

```
</process:CompositeProcess>
```

Figure 4.10 A Composition with the If-Then-Else Construct in OWL-S

```
axiom(happens(pIfThenElseExample([InputList],[OutputList]),T1, TN),
[
    happens(jpl_pIfCondition([InputList]), T2, T3),
    happens(pThenCase([InputList],[OutputList]), T4, T5),
    before(T1, T2),
    before(T3, T4),
    before(T5, TN),
]).

axiom(happens(pIfThenElseExample([InputList],[OutputList]),T1, TN),
[
    happens(jpl_pElseCondition([InputList]), T2, T3),
    happens(pElseCase([InputList],[OutputList]), T4, T5),
    before(T1, T2),
    before(T3, T4),
    before(T5, TN),
]).
```

Figure 4.11 Translation of If-Then-Else to Event Calculus

Since in the planning time, the input parameters from the user are not instantiated with the inputs of the composition, and as a result it is not known whether the if-condition would hold or not, plans for both possibilities are generated. Two event calculus axioms are generated for ensuring this: one for the “then” case and one for the “else” case. This is done to show user the possible execution paths. When the user selects one of the plans from the list containing plans for all discovered services, s/he in fact declares which discovered service s/he would prefer. On execution, if the “Then” case is selected, and the if-condition fails, the execution would fail.

4.4 Translation of the Preconditions

An example precondition definition can be seen in Figure 4.12. In this precondition, SWRL is chosen as the language for specifying the condition. The condition is whether Input1 is less-than Input2. The inputs are either provided by the user or by another service as its outputs. The source of them are specified by the binding declarations which are not shown here. Those bindings should be handled before the translation to event calculus, because the parameters representing the same variables should have the same names in the event calculus.

```
<process:CompositeProcess rdf:ID="PreconditionExp">
...
<process:hasPrecondition>
      <expr:SWRL-Condition rdf:ID="lessThan">
      <expr:expressionLanguage rdf:resource="&expr;#SWRL" />
      <expr:expressionBody rdf:parseType="Literal">
      <swrl:AtomList>
          <rdf:first>
               <swrl:BuiltinAtom>
               <swrl:builtin rdf:resource="&swrlb;#lessThan" />
                    <swrl:arguments>
                         <rdf:List>
                         <rdf:first rdf:resource="Input1" />
                         <rdf:rest>
                         <rdf:List>
                         <rdf:first rdf:resource="Input2" />
                         <rdf:rest rdf:resource="&rdf;#nil" />
                         </rdf:List>
                         </rdf:rest>
                         </rdf:List>
                    </swrl:arguments>
               </swrl:BuiltinAtom>
          </rdf:first>
          <rdf:rest rdf:resource="&rdf;#nil" />
      </swrl:AtomList>
      </expr:expressionBody>
      </expr:SWRL-Condition>
</process:hasPrecondition>
...
</process:CompositeProcess>
```

Figure 4.12 A Precondition Example in OWL-S

This precondition is translated to a simple event in event calculus, which is appended to the beginning of the event to which this precondition belongs. If the precondition does not hold, the event fails in the first step, so that no plan containing this event is generated. The translation can be seen in Figure 4.13.

```
axiom(happens(pPreconditionExp([InputList],[OutputList]),T1, TN),
[
      jpl_pPrecondition([InputList]),
      ...
      [Other Event/Events and Temporal Orderings]
      ...
]).
```

Figure 4.13 Translation of Precondition to Event Calculus

The body of the precondition is defined in the precondition event as shown in Figure 4.14.

```
      jpl_pPrecondition ([InputList]):-
                    atom_number (Input1, Arg1),
                    atom_number (Input2, Arg2),
                    Arg1<Arg2,
                    true.
```

Figure 4.14 Body of the Precondition Event

The translations from OWL-S to event calculus domain have been shown in this chapter. After the translation, the planning phase is initiated with the query to the abductive theorem prover including the goal state.

CHAPTER 5

IMPLEMENTATION

The implementation part of our system mostly consists of Java language, as a web based J2EE application. The front-end is developed using HTML, JSP, JavaScript and CSS technologies. In the back-end, Java and Prolog languages are used. The created WAR artifact can be deployed to a J2EE container; in our case JBoss was used.

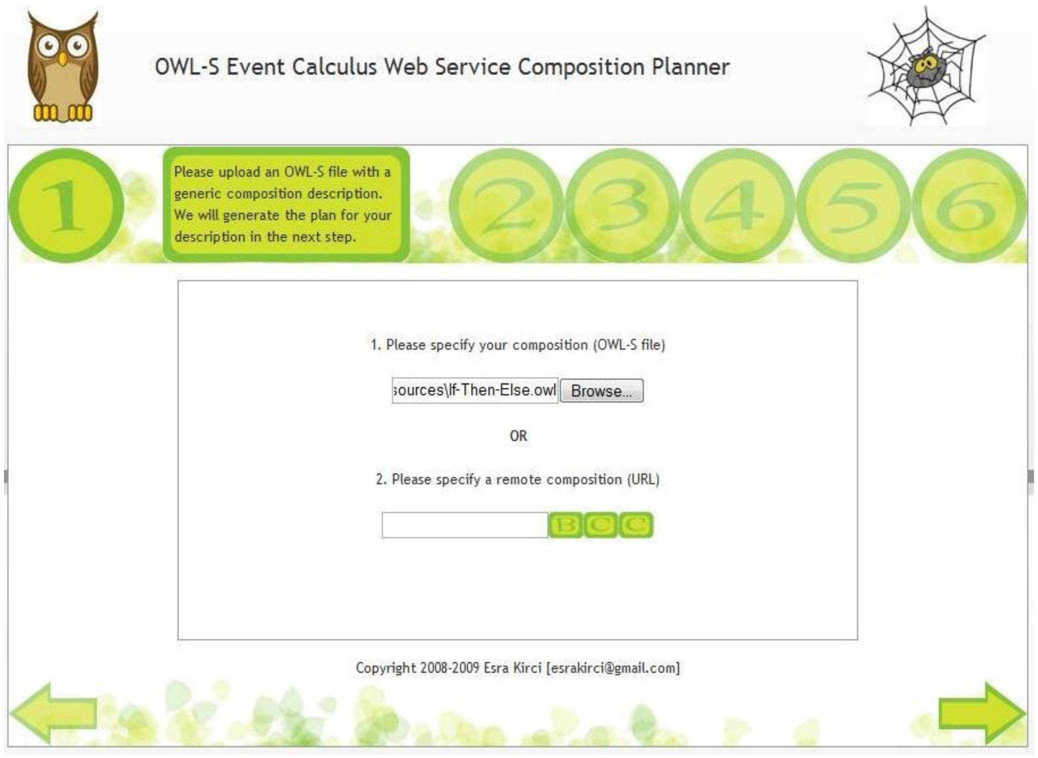
For OWL-S parsing, two different parsers -MindSwap's OWL-S API [63] and CMU's OWL-S Parser [70] are used. For the interaction between the Prolog code and Java code, namely to call Prolog code from within Java, the JPL library [68] is used. Java Universal Network/Graph Framework (JUNG) [69] is used for the graphical representation of the generic compositions. The modules of the system are examined in detail below.

5.1 Web Interface

Our system is a web based application, and can be accessible via most browsers, including Firefox and Internet Explorer. The composition process in the system is divided into 6 steps with an easy to use HTML front-end.

Using the front-end, the user can provide the system with a generic service composition, see the graphical representation of the composition, select plans for the composition with matching services, and run a simulated execution of the given composition with selected services.

Figure 5.1 shows the screen for providing the generic composition. The user can either upload an OWL-S file or provide the URL of the OWL-S file.


OWL-S Event Calculus Web Service Composition Planner

Please upload an OWL-S file with a generic composition description. We will generate the plan for your description in the next step.

1. Please specify your composition (OWL-S file)

sources\If-Then-Else.owl

OR

2. Please specify a remote composition (URL)

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Figure 5.1 OWL-S File/URL Upload Step

5.2 OWL-S Parsing

Off-the-shelf OWL-S APIs are used to parse OWL-S files. These APIs are *MindSwap OWL-S API* and *CMU OWL-S API*. The main reason behind using two libraries is that none of the currently available APIs are able to parse every type of valid OWL-S document successfully. For instance MindSwap OWL-S API does not have full support for SWRL expressions, and CMU OWL-S API can not operate with input-output bindings successfully.

When the user provides a file or a URL of an OWL-S file to the system, OWL-S parsers are used to parse the given OWL-S documents. For the file resources MindSwap OWL-S API, for the URL resources, CMU OWL-S API is used. The aim of parsing is to determine a common, easily navigable and recursive business model containing all the necessary data for the processes involved in the composition.

While parsing OWL-S files, the IOPE information is extracted from each of the participating processes, and added to the Process business object. The types of the inputs and outputs are also stored within the object. The names of the inputs and outputs will be changed to reflect input/output bindings in a future phase.

Apart from IOPE information, each composite process object also contains composition type information. The business model for the process object is recursive. Hence a composite process object with the composition type Sequence has an array of child processes, reflecting the execution order of the children in the Sequence construct.

After parsing OWL-S to generate the process model, the parsers are used to extract meaningful content for the end-users to see on the front-end. These include the description of the service composition, the labels for the inputs outputs, the type of the composition constructs used etc.

5.2.1 OWL-S API

OWL-S API is a library by Maryland Information and Network Dynamics Lab Semantic Web Agents Project (Mindswap) which provides methods to read from, write to OWL-S service descriptions. The API also provides a built-in Service Execution Engine to execute atomic services and certain composite services with WSDL or UPnP groundings. The supported composite services are limited to Sequence, Unordered and Split.

OWL-S API has limited support for preconditions and effects. As of version 1.0.1, built-in SWRL parsing is not provided. There are certain cases where one can reach the same OWL-S class or property by following two different programmatic paths and face with two different objects, with certain non-matching fields.

OWL-S parser cannot parse every OWL Full document validated by WonderWeb OWL Ontology validator [76] either.

5.2.2 CMU OWL-S API

CMU OWL-S API is a library developed by the Software Agents Group of the Carnegie Mellon University. CMU OWL-S API provides routines to parse and read the OWL-S service descriptions. As of version 1.1 of the API there's a solid model tier to navigate through the OWL-S document easily.

Since the model is more intuitive to navigate, creating business objects to construct Prolog code becomes easier. The API provides routines to parse OWL-S descriptions located at files, URLs and etc. However the source stream selection is important, since there are cases where even though the OWL-S description located at a URL is easily parsed by the API, the same content cannot be parsed when the source of the stream is a local file.

The problem with CMU OWL-S API is that there's no practical and/or reliable way of traversing input and output bindings declared in an OWL-S service description.

There are conflicting libraries between the dependencies of the described APIs. Therefore the configuration of the implementation becomes important when both of these libraries are necessary in the same project. In the implementation phase of this thesis application server's class loader has been examined and configured properly to operate both libraries within the application. However a better and easier approach is to opt for only one of these APIs.

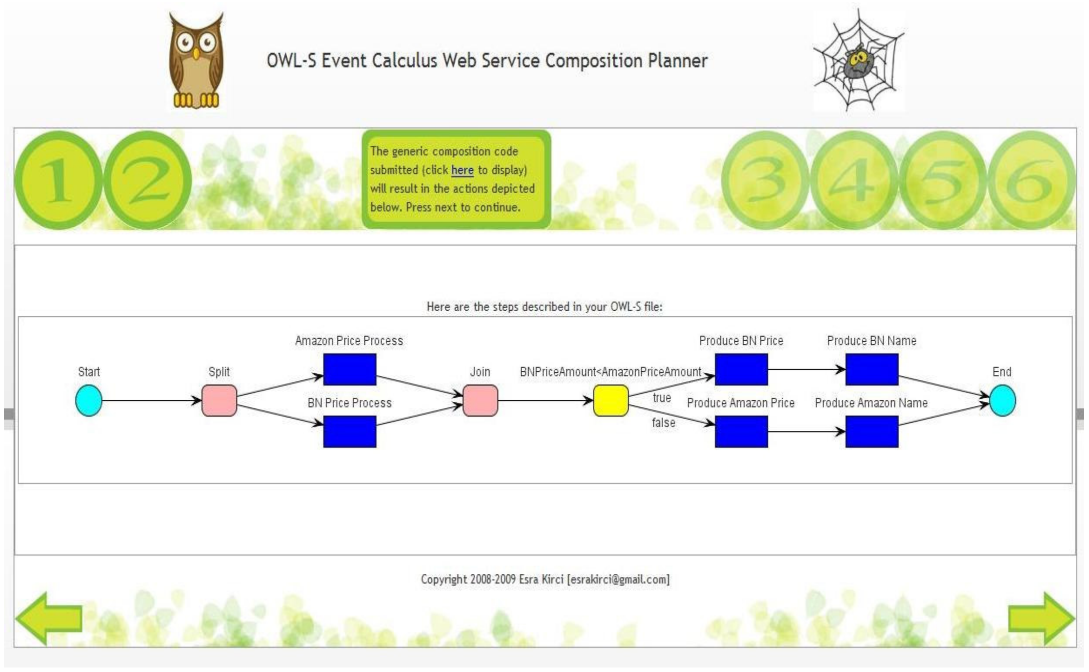
5.3 Graphical Representation

The graphical representation of the composition is necessary to let the user know what kind of a workflow is to be executed with the given generic service description. To enable a better viewing experience, a left to right ordering is used, with arrows showing time dependencies and pointing to nodes from the initial start node, to the end node.

When an arrow is split from a node this means that a Split/Split+Join construct or an If-Then-Else construct is encountered. In the second case, the condition stated in the if-condition is parsed and displayed to the user in a meaningful way, so that the user can understand what will happen if the generic composition provided is executed. As specified earlier, conditions can be specified in several logical languages including SWRL, DRS and KIF. In our implementation, SWRL conditions are supported due to the higher popularity of the language.

The Java Universal Network/Graph framework JUNG is used to display the graphical representation. The processes are displayed as vertices in a graph, and the transitions for the *perform* structures are displayed as edges. The graph constructed with JUNG is then exported to a Graphics Interchange Format (GIF) image and displayed in the browser to the user.

Since one instance of the application might generate multiple files for a single user or concurrent users, the naming of the GIF files is important in the web application. The files are named after the id of the session used by the current user, and the time of image generation request in milliseconds precision. A sample graphical representation for an If-Then-Else composition is illustrated in Figure 5.2.


OWL-S Event Calculus Web Service Composition Planner

The generic composition code submitted (click here to display) will result in the actions depicted below. Press next to continue.

Here are the steps described in your OWL-S file:

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Figure 5.2 OWL-S Composition: Graphical Representation Step

5.4 Generation of Prolog code

The generation of Prolog code is the third step in the process of Event Calculus based Web Service Composition, and is made after the OWL-S file is parsed. Since there are two different OWL-S parsers, there are also two different Prolog code generation routines.

5.4.1 Incremental Prolog Code Generator

The first type of Prolog code generator used is an incremental code generator, and is paired with the MindSwap OWL-S API. The incremental Prolog generator generates the code as the parser starts parsing the file, and starts embedding Prolog axioms for the processes as the children are parsed.

For instance, if a process “A” with sequential child processes “C1” and “C2” are determined, the axiom A containing C1 and C2 is generated right away, and appended to the buffer. There is no look-ahead approach within the incremental generator. The Prolog code generated does not change whether C1 is an atomic process or a composite If-Then-Else statement.

This approach brings certain restrictions on how the compositions and preconditions are expressed. For instance a precondition for a child process cannot be placed before the reference to the axiom of the process; it should be placed within the axiom of the child process. In a similar fashion, If-Then-Else constructs cannot be externalized to form a relatively flat and easy to trace code, they should be embedded within the axiom containing the constructs.

The incremental builder also has several drawbacks in input-output bindings, since it requires a pre-mapped set of inputs and outputs to work with or an intelligent code generator which will continuously detect bindings and alter previously generated code to reflect the actual process.

5.4.2 Process Model Based Prolog Generator

The second type of Prolog code generator is a process model based code generator, which makes use of an already parsed process to generate the code, with all the information at hand. This code generator is used with the CMU OWL-S API.

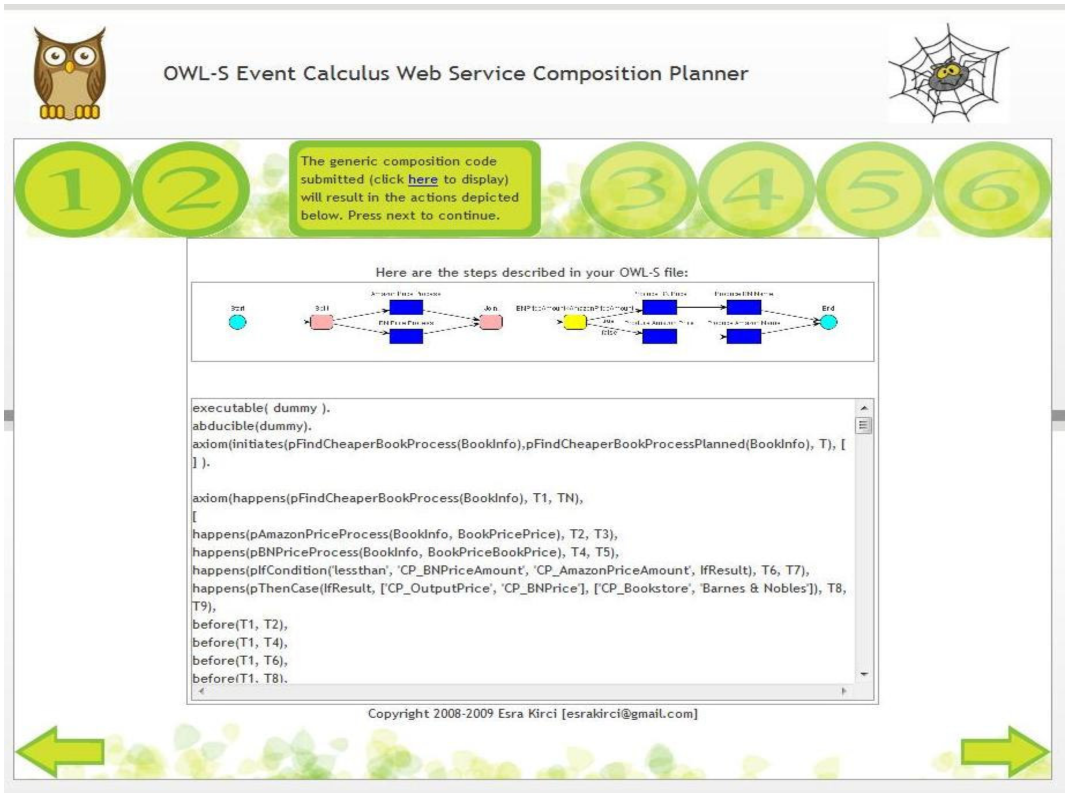
The process model is generated by the CMU OWL-S API as a recursive tree structure, where the leaves of the tree are the processes, and the branches of the tree are the transitions between the processes. The preconditions, input-output bindings and types of the child processes are all known priori when such a model is used.

The process model based Prolog generator can generate all the static declarations for axioms and JPL calls at one pass, therefore no additional passes for the generated code is necessary. The input-output mappings can be made on the generated process model prior to code generation so that the generator will not make any additional passes.

The process model based Prolog generator is a more robust code generator than the incremental code generator, since it works on a pre-processed and parsed model with more information available at every step.

An individual process object contains a reference to the list of child processes it has, the inputs and outputs of itself, the composition type of the process, and the preconditions applicable to the process. The input-output lists for the composite processes also include inputs and outputs of the child processes. This is a necessary step since when a child process returns an output, this output should be made visible to the processes at the same level as the composite process, and Prolog does not support global variables.

The generated Prolog is displayed to the users on the web interface for informative purposes as below:



The generic composition code submitted (click here to display) will result in the actions depicted below. Press next to continue.

Here are the steps described in your OWL-S file:

```
executable( dummy ).
abducible(dummy).
axiom(initiates(pFindCheaperBookProcess(BookInfo),pFindCheaperBookProcessPlanned(BookInfo), T), [
] ).

axiom(happens(pFindCheaperBookProcess(BookInfo), T1, TN),
[
happens(pAmazonPriceProcess(BookInfo, BookPricePrice), T2, T3),
happens(pBNPriceProcess(BookInfo, BookPriceBookPrice), T4, T5),
happens(pIfCondition('lessthan', 'CP_BNPriceAmount', 'CP_AmazonPriceAmount', IfResult), T6, T7),
happens(pThenCase(IfResult, ['CP_OutputPrice', 'CP_BNPrice'], ['CP_Bookstore', 'Barnes & Nobles']), T8,
T9),
before(T1, T2),
before(T1, T4),
before(T1, T6),
before(T1, T8),
```

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Figure 5.3 Prolog Code Display

5.5 Input and Output Bindings

In a web service composition, inputs of atomic or composite processes can be the outputs of other processes in the composition. For instance, if process A with inputs i1 and i2 and outputs o1 and o2 is invoked before process B with inputs i3 and i4 and outputs o3 and o4, and i4 is bound to o2 (the output of process A), the process B should be invoked with an input dynamically obtained in the runtime.

The concept of input and output bindings is very similar to symbolic links in Linux, or reference pointers in C/C++. However these constructs are not supported via Prolog. Therefore the naming of the inputs needs attention. This means that all the variable names which point to a certain value should have the same name, so that the Prolog interpreter can pass the correct value when processes are to be executed. For instance, consider the output binding in OWL-S in Figure 5.4.

```
<process:OutputBinding>
     <process:toParam rdf:resource="#BookPrice"/>
     <process:valueSource>
          <process:ValueOf>
          <process:fromProcess rdf:resource="#ComparePrices"/>
          <process:theVar rdf:resource="#CP_OutputPrice"/>
          </process:ValueOf>
     </process:valueSource>
</process:OutputBinding>
```

Figure 5.4 A Sample Output Binding in OWL-S

In the example OWL-S code, the output "BookPrice" of the current process is assigned to the output "CP_OutputPrice" of the "ComparePrices" process, which has been executed prior to the binding. The Prolog approach would name the "CP_OutputPrice" variable as "BookPrice" as shown below:

```
axiom(happens(pCurrentProcess(BookName, BookPrice), T1, TN),
[    ...
     happens(pComparePrices, BookName, BookPrice, T2, T2),
     ...
]).
```

Since the names of the variables are changed when the Prolog code is generated, the inputs and outputs displayed later in the plan display phase also change. This might lead to misunderstandings on the user side, i.e. the user who expects an output with the name “reservation_id” would get an output with the name “output_id”. Different approaches exist for input and output bindings.

The output bindings are processed in a bottom up manner whereas the input bindings are processed in a top down manner. The names of the outputs of the main composition are propagated up. The names of the inputs of sub-processes are changed based on the names of the outputs of the previously executed processes. A simple example for variable naming & binding scenario is provided below:

<u>OWL-S Process Descriptions</u>:
Process A has inputs i1 and i2, and outputs o1 and o2.
Process B has inputs i3 and i4, and outputs o3 and o4.
Composite process C has inputs i5, i6 and i7, and outputs o5, o6, o7.

<u>OWL-S Input & Output Bindings:</u>
The input bindings are between i5 and i1, i6 and i2, i7 and i3, and o1 and i4
The output bindings are between o5 and o2, o6 and o3 and o7 and o4

<u>Prolog Variable Naming</u>:
Process A has inputs i5 and i6, outputs o1 and o5
Process B has inputs i7 and o1, outputs o6 and o7
Composite process C has inputs i5, i6 and i7, and outputs o5, o6, o7

5.6 Simple Compositions

Since Prolog does not provide a class structure equivalent to object oriented languages, handling simple compositions is easier. A sample simple composition is given in Figure 5.5.

```
<process:CompositeProcess rdf:about="#BookPriceProcess">
<process:composedOf>
     <process:Any-Order>
     <process:components>
     <process:ControlConstructBag>
     <list:first>
          <process:Perform rdf:nodeID="Any-Order-Perform1" />
     </list:first>
     <list:rest>
          <process:ControlConstructBag>
          <list:first>
          <process:Perform rdf:nodeID="Any-Order-Perform2" />
          </list:first>
          <list:rest rdf:resource="&list;#nil" />
          </process:ControlConstructBag>
     </list:rest>
     </process:ControlConstructBag>
     </process:components>
     </process:Any-Order>
</process:composedOf>
```

Figure 5.5 A Simple Composition in OWL-S

The above composition is of type Any-Order, and simply references two atomic processes that can be called with any desired order.

For a simple composition, the generated Prolog code consists of four main parts: First part contains the static declarations for the Abductive Planner; second part contains the description of the simple composite process; third part contains the individual atomic process declarations including their JPL references; and the last part contains the JPL declarations for the contained atomic processes

The invocation ordering of the atomic processes is made within the description of the simple composite process (the second part described above), based on the type of the composition. A sample ordering is given in Figure 5.6.

```
axiom( happens(pSequenceProcess(Input1, Input2, Output), T1, TN),
[    happens(pSequenceProcess1(Input1, OutputP1), T2, T2),
     happens(pSequenceProcess2(Input2, OutputP2), T3, T3),
     happens(pSequenceProcess3(OutputP1, OutputP2, Output),T4,T4),
     before(T1, T2),
     before(T2, T3),
     before(T3, T4),
     before(T4, TN)
] ).
```

Figure 5.6 A Simple Composition Axiom in Prolog

The above process shows the composite process “pSequenceProcess” which is formed by three atomic processes, with several input-output bindings. The time variance is specified with the “before” constructs after the “happens” declarations. Since this is a sequential composition, each process is executed after the execution of the preceding process is finished.

5.7 Recursive Compositions

Recursive compositions require extra care in the generation of Prolog code since Prolog has restrictions on where certain constructs can be defined, and it does not have support for a hierarchical class-like structure. A sample recursive composition is illustrated in Figure 5.7.

```
...
<process:composedOf>
<process:Sequence>
<process:components>
     <process:ControlConstructList>
     <list:first>
          <process:Split-Join>
               <process:components>
               <process:ControlConstructBag>
               <list:first
                    rdf:resource="#AtomicProcess1" />
               <list:rest>
               <process:ControlConstructBag>
               <list:first
                    rdf:resource="#AtomicProcess2" />
               <list:rest
                    rdf:resource="&list;#nil" />
               </process:ControlConstructBag>
               </list:rest>
               </process:ControlConstructBag>
               </process:components>
          </process:Split-Join>
     </list:first>
     <list:rest>
          <process:ControlConstructList>
          <list:first
               rdf:resource="#CompositeProcess1" />
          <list:rest rdf:resource="&list;#nil" />
          </process:ControlConstructList>
     </list:rest>
     </process:ControlConstructList>
</process:components>
```

```
</process:Sequence>
</process:composedOf>
...
<process:CompositeProcess rdf:ID="CompositeProcess1">
<process:composedOf>
     <process:If-Then-Else>
     <process:ifCondition/>
     <process:then>
          <process:Sequence>
          <process:components>
               <process:ControlConstructList/>
          </process:components>
          </process:Sequence>
     </process:then>
     <process:else>
          <process:Sequence>
          <process:components>
               <process:ControlConstructList/>
          </process:components>
          </process:Sequence>
     </process:else>
     </process:If-Then-Else>
</process:composedOf>
</process:CompositeProcess>
...
```

Figure 5.7 A Recursive Composition

In the given example, the currently described process is a composite, Sequence process. As the first step it includes a Split-Join between two atomic processes. As the second step, it has a reference to a composite process, which is an If-Then-Else type of composite process. The then and else cases of the If-Then-Else processes can still be composite processes. Note that for simplicity, these processes and several required constructs are omitted.

In a recursive composition there are four buffers to which the code generator appends Prolog code. These buffers are similar to the four main parts of code generated for simple compositions. The main difference between the approaches is that, in a simple composition there is only one composite axiom, whereas in the recursive composition the composite axiom count is equal to the composite process count. Also, the static declarations are not made per composite process, but rather per Prolog file.

Also the linear code generation approach is not possible with recursive compositions, because the “external” and “JPL” definitions have to be altogether in the code. Therefore these definitions are appended to their own buffers during code generation. When the code generation is completed, all the buffers are merged to a single Prolog file.

5.8 Handling Preconditions

This thesis focuses on arithmetic preconditions, defined as SWRL expressions. However, a similar approach can be taken to handle different preconditions.

Each precondition is treated as another process with the SWRL inputs and a boolean output. The process declaration of the precondition precedes the declaration of the actual process the precondition is bound to. If the precondition fails, the whole axiom including the precondition fails.

If a process A with inputs i1 and i2 and output o1, has a precondition P which contains an SWRL condition “i1 'not equals' i2”, an imaginary precondition process with inputs i1 and i2 and output p1 is generated before A, which controls i1 and i2's equality, and returns false as p1 when they are equal since the tested condition is i1 and i2's inequality.

A special case is present for the If-Then-Else conditions, where the process in the Then or Else clauses depend on the condition specified in the If construct. For such cases two instances of composite process definitions containing the If-Then-Else process is necessary: one which executes the then case, and the other which executes the else case; then case testing the if-condition, else case testing the “not” if-condition.

5.9 Invocation and Plan Generation

Once the Prolog code is generated, it has to be invoked with the parameters provided by the user for both plan simulation and execution purposes. The invocation step is again done via the web interface, with HTML input fields. The details of the invocation and plan generation phase are outlined below.

5.9.1 JPL Library

The Java Interface to Prolog (JPL) library is used for the two-way Prolog – Java communication in which both Java calls Prolog, and Prolog calls Java. It is used both to access Prolog codes generated to feed the code with the inputs provided by the user from the web interface, and to access a stub web service discovery and invocation engine. The details of the calls made, and certain code samples for the calls are provided in this section.

5.9.2 Calls from Prolog to Java

Prolog to Java calls are made from within dynamically generated Prolog files, for service discovery, service invocation and condition evaluation purposes during plan generation and execution phases.

For both composite and atomic processes, the Prolog code generated by the code generator is grounded with a JPL call. The Prolog code generated for a sample atomic process with a simple precondition is provided in Figure 5.8.

```
axiom(initiates(pProcessGeneric(Input1,Input2),
             pProcessPlanned(Input1, Input2), T), [ ] ).

axiom(happens(pProcessGeneric(Input1, Input2), T1, TN),
[
     happens(pProcess(Input1, Input2, Output1), T2, T3),
     before(T1, T2),
     before(T3, TN)
] ).

axiom(happens(pProcess(Input1, Input2, Output1), T1, TN),
[
     jpl_pProcessPrecondition(Input1, Input2),
     jpl_pProcess(Input1, Input2, Output1)
]).
```

Figure 5.8 Prolog for An Atomic Process with a Simple Precondition

The JPL calls in this composition are defined as shown in Figure 5.9.

```
ex_WebService(jpl_pProcessPrecondition(_,_)).
ex_WebService(jpl_pProcess(_,_,_)).

jpl_pProcessPrecondition(Input1, Input2) :-
      atom_number(Input1, Arg1),
      atom_number(Input2, Arg2),
      Arg1<Arg2,
      true.

jpl_pProcess(Input1, Input2, Output1) :-
      jpl_new('tr.edu.metu.prolog.WebServiceInvocation', [], WSI),
      jpl_list_to_array([Input1, Input2], InputArray),
      jpl_call(WSI,invokeService,['pProcess',InputArray],OutputArray),
      (OutputArray == @(null) ->  OutputList = [] ;
      jpl_array_to_list(OutputArray, OutputList)),
      length(OutputList,Length),
      (
      Length==1 ->
      [A] = OutputList,
      (A == @(null) ->  TempList1 = [] ;
      jpl_array_to_list(A, TempList1)),
      WholeList = [TempList1];
         (
         Length==2 ->
         [A,B] = OutputList,
         (A == @(null) ->  TempList1 = [] ;
         jpl_array_to_list(A, TempList1)),
         (B == @(null) ->  TempList2 = [] ;
         jpl_array_to_list(B, TempList2)),
         WholeList = [TempList1, TempList2];
              (
              Length==3 ->
              [A,B,C] = OutputList,
              (A == @(null) ->  TempList1 = [] ;
              jpl_array_to_list(A, TempList1)),
              (B == @(null) ->  TempList2 = [] ;
              jpl_array_to_list(B, TempList2)),
              (C == @(null) ->  TempList3 = [] ;
              jpl_array_to_list(C, TempList3)),
              WholeList = [TempList1, TempList2, TempList3];
                   (
                   Length==4 ->
                   [A,B,C,D] = OutputList,
                   (A == @(null) ->  TempList1 = [] ;
                   jpl_array_to_list(A, TempList1)),
                   (B == @(null) ->  TempList2 = [] ;
                   jpl_array_to_list(B, TempList2)),
                   (C == @(null) ->  TempList3 = [] ;
                   jpl_array_to_list(C, TempList3)),
                   (D == @(null) ->  TempList4 = [] ;
                jpl_array_to_list(D, TempList4)),
                WholeList = [TempList1,TempList2,TempList3,

                                                     TempList4];
                true
                )
            )
        )
    ),
    member([Output1], WholeList),
    true.
```

Figure 5.9 JPL Method Definitions in Event Calculus

In the above example, the atomic process named “Process” has two inputs *Input1* and *Input2*. There's a precondition between these two inputs, which states that *Input1* should have a smaller value than *Input2* numerically.

This precondition control is defined as an external JPL call in Figure 5.8, however no JPL routine is provided inside. This is a trick to deceive the Prolog interpreter to fail the plan automatically if the boolean value of the comparison is false.

There's also an other call, the second one in Figure 5.9, which is a real JPL call invoking the WebServiceInvocation Java class for the process “Process”. This is done by first creating an instance of the class with the full canonical name from the current classpath, and assigning it to a temporary variable. The JPL call receives the inputs of the process as parameters, and wraps them to a Java array using the *jpl_list_to_array* routine. This is required since JPL can not send nested Prolog lists to a Java class. The name of the caller process, and the Java array created is then wrapped as a list and fed to the *invokeService* method of the *WebServiceInvocation* class.

Additional pieces of information could be passed to the *invokeService* method to enable better service discovery in the runtime, however for the scope of this thesis, simply the process name is used as a distinguisher.

An array of output lists is then received and via certain JPL and Prolog tricks the array is converted to a list of lists. The service invocation method returns multiple output lists, since more than one service might be discovered with the along passed information, and each of these services may return their own outputs.

Prolog should handle all the outputs for the given services, however a direct “array of arrays” conversion is not provided in JPL, hence the manual routine. For the scope of this thesis, a set of 4 distinct services are supported per each discovery, and unlimited outputs are supported for each process.

In the last step the member operator is used to enumerate the output lists against the outputs of the process (which are listed in a Prolog list in the order defined in the OWL-S composition).

A second type of Prolog to Java call is made for SWRL conditions specified in the If case of If-Then-Else compositions. This is a selected approach since evaluating an SWRL condition in Prolog takes considerably larger effort than evaluating the condition in Java. A sample JPL call made for an If evaluation is provided in Figure 5.10.

```
jpl_ifCondition(IfOperator, Input1, Input2, IfResult) :-
     jpl_new('tr.edu.metu.prolog.WebServiceInvocation', [], WSI),
     jpl_list_to_array([IfOperator, Input1, Input2], InputArray),
     jpl_call(WSI, evaluateIf, [InputArray], OutputArray),
     (OutputArray == @(null) ->  OutputList = [] ;
     jpl_array_to_list(OutputArray, OutputList)),
     member(IfResult, OutputList),
     IfResult.
```

Figure 5.10 JPL Call of an If Condition in an If-Then-Else Process

In the above example, there's an if condition which takes *Input1* and *Input2* literals as inputs, and operates with *IfOperator* over those inputs. The if operator is parsed from the SWRL expression in the OWL-S file, and provided to the Java class for condition evaluation. Sample condition operators include “less than”, “equal”, “not equal” etc.

5.9.3 Calls from Java to Prolog

Java to Prolog interaction with JPL calls are made from the web application, to pass the inputs provided by the user to the Prolog engine. The abductive event calculus planner and the dynamically generated Prolog code for the composition are both consulted to a Prolog session. Then the Prolog query is created with the user inputs and fed to JPL to generate all possible plans for the currently selected composition.

Results of the query are received via a Hashmap in JPL result object hierarchy. Each entry in the Hashmap denotes a possible plan for the user query. These entries are then parsed with the plan visualizer to be displayed on the web.

A sample code snippet is provided in Figure 5.11.

```
Query consultEventCalculus = new Query("consult", new Term[] {

new Atom(eventCalculusPlanner.getAbsolutePath()) });

consultEventCalculus.query();

Query consultDynamicProlog = new Query("consult", new Term[] {
                        new Atom(dynamicProlog.getAbsolutePath())
});

consultDynamicProlog.query();

Query query = new Query(prologQuery);

results = query.allSolutions();
```

Figure 5.11 JPL Call to a Composition from Java

In the above sample, firstly the event calculus library is loaded, and then the dynamically generated Prolog code is loaded to the Prolog interpreter. Lastly the Prolog query generated with the inputs of the user is sent to the interpreter, and the results are requested. A sample Prolog query is as follows:

```
abdemo([holds_at(pProcessPlanned("UserInput1","UserInput2"),t)], R).
```

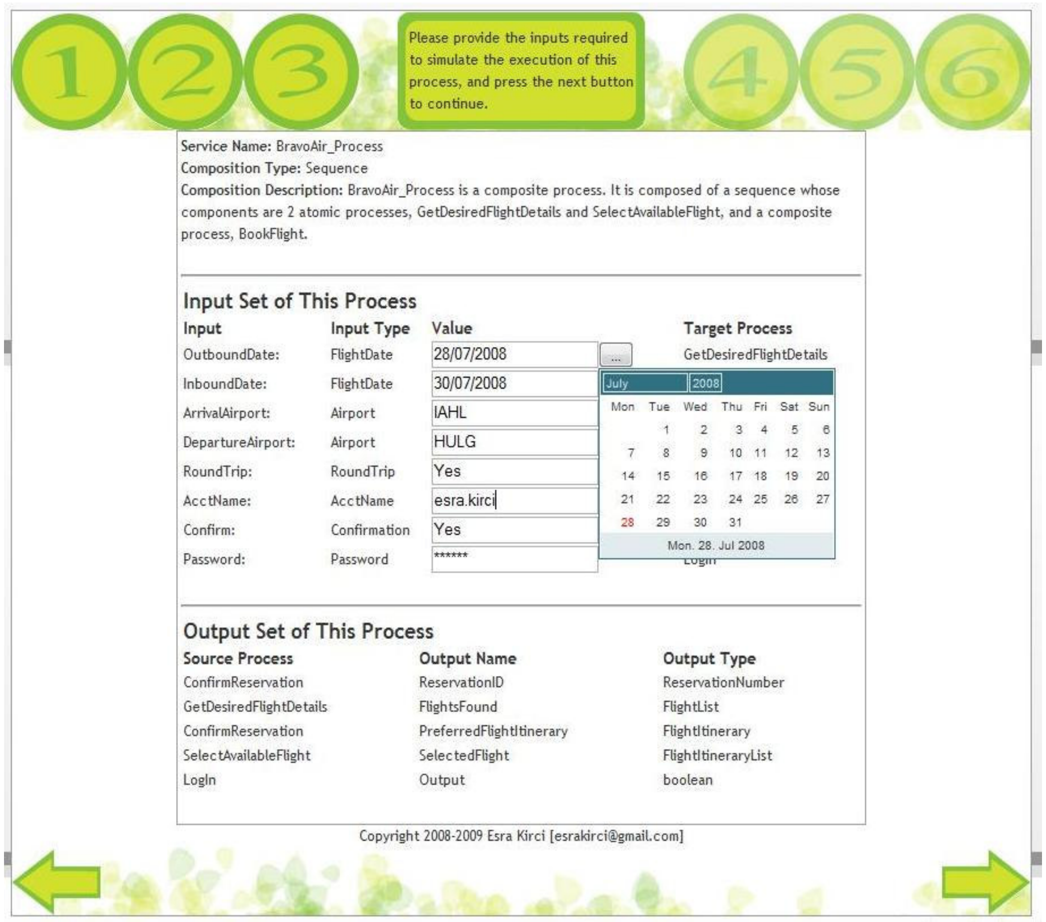
In the above example, the inputs “UserInput1” and “UserInput 2” are two Strings provided by the user of the system from the web interface for execution.

5.9.4 Input Types

The intermediate step between Prolog generation and execution is the interactive input request screen. In this screen, the inputs required by the process are requested from the user. The screen contains the names of the inputs and hints the processes within the composition that will use the input. This way it is easier for the user to provide values for fields with non-descriptive and generic names like “Date” or “Name”.

A second feature is different field handlers for certain inputs. By default, each input is provided a text-field accepting alphanumeric characters. However, for known types like Date, Time and Password, date-time pickers and password fields are also provided. This way, the user does not have to type in everything manually.

The decision for specific field handlers are given based on two factors, first one being the type attribute of the field. If the type of a field is Date, an immediate positive signal is given for a Date field handler. However, not every field type is known apriori by the application, therefore field names are also parsed. This way missing field types are also handled, for instance if an input has the label “Expiration Date”, and its type is “String” in the OWL-S file, the application will still provide a Date field handler for this input. A sample user input screen of the web application is shown in Figure 5.12.



Please provide the inputs required to simulate the execution of this process, and press the next button to continue.

Service Name: BravoAir_Process
Composition Type: Sequence
Composition Description: BravoAir_Process is a composite process. It is composed of a sequence whose components are 2 atomic processes, GetDesiredFlightDetails and SelectAvailableFlight, and a composite process, BookFlight.

Input Set of This Process

Input	Input Type	Value	Target Process
OutboundDate:	FlightDate	28/07/2008	GetDesiredFlightDetails
InboundDate:	FlightDate	30/07/2008	
ArrivalAirport:	Airport	IAHL	
DepartureAirport:	Airport	HULG	
RoundTrip:	RoundTrip	Yes	
AcctName:	AcctName	esra.kirci	
Confirm:	Confirmation	Yes	
Password:	Password	******	Login

July	2008					
Mon	Tue	Wed	Thu	Fri	Sat	Sun
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

Mon. 28. Jul 2008

Output Set of This Process

Source Process	Output Name	Output Type
ConfirmReservation	ReservationID	ReservationNumber
GetDesiredFlightDetails	FlightsFound	FlightList
ConfirmReservation	PreferredFlightItinerary	FlightItinerary
SelectAvailableFlight	SelectedFlight	FlightItineraryList
LogIn	Output	boolean

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Figure 5.12 OWL-S Composition Input Screen

5.9.5 Service Discovery at Execution Time

Neither the OWL-S description nor the generated Prolog code includes any grounding information, thus to plan the composition, discovery for the services matching the given specifications is necessary. Since service discovery is beyond the scope of this thesis, this part is simulated with a service discovery stub.

The JPL calls in the generated Prolog code carry the following information about the services that are to be discovered: the name of the process, the number and names of the inputs and outputs. Further information like the type of the inputs and outputs, the preconditions, quality of service requirements, labels of IOPEs and descriptions of processes can also be provided to service discovery engine, for a better semantic discovery.

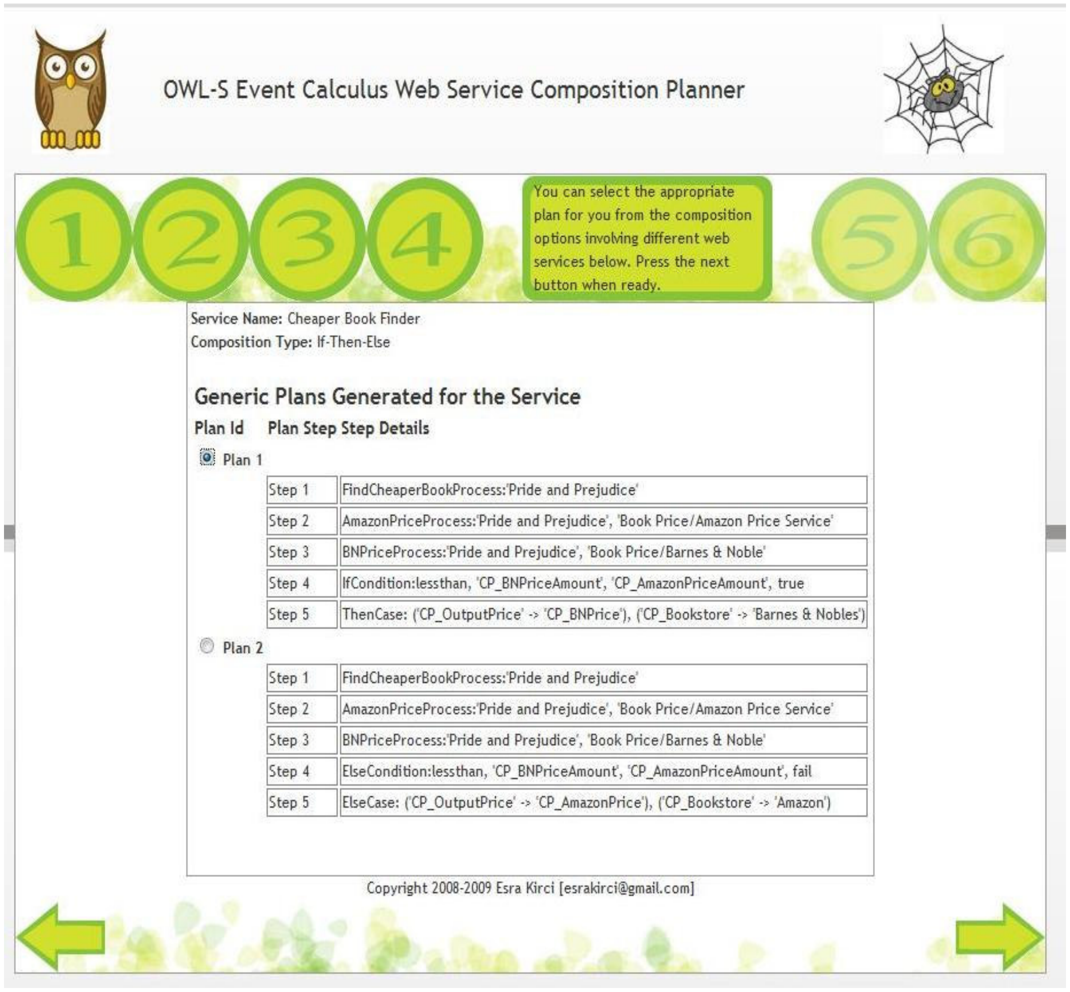
The current service discovery engine responds to discovery queries with a pre-established set of services suitable for the set of processes that have been tested for demo purposes.

5.9.6 Plan Selection

After the inputs are at hand, and the necessary services are discovered via the service discovery engine, the generated Prolog code returns plans for the given generic service composition. The number of plans returned by the abductive planner depends on the number of services discovered and the type of the composition at hand.

For instance, for a “Choice” type of composition, the amount of plans is at least the number of processes in the Choice construct. Permutations regarding the available services, types of composition(s) are all handled by Prolog.

The user is then provided a set of plans, which contain an ordering with the name of the processes that will be executed. The inputs provided by the user are also embedded in the plans, for a better understanding of what will happen if the composition is executed. Since no execution has been performed yet, the generated plans do not contain any real outputs, rather they include the names of the outputs to be obtained. The user can then select a plan for execution. A sample plan selection screen can be seen in Figure 5.13.



You can select the appropriate plan for you from the composition options involving different web services below. Press the next button when ready.

Service Name: Cheaper Book Finder
Composition Type: If-Then-Else

Generic Plans Generated for the Service

Plan Id	Plan Step	Step Details
● Plan 1		
	Step 1	FindCheaperBookProcess:'Pride and Prejudice'
	Step 2	AmazonPriceProcess:'Pride and Prejudice', 'Book Price/Amazon Price Service'
	Step 3	BNPriceProcess:'Pride and Prejudice', 'Book Price/Barnes & Noble'
	Step 4	IfCondition:lessthan, 'CP_BNPriceAmount', 'CP_AmazonPriceAmount', true
	Step 5	ThenCase: ('CP_OutputPrice' -> 'CP_BNPrice'), ('CP_Bookstore' -> 'Barnes & Nobles')
○ Plan 2		
	Step 1	FindCheaperBookProcess:'Pride and Prejudice'
	Step 2	AmazonPriceProcess:'Pride and Prejudice', 'Book Price/Amazon Price Service'
	Step 3	BNPriceProcess:'Pride and Prejudice', 'Book Price/Barnes & Noble'
	Step 4	ElseCondition:lessthan, 'CP_BNPriceAmount', 'CP_AmazonPriceAmount', fail
	Step 5	ElseCase: ('CP_OutputPrice' -> 'CP_AmazonPrice'), ('CP_Bookstore' -> 'Amazon')

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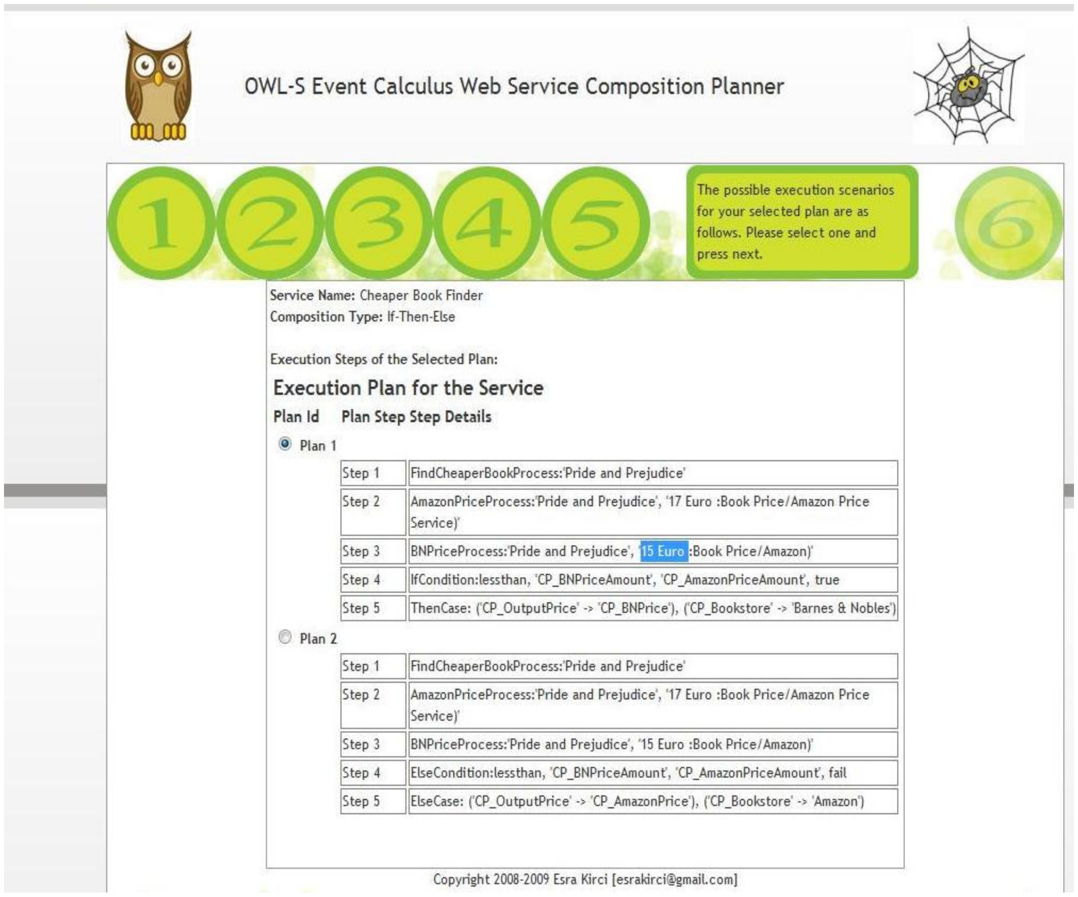
Figure 5.13 Plan Selection Step

5.9.7 Execution Mode

In the execution mode, the services in the plan which are selected by the user in the previous step are executed in the order specified in the plan. Service execution is beyond the scope of this thesis, therefore the outputs obtained are simulated outputs, and do not differ based on the given input.

To differentiate world-altering and information-providing services, the execution mode takes one step for the information-providing services and two steps for the world-altering services. For the information providing services, after the plan selection, the actual service is executed and the outputs of it are shown immediately. For the world-altering services and composite services containing at least one world-altering service as a child, in the first step of execution mode, after the plan selection, simulated outputs are displayed to the user. The user has to proceed one more step to execute the actual service and see the actual outputs of it for these type of services. A sample execution step is illustrated in Figure 5.14.



The possible execution scenarios for your selected plan are as follows. Please select one and press next.

Service Name: Cheaper Book Finder
Composition Type: If-Then-Else

Execution Steps of the Selected Plan:

Execution Plan for the Service

Plan Id	Plan Step	Step Details
● Plan 1		
	Step 1	FindCheaperBookProcess:'Pride and Prejudice'
	Step 2	AmazonPriceProcess:'Pride and Prejudice', '17 Euro :Book Price/Amazon Price Service)'
	Step 3	BNPriceProcess:'Pride and Prejudice', '15 Euro :Book Price/Amazon)'
	Step 4	IfCondition:lessthan, 'CP_BNPriceAmount', 'CP_AmazonPriceAmount', true
	Step 5	ThenCase: ('CP_OutputPrice' -> 'CP_BNPrice'), ('CP_Bookstore' -> 'Barnes & Nobles')
○ Plan 2		
	Step 1	FindCheaperBookProcess:'Pride and Prejudice'
	Step 2	AmazonPriceProcess:'Pride and Prejudice', '17 Euro :Book Price/Amazon Price Service)'
	Step 3	BNPriceProcess:'Pride and Prejudice', '15 Euro :Book Price/Amazon)'
	Step 4	ElseCondition:lessthan, 'CP_BNPriceAmount', 'CP_AmazonPriceAmount', fail
	Step 5	ElseCase: ('CP_OutputPrice' -> 'CP_AmazonPrice'), ('CP_Bookstore' -> 'Amazon')

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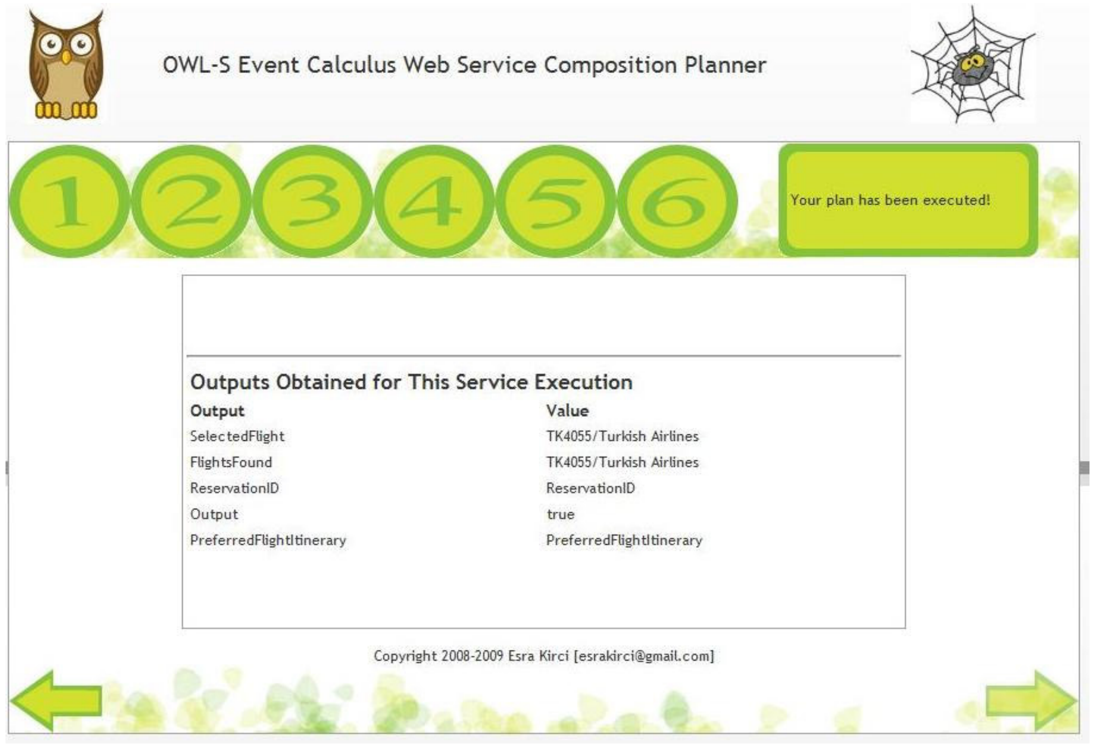
Figure 5.14 Plan Execution Step

After the plan execution step, the user selects the plan to be executed, and the outputs obtained from that plan are listed on a separate screen for execution confirmation, and a better viewing experience, as in Figure 5.15.



Your plan has been executed!

Outputs Obtained for This Service Execution

Output	Value
SelectedFlight	TK4055/Turkish Airlines
FlightsFound	TK4055/Turkish Airlines
ReservationID	ReservationID
Output	true
PreferredFlightItinerary	PreferredFlightItinerary

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Figure 5.15 Execution Output Step

5.10 System Performance

The performance of the system is affected by many factors. The system runs in a J2EE server, and main reasons for the delays are network overheads, RDF parsing and Prolog invocation via Java.

5.10.1 Network Delays

Most OWL-S documents include *namespace* and *import* declarations to external resources. The OWL-S parsers need to download the referenced resources via their provided paths. Even though this necessity seems fair theoretically, in practice it yields to long download delays. Since certain resources referred by the OWL-S descriptions are either no longer present or hosted at different locations, even longer delays are encountered with timeouts.

To provide a better user experience with the download of these resources, local mechanisms should be used whenever possible. Throughout the implementation of this thesis, the productive environment for the web application had several DNS mappings and a local HTTP server to decrease delays with widely used imports.

As an example, the resource "http://www.w3.org/2000/01/rdf-schema" is mapped as "rdfs" entity in valid OWL-S documents. Normally, the parser tries to navigate to the server "www.w3.org" and to the folder "2000/01/rdf-schema". Since external Domain Name Servers correctly respond with the IP "128.30.52.51" to the name server query for "www.w3.org", the OWL-S parsers try to connect to this server. To disable this, a DNS record can be inserted to the *hosts* file of the operating system. When this record is created, an external DNS query is not even necessary. In a Linux environment this can be achieved by inserting "127.0.0.1 www.w3.org" line to "/etc/hosts" file.

Since parsers now try to connect to the localhost to download the required file, the file and folder structure should be created properly for a successful download. Apache2 WWW Server has been used in this case. In the WWW root of Apache2, the "2000/01" folder hierarchy is created and "rdf-schema" document is placed exactly as the same folder structure as in www.w3.org.

As a final step, an additional trick is necessary in the Java code since the Java Virtual Machine (JVM) has its own DNS caching mechanism, which caches an address forever once it has been looked up. This poses a problem since www.w3.org or any other address could have been cached via JVM prior to this project. To prevent this JVM DNS caching, “networkaddress.cache.ttl” Java system property should be set to “0”.

Figure 5.16 illustrates the OWL-S parsing delays for locally hosted vs. remote resources.

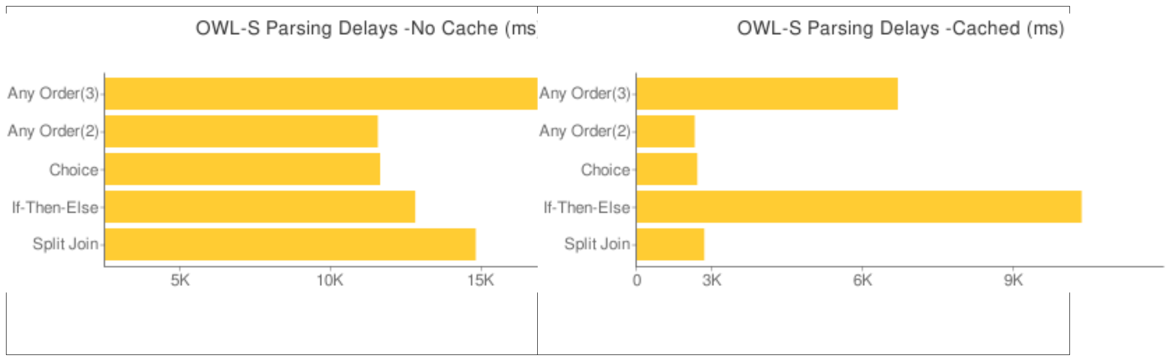

Figure 5.16 Local vs. Remote Resource Usage

Apart from the complex and CPU intensive If-Then-Else compositions, there are 3 to 5 times performance gains with the usage of locally hosted resources. More detailed comparison charts are provided in the Appendix C.

5.10.2 RDF Parsing

Since OWL-S documents are in RDF format, these documents should be parsed via the OWL-S APIs to create the business model. The parsing takes quite less time in contrast with the experienced network delays.

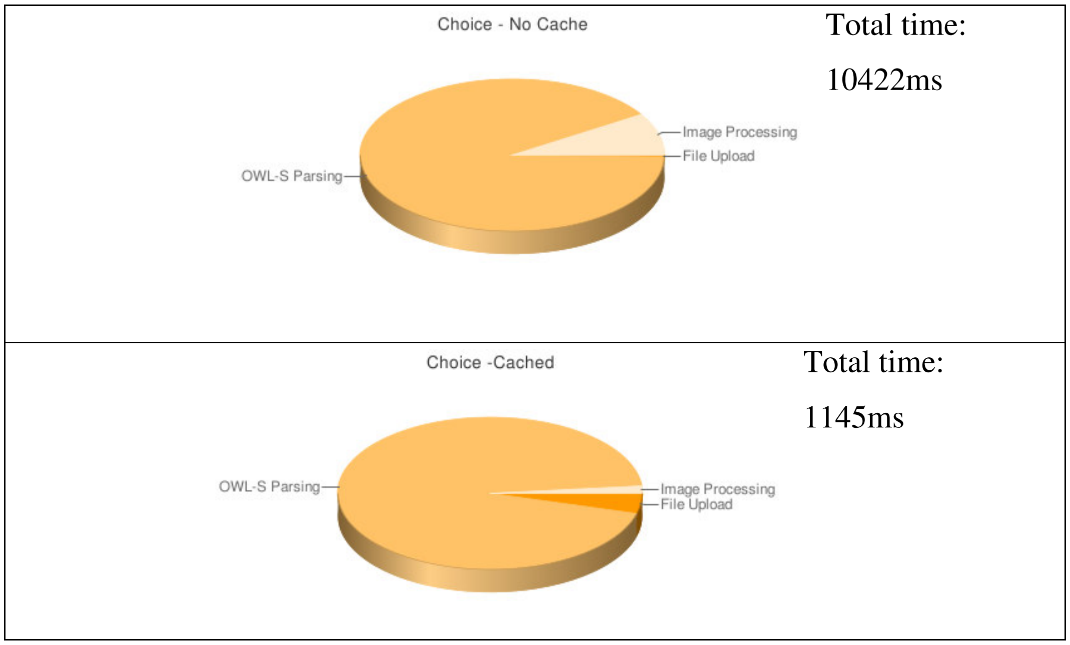

Figure 5.17 Distribution of Delays in a Choice Type of Composition

Figure 5.17 depicts the time distribution of tasks in a sample composition for the first three steps of the application. When local (cached) resources are used for OWL-S parsing, the total time required for the Prolog generation decreases dramatically, however the percentage of OWL-S parsing still increases. This is because the “Image Processing” step also does an amount of OWL-S parsing to generate a business model for the composition, and that step also takes less time when resources are local.

5.10.3 JPL Calls and Prolog

The system uses SWI Prolog, and Java Interface to Prolog to bind to the generated Prolog codes. Individual JPL calls are not as expensive as running Prolog code from an editor visually. The cost of a Prolog call is shown in Figure 5.18.

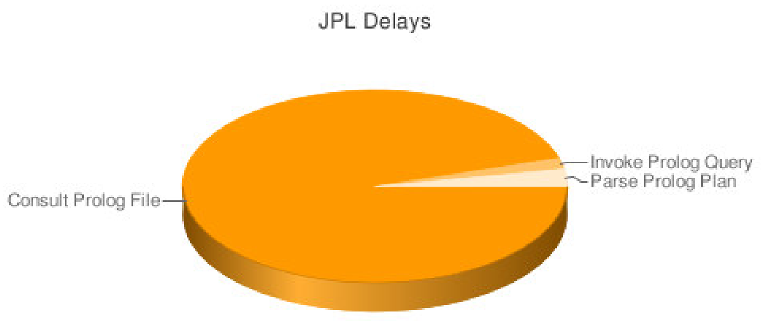

Figure 5.18 JPL Delays for a Sample Any-Order Composition

As illustrated above, there are three types of JPL delays: firstly the Prolog file consultation, secondly invocation and thirdly parsing of JPL results. The most expensive operation is consulting a Prolog file (888ms in the above example), however this step needs to be executed only once. A consulted Prolog file can be used many times with different Prolog queries.

CHAPTER 6

CONCLUSION AND FUTURE WORK

6.1 Summary and Conclusions

In this thesis, an approach and its implementation are presented for the automated composition of semantic web services problem. The applicable scenario for our approach is that, given a generic web service composition definition, our system generates plans as compositions including available services matching the requirements of the generic composition definition. The inputs needed by the composition are provided by the user, and after the planning phase the user is able to select a plan from the generated list of possible plans and execute it with the provided inputs.

A subset of OWL-S ontology is used for generic web service composition definitions. OWL-S process model has the necessary features for defining the structure of the composition with its semantic information. The generic composition definition in OWL-S includes:

- The definitions for the composite services and the atomic services included in them with their inputs, outputs, preconditions and effects,

- The data flow and binding information for the parameters of services,
- The control flow information which characterizes the structure of the composition and temporal relationship between the included services.

The composition is defined similar to a workflow structure with these elements. Profile and grounding parts of OWL-S are not needed for our framework, but profile definition is displayed to the user if it exists. Also it may be beneficial for the discovery phase, which is not covered in this work.

The generic service compositions are provided to our system via uploading the actual OWL-S file, or providing the necessary URL. Then our framework reads in the generic composition definition and displays the graphical representation of it for a better understanding of the composition. Then the inputs needed by the composition are taken from the user and the planning phase begins.

Abductive planning capability of the event calculus, which is a logical formalism for the description of actions and their effects in dynamic environments, is used for planning. The generic composition in OWL-S is converted to the event calculus axioms in Prolog language. Then a goal situation is given and plans, which constitute the necessary middle steps between the initial state and the goal state, are generated by the abductive theorem prover in the event calculus to reach that goal. In the plan generation phase, the abductive planner communicates with the web service discovery module and gets the properties of the atomic services matching the atomic events in the composition whenever such an event is encountered in the planning process. After the plans are generated, there are two steps before the execution of the composition. First, the plans including just the names of the discovered services and names of the parameters belonging to those services are presented to the user. In this step, the user can select the plan including the actual services which s/he prefers. Second, after the user selects the preferred plan and presses the *Next* button, the information-providing services included in the selected plan are executed and the plan is again shown to the user for confirmation before executing the whole plan with the world-altering services.

In some cases, when the information-providing service has an input which is an output of a world-altering service, the information-providing service is not executed either. The outputs of it are simulated as if it is a world-altering service.

The event calculus is used as a middleground for the execution phase as well as for the planning phase. The only difference is that, in the planning phase, the abductive theorem prover is connected with the discovery module; whereas in the execution phase, it is connected with the execution module. In the planning and execution phases, the preconditions are also checked, and the service takes place in the plan or is executed only if its preconditions are satisfied.

Our tool provides the first web service composition platform using abductive event calculus as the framework for planning. As a proof of concept, it is shown that, it is possible to represent composite processes defined in OWL-S in event calculus domain automatically in a lossless manner. Also, it is shown that the event calculus, which is declarative and has clear semantics, is a very suitable platform for web service composition problem, because of the ease in plan generation. Unlike methods using the situation calculus, our tool can differentiate between the information-providing and world-altering services, and treats them according to their nature without making any assumptions.

6.2 Future Work

In our framework, the service discovery and execution modules are simulated. As a future work, these modules can be replaced with the actual discovery and execution components and integrated to our system. Also, currently our system does not handle conditional outputs. The event calculus axioms are generated dynamically just after the OWL-S file is provided to the system, and these axioms include the definitions of the services including the inputs and outputs of them. The number of outputs of a service should be static and match with the event calculus definition of that service for the planner to work successfully. Another layer can be added as a future work to handle conditional outputs as well.

Our system takes ready OWL-S files as generic composition definitions. Another component for creating the OWL-S files dynamically according to the user's needs can be integrated to our system as another future work. This component may gather the user's needs graphically and generate the corresponding OWL-S file.

In the screen used for taking the input values from the user in the web module, which can be seen in Figure 5.12, custom input fields are shown only for a limited number of types of inputs. Only the fields for the date-time picker and password are currently handled. The usual textbox is displayed for all other types of inputs. This can be improved to handle also the types such as credit card, telephone number, bollean values, currency, only-numeric etc.

In our tool, performance loss is mainly due to the delay in Java-Prolog interface and to the effort spent to make the plans coming ATP more representable in a human-readable format. If ATP could be implemented in Java, in such a way that the plans from it are generated in a more representable way, such as a graph, the performance would increase vastly and the effort to develep a program using ATP would be so much easier.

Only the primitive types string and integer are handled in ATP due to the restrictions of Prolog. A layer can be put in between Java and Prolog in order to enable passing other complex types to the planner.

Another future work might include handling all types of conditions written in SWRL to use the full power of it. Our tool handles only numeric values for the conditions. SWRL has some other built-in structures for strings, boolean values, date, time, duration, URIs and lists. Extensions can be made for handling these other structures.

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APPENDIX A

SEQUENCE EXAMPLE

A composition example with Sequence control construct in OWL-S, and its translation to the Event Calculus in Prolog are provided below respectively.

```
<?xml version="1.0" encoding="windows-1254"?>
<!DOCTYPE uridef[
<!ENTITY rdf "http://www.w3.org/1999/02/22-rdf-syntax-ns">
<!ENTITY rdfs "http://www.w3.org/2000/01/rdf-schema">
<!ENTITY owl "http://www.w3.org/2002/07/owl">
<!ENTITY xsd "http://www.w3.org/2001/XMLSchema">
<!ENTITY service "http://www.daml.org/services/owl-
s/1.1/Service.owl">
<!ENTITY profile "http://www.daml.org/services/owl-
s/1.1/Profile.owl">
<!ENTITY process "http://www.daml.org/services/owl-
s/1.1/Process.owl">
<!ENTITY grounding "http://www.daml.org/services/owl-
s/1.1/Grounding.owl">
<!ENTITY expr "http://www.daml.org/services/owl-
s/1.1/generic/Expression.owl">
<!ENTITY swrl "http://www.w3.org/2003/11/swrl">
<!ENTITY swrlb "http://www.w3.org/2003/11/swrlb">
<!ENTITY list "http://www.daml.org/services/owl-
s/1.1/generic/ObjectList.owl">
<!ENTITY concepts "http://www.daml.org/services/owl-
s/1.1/Concepts.owl">
<!ENTITY this "http://localhost:801/owl-s/Sequence.owl">
]>
<rdf:RDF xmlns:rdf="&rdf;#" xmlns:rdfs="&rdfs;#" xmlns:owl="&owl;#"
xmlns:xsd="&xsd;#" xmlns:service="&service;#"
xmlns:profile="&profile;#"
xmlns:process="&process;#" xmlns:grounding="&grounding;#"
xmlns:expr="&expr;#"
```

```
xmlns:swrl="&swrl;#" xmlns:list="&list;#" xml:base="&this;">
<owl:Ontology rdf:about="">
<rdfs:comment>OWL-S Example: Sequence</rdfs:comment>
<owl:imports rdf:resource="&service;" />
<owl:imports rdf:resource="&process;" />
<owl:imports rdf:resource="&profile;" />
<owl:imports rdf:resource="&concepts;" />
<owl:imports rdf:resource="&list;" />
</owl:Ontology>

<!-- Service description -->
<service:Service rdf:ID="TravelService">
<service:presents rdf:resource="#TravelProfile" />
<service:describedBy rdf:resource="#TravelProcess" />
</service:Service>

<!-- Profile description -->
<profile:Profile rdf:ID="TravelProfile">
<service:presentedBy rdf:resource="#TravelService" />
<profile:serviceName>TravelService</profile:serviceName>
<profile:has_process rdf:resource="#TravelProcess"/>
<profile:hasInput rdf:resource="#City" />
<profile:hasInput rdf:resource="#TravelDate" />
<profile:hasInput rdf:resource="#ReturnDate" />
<profile:hasOutput rdf:resource="#FlightNumber" />
<profile:hasOutput rdf:resource="#HotelReservationNumber" />
</profile:Profile>

<!-- Process description -->
<process:CompositeProcess rdf:ID="TravelProcess">
<rdfs:label>This is the top level process for Sequence
</rdfs:label>
<rdfs:comment> TravelProcess is a composite process.</rdfs:comment>
<process:invocable rdf:datatype="&xsd;#boolean">true
</process:invocable>
<service:describes rdf:resource="#TravelService" />
<process:hasInput>
<process:Input rdf:ID="City">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
<rdfs:label>City</rdfs:label>
</process:Input>
</process:hasInput>
<process:hasInput>
<process:Input rdf:ID="TravelDate">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
<rdfs:label>TravelDate</rdfs:label>
</process:Input>
</process:hasInput>
<process:hasInput>
```

```
<process:Input rdf:ID="ReturnDate">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
<rdfs:label>ReturnDate</rdfs:label>
</process:Input>
</process:hasInput>
<process:hasOutput>
<process:Output rdf:ID="FlightNumber">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
<rdfs:label>FlightNumber</rdfs:label>
</process:Output>
</process:hasOutput>
<process:hasOutput>
<process:Output rdf:ID="HotelReservationNumber">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
<rdfs:label>HotelReservationNumber
</rdfs:label>
</process:Output>
</process:hasOutput>
<process:hasResult>
<process:Result>
<process:withOutput>
<process:OutputBinding>
<process:toParam rdf:resource="#FlightNumber" />
<process:valueSource>
<process:ValueOf>
<process:fromProcess rdf:resource="#PerformFindFlight" />
<process:theVar rdf:resource="#FindFlight_FlightNumber" />
</process:ValueOf>
</process:valueSource>
</process:OutputBinding>
</process:withOutput>
</process:Result>
</process:hasResult>
<process:hasResult>
<process:Result>
<process:withOutput>
<process:OutputBinding>
<process:toParam rdf:resource="#HotelReservationNumber" />
<process:valueSource>
<process:ValueOf>
<process:fromProcess rdf:resource="#PerformFindHotel" />
<process:theVar rdf:resource="#FindHotel_HotelReservationNumber" />
</process:ValueOf>
</process:valueSource>
</process:OutputBinding>
</process:withOutput>
</process:Result>
</process:hasResult>
```

```
<process:composedOf>
<process:Sequence>
<process:components>
<process:ControlConstructList>
<list:first>
<process:Perform rdf:ID="PerformFindFlight">
<process:process>
<process:AtomicProcess rdf:ID="FindFlight">
<rdfs:label>FindFlight</rdfs:label>
<rdfs:comment>Finds an available flight</rdfs:comment>
<process:hasInput>
<process:Input rdf:ID="FindFlight_City">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Input>
</process:hasInput>
<process:hasInput>
<process:Input rdf:ID="FindFlight_TravelDate">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Input>
</process:hasInput>
<process:hasInput>
<process:Input rdf:ID="FindFlight_ReturnDate">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Input>
</process:hasInput>
<process:hasOutput>
<process:Output rdf:ID="FindFlight_FlightNumber">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Output>
</process:hasOutput>
</process:AtomicProcess>
</process:process>
<process:hasDataFrom>
<process:InputBinding>
<process:toParam rdf:resource="#FindFlight_City" />
<process:valueSource>
<process:ValueOf>
<process:fromProcess rdf:resource="&process;#TheParentPerform" />
<process:theVar rdf:resource="#City" />
</process:ValueOf>
</process:valueSource>
</process:InputBinding>
</process:hasDataFrom>
<process:hasDataFrom>
<process:InputBinding>
<process:toParam rdf:resource="#FindFlight_TravelDate" />
<process:valueSource>
```

```
<process:ValueOf>
<process:fromProcess rdf:resource="&process;#TheParentPerform" />
<process:theVar rdf:resource="#TravelDate" />
</process:ValueOf>
</process:valueSource>
</process:InputBinding>
</process:hasDataFrom>
<process:hasDataFrom>
<process:InputBinding>
<process:toParam rdf:resource="#FindFlight_ReturnDate" />
<process:valueSource>
<process:ValueOf>
<process:fromProcess rdf:resource="&process;#TheParentPerform" />
<process:theVar rdf:resource="#ReturnDate" />
</process:ValueOf>
</process:valueSource>
</process:InputBinding>
</process:hasDataFrom>
</process:Perform>
</list:first>
<list:rest>
<process:ControlConstructList>
<list:first>
<process:Perform rdf:ID="PerformFindHotel">
<process:process>
<process:AtomicProcess rdf:ID="FindHotel">
<rdfs:label>FindHotel</rdfs:label>
<rdfs:comment>Finds an available hotel</rdfs:comment>
<process:hasInput>
<process:Input rdf:ID="FindHotel_City">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Input>
</process:hasInput>
<process:hasInput>
<process:Input rdf:ID="FindHotel_TravelDate">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Input>
</process:hasInput>
<process:hasInput>
<process:Input rdf:ID="FindHotel_ReturnDate">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Input>
</process:hasInput>
<process:hasOutput>
<process:Output rdf:ID="FindHotel_HotelReservationNumber">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Output>
```

```
</process:hasOutput>
</process:AtomicProcess>
</process:process>
<process:hasDataFrom>
<process:InputBinding>
<process:toParam rdf:resource="#FindHotel_City" />
<process:valueSource>
<process:ValueOf>
<process:fromProcess rdf:resource="&process;#TheParentPerform" />
<process:theVar rdf:resource="#City" />
</process:ValueOf>
</process:valueSource>
</process:InputBinding>
</process:hasDataFrom>
<process:hasDataFrom>
<process:InputBinding>
<process:toParam rdf:resource="#FindHotel_TravelDate" />
<process:valueSource>
<process:ValueOf>
<process:fromProcess rdf:resource="&process;#TheParentPerform" />
<process:theVar rdf:resource="#TravelDate" />
</process:ValueOf>
</process:valueSource>
</process:InputBinding>
</process:hasDataFrom>
<process:hasDataFrom>
<process:InputBinding>
<process:toParam rdf:resource="#FindHotel_ReturnDate" />
<process:valueSource>
<process:ValueOf>
<process:fromProcess rdf:resource="&process;#TheParentPerform" />
<process:theVar rdf:resource="#ReturnDate" />
</process:ValueOf>
</process:valueSource>
</process:InputBinding>
</process:hasDataFrom>
</process:Perform>
</list:first>
<list:rest rdf:resource="&list;#nil" />
</process:ControlConstructList>
</list:rest>
</process:ControlConstructList>
</process:components>
</process:Sequence>
</process:composedOf>
</process:CompositeProcess>
</rdf:RDF>
```

```
executable( dummy ).
```

```
abducible(dummy).
:- use_module(library(jpl)).

%abdemo([holds_at(pTravelProcessPlanned(ReturnDate, TravelDate, City), t)],
R).

axiom(initiates(pTravelProcess(ReturnDate, TravelDate,
City),pTravelProcessPlanned(ReturnDate, TravelDate, City), T), [ ] ).


axiom(happens(pTravelProcess(ReturnDate, TravelDate, City), T1, TN),
[
happens(pFindFlight(ReturnDate, TravelDate, City, FlightNumber), T2, T3),
happens(pFindHotel(ReturnDate, TravelDate, City, HotelReservationNumber),
T4, T5),
before(T1, T2),
before(T3, T4),
before(T5, TN)
] ).

%Atomic Process Prolog:FindFlight
%Atomic Process Prolog:FindHotel
%%% INDIVIDUAL AXIOMS %%%
axiom(happens(pFindFlight(ReturnDate, TravelDate, City, FlightNumber), T1,
TN),
[
    jpl_pFindFlight(ReturnDate, TravelDate, City, FlightNumber)
]).

axiom(happens(pFindHotel(ReturnDate, TravelDate, City,
HotelReservationNumber), T1, TN),
[
    jpl_pFindHotel(ReturnDate, TravelDate, City, HotelReservationNumber)
]).

%%% EX_WEBSERVICE DECLARATIONS %%%
ex_WebService(jpl_pFindFlight(_,_,_,_)).
ex_WebService(jpl_pFindHotel(_,_,_,_)).

%%% JPL METHOD DEFINITIONS %%%
jpl_pFindFlight(ReturnDate, TravelDate, City, FlightNumber) :-
    jpl_new('tr.edu.metu.prolog.WebServiceInvocation', [], WSI),
    jpl_list_to_array([ReturnDate, TravelDate, City], InputArray),
    jpl_call(WSI, invokeService, ['pFindFlight', InputArray], OutputArray),
    (OutputArray == @(null) ->  OutputList = [] ;
    jpl_array_to_list(OutputArray, OutputList)),
    length(OutputList,Length),
    (
    Length==1 ->
    [A] = OutputList,
    (A == @(null) ->  TempList1 = [] ;
    jpl_array_to_list(A, TempList1)),
    WholeList = [TempList1];
        (
        Length==2 ->
        [A,B] = OutputList,
        (A == @(null) ->  TempList1 = [] ;
        jpl_array_to_list(A, TempList1)),
        (B == @(null) ->  TempList2 = [] ;
        jpl_array_to_list(B, TempList2)),
        WholeList = [TempList1, TempList2];
            (
            Length==3 ->
            [A,B,C] = OutputList,
            (A == @(null) ->  TempList1 = [] ;
            jpl_array_to_list(A, TempList1)),
            (B == @(null) ->  TempList2 = [] ;
            jpl_array_to_list(B, TempList2)),
            (C == @(null) ->  TempList3 = [] ;
            jpl_array_to_list(C, TempList3)),
            WholeList = [TempList1, TempList2, TempList3];
                (
                Length==4 ->
                [A,B,C,D] = OutputList,
                (A == @(null) ->  TempList1 = [] ;
                jpl_array_to_list(A, TempList1)),
                (B == @(null) ->  TempList2 = [] ;
                jpl_array_to_list(B, TempList2)),
                (C == @(null) ->  TempList3 = [] ;
                jpl_array_to_list(C, TempList3)),
                (D == @(null) ->  TempList4 = [] ;
                jpl_array_to_list(D, TempList4)),
                WholeList = [TempList1, TempList2, TempList3, TempList4];
                true
                )
            )
        )
    ),
    member([FlightNumber], WholeList),
    true.

jpl_pFindHotel(ReturnDate, TravelDate, City, HotelReservationNumber) :-
    jpl_new('tr.edu.metu.prolog.WebServiceInvocation', [], WSI),
    jpl_list_to_array([ReturnDate, TravelDate, City], InputArray),
    jpl_call(WSI, invokeService, ['pFindHotel', InputArray], OutputArray),
    (OutputArray == @(null) ->  OutputList = [] ;
    jpl_array_to_list(OutputArray, OutputList)),
    length(OutputList,Length),
    (
    Length==1 ->
    [A] = OutputList,
    (A == @(null) ->  TempList1 = [] ;
    jpl_array_to_list(A, TempList1)),
    WholeList = [TempList1];
        (
        Length==2 ->
        [A,B] = OutputList,
        (A == @(null) ->  TempList1 = [] ;
        jpl_array_to_list(A, TempList1)),
        (B == @(null) ->  TempList2 = [] ;
        jpl_array_to_list(B, TempList2)),
        WholeList = [TempList1, TempList2];
            (
            Length==3 ->
            [A,B,C] = OutputList,
            (A == @(null) ->  TempList1 = [] ;
            jpl_array_to_list(A, TempList1)),
            (B == @(null) ->  TempList2 = [] ;
            jpl_array_to_list(B, TempList2)),
            (C == @(null) ->  TempList3 = [] ;
            jpl_array_to_list(C, TempList3)),
            WholeList = [TempList1, TempList2, TempList3];
                (
                Length==4 ->
                [A,B,C,D] = OutputList,
                (A == @(null) ->  TempList1 = [] ;
                jpl_array_to_list(A, TempList1)),
                (B == @(null) ->  TempList2 = [] ;
                jpl_array_to_list(B, TempList2)),
                (C == @(null) ->  TempList3 = [] ;
                jpl_array_to_list(C, TempList3)),
                (D == @(null) ->  TempList4 = [] ;
                jpl_array_to_list(D, TempList4)),
                WholeList = [TempList1, TempList2, TempList3, TempList4];
                true
                )
            )
        )
    ),
    member([HotelReservationNumber], WholeList),
    true.
```

APPENDIX B

EXAMPLE IN TRAVEL DOMAIN

A generic composition in travel domain including various control constructs is provided below. First the OWL-S file, then its translation to the Event Calculus domain in Prolog will be provided.

```
<?xml version="1.0" encoding="windows-1254"?>
<!DOCTYPE uridef[
<!ENTITY rdf "http://www.w3.org/1999/02/22-rdf-syntax-ns">
<!ENTITY rdfs "http://www.w3.org/2000/01/rdf-schema">
<!ENTITY owl "http://www.w3.org/2002/07/owl">
<!ENTITY xsd "http://www.w3.org/2001/XMLSchema">
<!ENTITY service "http://www.daml.org/services/owl-s/1.1/Service.owl">
<!ENTITY profile "http://www.daml.org/services/owl-s/1.1/Profile.owl">
<!ENTITY process "http://www.daml.org/services/owl-s/1.1/Process.owl">
<!ENTITY grounding "http://www.daml.org/services/owl-s/1.1/Grounding.owl">
<!ENTITY              expr              "http://www.daml.org/services/owl-
s/1.1/generic/Expression.owl">
<!ENTITY swrl "http://www.w3.org/2003/11/swrl">
<!ENTITY swrlb "http://www.w3.org/2003/11/swrlb">
<!ENTITY              list              "http://www.daml.org/services/owl-
s/1.1/generic/ObjectList.owl">
<!ENTITY concepts "http://www.daml.org/services/owl-s/1.1/Concepts.owl">
<!ENTITY this "http://localhost:801/owl-s/Sequence.owl">
]>
<rdf:RDF xmlns:rdf="&rdf;#" xmlns:rdfs="&rdfs;#" xmlns:owl="&owl;#"
xmlns:xsd="&xsd;#" xmlns:service="&service;#" xmlns:profile="&profile;#"
xmlns:process="&process;#"                   xmlns:grounding="&grounding;#"
xmlns:expr="&expr;#"
xmlns:swrl="&swrl;#" xmlns:list="&list;#" xml:base="&this;">
<owl:Ontology rdf:about="">
<rdfs:comment>OWL-S Example: Sequence</rdfs:comment>
<owl:imports rdf:resource="&service;" />
<owl:imports rdf:resource="&process;" />
<owl:imports rdf:resource="&profile;" />
<owl:imports rdf:resource="&concepts;" />
<owl:imports rdf:resource="&list;" />
```

```
</owl:Ontology>

<!-- Service description -->
<service:Service rdf:ID="TravelService">
<service:presents rdf:resource="#TravelProfile" />
<service:describedBy rdf:resource="#TravelProcess" />
</service:Service>

<!-- Profile description -->
<profile:Profile rdf:ID="TravelProfile">
<service:presentedBy rdf:resource="#TravelService" />
<profile:serviceName>TravelService</profile:serviceName>
<profile:has_process rdf:resource="#TravelProcess" />
<profile:hasInput rdf:resource="#City" />
<profile:hasInput rdf:resource="#TravelDate" />
<profile:hasInput rdf:resource="#ReturnDate" />
<profile:hasInput rdf:resource="#ShouldRentACar" />
<profile:hasOutput rdf:resource="#RemoteTransportationReservationNumber" />
<profile:hasOutput rdf:resource="#HotelReservationNumber" />
<profile:hasOutput rdf:resource="#TransportationReservationNumber" />
</profile:Profile>

<!-- Process description -->
<process:CompositeProcess rdf:ID="TravelProcess">
<rdfs:label> This is the top level process for Sequence</rdfs:label>
<rdfs:comment> TravelProcess is a composite process.</rdfs:comment>
<process:invocable rdf:datatype="&xsd;#boolean"> true
</process:invocable>
<service:describes rdf:resource="#TravelService" />
<process:hasInput>
<process:Input rdf:ID="City">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
<rdfs:label>City</rdfs:label>
</process:Input>
</process:hasInput>
<process:hasInput>
<process:Input rdf:ID="TravelDate">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
<rdfs:label>TravelDate</rdfs:label>
</process:Input>
</process:hasInput>
<process:hasInput>
<process:Input rdf:ID="ReturnDate">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
<rdfs:label>ReturnDate</rdfs:label>
</process:Input>
</process:hasInput>
<process:hasInput>
<process:Input rdf:ID="ShouldRentACar">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#boolean
</process:parameterType>
<rdfs:label>ShouldRentACar</rdfs:label>
</process:Input>
</process:hasInput>
```

```
<process:hasOutput>
<process:Output rdf:ID="RemoteTransportationReservationNumber">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
<rdfs:label>RemoteTransportationReservationNumber
</rdfs:label>
</process:Output>
</process:hasOutput>
<process:hasOutput>
<process:Output rdf:ID="HotelReservationNumber">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
<rdfs:label>HotelReservationNumber
</rdfs:label>
</process:Output>
</process:hasOutput>
<process:hasOutput>
<process:Output rdf:ID="TransportationReservationNumber">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
<rdfs:label>TransportationReservationNumber
</rdfs:label>
</process:Output>
</process:hasOutput>
<process:hasResult>
<process:Result>
<process:withOutput>
<process:OutputBinding>
<process:toParam rdf:resource="#RemoteTransportationReservationNumber" />
<process:valueSource>
<process:ValueOf>
<process:fromProcess rdf:resource="#PerformFindRemoteTransportation" />
<process:theVar
rdf:resource="#FindRemoteTransportation_RemoteTransportationReservationNumb
er" />
</process:ValueOf>
</process:valueSource>
</process:OutputBinding>
</process:withOutput>
</process:Result>
</process:hasResult>
<process:hasResult>
<process:Result>
<process:withOutput>
<process:OutputBinding>
<process:toParam rdf:resource="#HotelReservationNumber" />
<process:valueSource>
<process:ValueOf>
<process:fromProcess rdf:resource="#PerformFindHotel" />
<process:theVar rdf:resource="#FindHotel_HotelReservationNumber" />
</process:ValueOf>
</process:valueSource>
</process:OutputBinding>
</process:withOutput>
</process:Result>
</process:hasResult>
<process:hasResult>
```

```
<process:Result>
<process:withOutput>
<process:OutputBinding>
<process:toParam rdf:resource="#TransportationReservationNumber" />
<process:valueSource>
<process:ValueOf>
<process:fromProcess rdf:resource="#PerformFindLocalTransportation" />
<process:theVar
rdf:resource="#FindLocalTransportation_TransportationReservationNumber" />
</process:ValueOf>
</process:valueSource>
</process:OutputBinding>
</process:withOutput>
</process:Result>
</process:hasResult>
<process:composedOf>
<process:Sequence>
<process:components>
<process:ControlConstructList>
<list:first>
<process:Perform rdf:ID="PerformFindRemoteTransportation">
<process:process>
<process:CompositeProcess rdf:ID="FindRemoteTransportation">
<rdfs:label> FindRemoteTransportation</rdfs:label>
<rdfs:comment> FindRemoteTransportation</rdfs:comment>
<process:hasInput>
<process:Input rdf:ID="FindRemoteTransportation_City">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Input>
</process:hasInput>
<process:hasInput>
<process:Input rdf:ID="FindRemoteTransportation_TravelDate">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Input>
</process:hasInput>
<process:hasInput>
<process:Input rdf:ID="FindRemoteTransportation_ReturnDate">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Input>
</process:hasInput>
<process:hasOutput>
<process:Output
rdf:ID="FindRemoteTransportation_RemoteTransportationReservationNumber">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Output>
</process:hasOutput>
<process:composedOf>
<process:Choice>
<process:components>
<process:ControlConstructBag>
<list:first>
<process:Perform rdf:ID="PerformFindFlight">
<process:process>
```

```
<process:AtomicProcess rdf:ID="FindFlight">
<rdfs:label>FindFlight</rdfs:label>
<rdfs:comment>FindFlight</rdfs:comment>
<process:hasInput>
<process:Input rdf:ID="FindFlight_City">
<process:parameterType
rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Input>
</process:hasInput>
<process:hasInput>
<process:Input rdf:ID="FindFlight_TravelDate">
<process:parameterType
rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Input>
</process:hasInput>
<process:hasInput>
<process:Input rdf:ID="FindFlight_ReturnDate">
<process:parameterType
rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Input>
</process:hasInput>
<process:hasOutput>
<process:Output
rdf:ID="FindFlight_RemoteTransportationReservationNumber">
<process:parameterType
rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Output>
</process:hasOutput>
</process:AtomicProcess>
</process:process>
<process:hasDataFrom>
<process:InputBinding>
<process:toParam rdf:resource="#FindFlight_City" />
<process:valueSource>
<process:ValueOf>
<process:fromProcess
rdf:resource="&process;#TheParentPerform" />
<process:theVar rdf:resource="#City" />
</process:ValueOf>
</process:valueSource>
</process:InputBinding>
</process:hasDataFrom>
<process:hasDataFrom>
<process:InputBinding>
<process:toParam rdf:resource="#FindFlight_TravelDate" />
<process:valueSource>
<process:ValueOf>
<process:fromProcess
rdf:resource="&process;#TheParentPerform" />
<process:theVar rdf:resource="#TravelDate" />
</process:ValueOf>
</process:valueSource>
</process:InputBinding>
```

```
</process:hasDataFrom>
<process:hasDataFrom>
<process:InputBinding>
<process:toParam rdf:resource="#FindFlight_ReturnDate" />
<process:valueSource>
<process:ValueOf>
<process:fromProcess
rdf:resource="&process;#TheParentPerform" />
<process:theVar rdf:resource="#ReturnDate" />
</process:ValueOf>
</process:valueSource>
</process:InputBinding>
</process:hasDataFrom>
<process:hasDataFrom>
<process:InputBinding>
<process:toParam
rdf:resource="#FindFlight_RemoteTransportationReservationNumber" />
<process:valueSource>
<process:ValueOf>
<process:fromProcess
rdf:resource="&process;#TheParentPerform" />
<process:theVar
rdf:resource="#RemoteTransportationReservationNumber" />
</process:ValueOf>
</process:valueSource>
</process:InputBinding>
</process:hasDataFrom>
</process:Perform>
</list:first>
<list:rest>
<process:ControlConstructBag>
<list:first>
<process:Perform rdf:ID="PerformFindBus">
<process:process>
<process:AtomicProcess rdf:ID="FindBus">
<rdfs:label> FindBus</rdfs:label>
<rdfs:comment> Bike</rdfs:comment>
<process:hasInput>
<process:Input rdf:ID="FindBus_City">
<process:parameterType
rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Input>
</process:hasInput>
<process:hasInput>
<process:Input rdf:ID="FindBus_TravelDate">
<process:parameterType
rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Input>
</process:hasInput>
<process:hasInput>
<process:Input rdf:ID="FindBus_ReturnDate">
<process:parameterType
rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Input>
```

```
</process:hasInput>
<process:hasOutput>
<process:Output
rdf:ID="FindBus_RemoteTransportationReservationNumber">
<process:parameterType
rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Output>
</process:hasOutput>
</process:AtomicProcess>
</process:process>
<process:hasDataFrom>
<process:InputBinding>
<process:toParam rdf:resource="#FindBus_City" />
<process:valueSource>
<process:ValueOf>
<process:fromProcess
rdf:resource="&process;#TheParentPerform" />
<process:theVar rdf:resource="#City" />
</process:ValueOf>
</process:valueSource>
</process:InputBinding>
</process:hasDataFrom>
<process:hasDataFrom>
<process:InputBinding>
<process:toParam rdf:resource="#FindBus_TravelDate" />
<process:valueSource>
<process:ValueOf>
<process:fromProcess
rdf:resource="&process;#TheParentPerform" />
<process:theVar rdf:resource="#TravelDate" />
</process:ValueOf>
</process:valueSource>
</process:InputBinding>
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<process:hasDataFrom>
<process:InputBinding>
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<process:valueSource>
<process:ValueOf>
<process:fromProcess
rdf:resource="&process;#TheParentPerform" />
<process:theVar rdf:resource="#ReturnDate" />
</process:ValueOf>
</process:valueSource>
</process:InputBinding>
</process:hasDataFrom>
<process:hasDataFrom>
<process:InputBinding>
<process:toParam
rdf:resource="#FindBus_RemoteTransportationReservationNumber" />
<process:valueSource>
<process:ValueOf>
<process:fromProcess
rdf:resource="&process;#TheParentPerform" />
<process:theVar
rdf:resource="#RemoteTransportationReservationNumber" />
```

```
</process:ValueOf>
</process:valueSource>
</process:InputBinding>
</process:hasDataFrom>
</process:Perform>
</list:first>
<list:rest rdf:resource="&list;#nil" />
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</list:rest>
</process:ControlConstructBag>
</process:components>
</process:Choice>
</process:composedOf>
</process:CompositeProcess>
</process:process>
<process:hasDataFrom>
<process:InputBinding>
<process:toParam rdf:resource="#FindRemoteTransportation_City" />
<process:valueSource>
<process:ValueOf>
<process:fromProcess rdf:resource="&process;#TheParentPerform" />
<process:theVar rdf:resource="#City" />
</process:ValueOf>
</process:valueSource>
</process:InputBinding>
</process:hasDataFrom>
<process:hasDataFrom>
<process:InputBinding>
<process:toParam rdf:resource="#FindRemoteTransportation_TravelDate" />
<process:valueSource>
<process:ValueOf>
<process:fromProcess rdf:resource="&process;#TheParentPerform" />
<process:theVar rdf:resource="#TravelDate" />
</process:ValueOf>
</process:valueSource>
</process:InputBinding>
</process:hasDataFrom>
<process:hasDataFrom>
<process:InputBinding>
<process:toParam rdf:resource="#FindRemoteTransportation_ReturnDate" />
<process:valueSource>
<process:ValueOf>
<process:fromProcess rdf:resource="&process;#TheParentPerform" />
<process:theVar rdf:resource="#ReturnDate" />
</process:ValueOf>
</process:valueSource>
</process:InputBinding>
</process:hasDataFrom>
</process:Perform>
</list:first>
<list:rest>
<process:ControlConstructList>
<list:first>
<process:Perform rdf:ID="PerformFindHotel">
<process:process>
<process:AtomicProcess rdf:ID="FindHotel">
<rdfs:label> FindHotel</rdfs:label>
```

```
<rdfs:comment> Finds an available hotel</rdfs:comment>
<process:hasInput>
<process:Input rdf:ID="FindHotel_City">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Input>
</process:hasInput>
<process:hasInput>
<process:Input rdf:ID="FindHotel_TravelDate">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Input>
</process:hasInput>
<process:hasInput>
<process:Input rdf:ID="FindHotel_ReturnDate">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Input>
</process:hasInput>
<process:hasOutput>
<process:Output rdf:ID="FindHotel_HotelReservationNumber">
<process:parameterType rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Output>
</process:hasOutput>
</process:AtomicProcess>
</process:process>
<process:hasDataFrom>
<process:InputBinding>
<process:toParam rdf:resource="#FindHotel_City" />
<process:valueSource>
<process:ValueOf>
<process:fromProcess rdf:resource="&process;#TheParentPerform" />
<process:theVar rdf:resource="#City" />
</process:ValueOf>
</process:valueSource>
</process:InputBinding>
</process:hasDataFrom>
<process:hasDataFrom>
<process:InputBinding>
<process:toParam rdf:resource="#FindHotel_TravelDate" />
<process:valueSource>
<process:ValueOf>
<process:fromProcess rdf:resource="&process;#TheParentPerform" />
<process:theVar rdf:resource="#TravelDate" />
</process:ValueOf>
</process:valueSource>
</process:InputBinding>
</process:hasDataFrom>
<process:hasDataFrom>
<process:InputBinding>
<process:toParam rdf:resource="#FindHotel_ReturnDate" />
<process:valueSource>
<process:ValueOf>
<process:fromProcess rdf:resource="&process;#TheParentPerform" />
<process:theVar rdf:resource="#ReturnDate" />
</process:ValueOf>
```

```
</process:valueSource>
</process:InputBinding>
</process:hasDataFrom>
</process:Perform>
</list:first>
<list:rest>
<process:ControlConstructList>
<list:first>
<process:Perform rdf:ID="PerformFindLocalTransportation">
<process:process>
<process:CompositeProcess rdf:ID="FindLocalTransportation">
<rdfs:label> FindLocalTransportation</rdfs:label>
<rdfs:comment> FindLocalTransportation</rdfs:comment>
<process:hasInput>
<process:Input rdf:ID="FindLocalTransportation_ShouldRentACar">
<process:parameterType
rdf:datatype="&xsd;#anyURI">&xsd;#boolean
</process:parameterType>
</process:Input>
</process:hasInput>
<process:hasInput>
<process:Input rdf:ID="FindLocalTransportation_City">
<process:parameterType
rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Input>
</process:hasInput>
<process:hasInput>
<process:Input rdf:ID="FindLocalTransportation_TravelDate">
<process:parameterType
rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Input>
</process:hasInput>
<process:hasInput>
<process:Input rdf:ID="FindLocalTransportation_ReturnDate">
<process:parameterType
rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Input>
</process:hasInput>
<process:hasOutput>
<process:Output
rdf:ID="FindLocalTransportation_TransportationReservationNumber">
<process:parameterType
rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Output>
</process:hasOutput>
<process:composedOf>
<process:If-Then-Else>
<process:ifCondition>
<expr:SWRL-Condition>
<rdfs:label> ShouldRentACar</rdfs:label>
<rdfs:comment> ShouldRentACar</rdfs:comment>
<expr:expressionBody
rdf:parseType="Literal">
```

```
<swrl:AtomList>
<rdf:first>
<swrl:ClassAtom>
<swrl:classPredicate
rdf:resource="#1" />
<swrl:argument1 rdf:resource="#ShouldRentACar" />
</swrl:ClassAtom>
</rdf:first>
<rdf:rest rdf:resource="&rdf;#nil" />
</swrl:AtomList>
</expr:expressionBody>
</expr:SWRL-Condition>
</process:ifCondition>
<process:then>
<!-- FIXME Then -->
<!--     FindLocalTransportation_TransportationReservationNumber     binding
necessary -->
<process:Sequence>
<process:components>
<process:ControlConstructList>
<list:first>
<process:Perform rdf:ID="PerformFindCar">
<process:process>
<process:AtomicProcess
rdf:ID="FindCar">
<rdfs:label> FindCar</rdfs:label>
<rdfs:comment> Car</rdfs:comment>
<process:hasInput>
<process:Input rdf:ID="FindCar_City">
<process:parameterType
rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Input>
</process:hasInput>
<process:hasInput>
<process:Input rdf:ID="FindCar_TravelDate">
<process:parameterType
rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Input>
</process:hasInput>
<process:hasInput>
<process:Input rdf:ID="FindCar_ReturnDate">
<process:parameterType
rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Input>
</process:hasInput>
<process:hasOutput>
<process:Output
rdf:ID="FindCar_TransportationReservationNumber">
<process:parameterType
rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Output>
</process:hasOutput>
</process:AtomicProcess>
```

```
</process:process>
</process:Perform>
</list:first>
<list:rest rdf:resource="&list;#nil" />
</process:ControlConstructList>
</process:components>
</process:Sequence>
</process:then>
<process:else>
<!-- FIXME Else -->
<process:Sequence>
<process:components>
<process:ControlConstructList>
<list:first>
<process:Perform rdf:ID="PerformFindBicycle">
<process:process>
<process:AtomicProcess
rdf:ID="FindBicycle">
<rdfs:label> FindBicycle</rdfs:label>
<rdfs:comment> Bike</rdfs:comment>
<process:hasInput>
<process:Input rdf:ID="FindBicycle_City">
<process:parameterType
rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Input>
</process:hasInput>
<process:hasInput>
<process:Input rdf:ID="FindBicycle_TravelDate">
<process:parameterType
rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Input>
</process:hasInput>
<process:hasInput>
<process:Input rdf:ID="FindBicycle_ReturnDate">
<process:parameterType
rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Input>
</process:hasInput>
<process:hasOutput>
<process:Output
rdf:ID="FindBicycle_TransportationReservationNumber">
<process:parameterType
rdf:datatype="&xsd;#anyURI">&xsd;#string
</process:parameterType>
</process:Output>
</process:hasOutput>
</process:AtomicProcess>
</process:process>
</process:Perform>
</list:first>
<list:rest rdf:resource="&list;#nil" />
</process:ControlConstructList>
</process:components>
</process:Sequence>
```

```
</process:else>
</process:If-Then-Else>
</process:composedOf>
</process:CompositeProcess>
</process:process>
<process:hasDataFrom>
<process:InputBinding>
<process:toParam rdf:resource="#FindLocalTransportation_City" />
<process:valueSource>
<process:ValueOf>
<process:fromProcess rdf:resource="&process;#TheParentPerform" />
<process:theVar rdf:resource="#City" />
</process:ValueOf>
</process:valueSource>
</process:InputBinding>
</process:hasDataFrom>
<process:hasDataFrom>
<process:InputBinding>
<process:toParam rdf:resource="#FindLocalTransportation_TravelDate" />
<process:valueSource>
<process:ValueOf>
<process:fromProcess rdf:resource="&process;#TheParentPerform" />
<process:theVar rdf:resource="#TravelDate" />
</process:ValueOf>
</process:valueSource>
</process:InputBinding>
</process:hasDataFrom>
<process:hasDataFrom>
<process:InputBinding>
<process:toParam rdf:resource="#FindLocalTransportation_ReturnDate" />
<process:valueSource>
<process:ValueOf>
<process:fromProcess rdf:resource="&process;#TheParentPerform" />
<process:theVar rdf:resource="#ReturnDate" />
</process:ValueOf>
</process:valueSource>
</process:InputBinding>
</process:hasDataFrom>
<process:hasDataFrom>
<process:InputBinding>
<process:toParam rdf:resource="#FindLocalTransportation_ShouldRentACar" />
<process:valueSource>
<process:ValueOf>
<process:fromProcess rdf:resource="&process;#TheParentPerform" />
<process:theVar rdf:resource="#ShouldRentACar" />
</process:ValueOf>
</process:valueSource>
</process:InputBinding>
</process:hasDataFrom>
</process:Perform>
</list:first>
<list:rest rdf:resource="&list;#nil" />
</process:ControlConstructList>
</list:rest>
</process:ControlConstructList>
</list:rest>
</process:ControlConstructList>
```

```
</process:components>
</process:Sequence>
</process:composedOf>
</process:CompositeProcess>
</rdf:RDF>
```

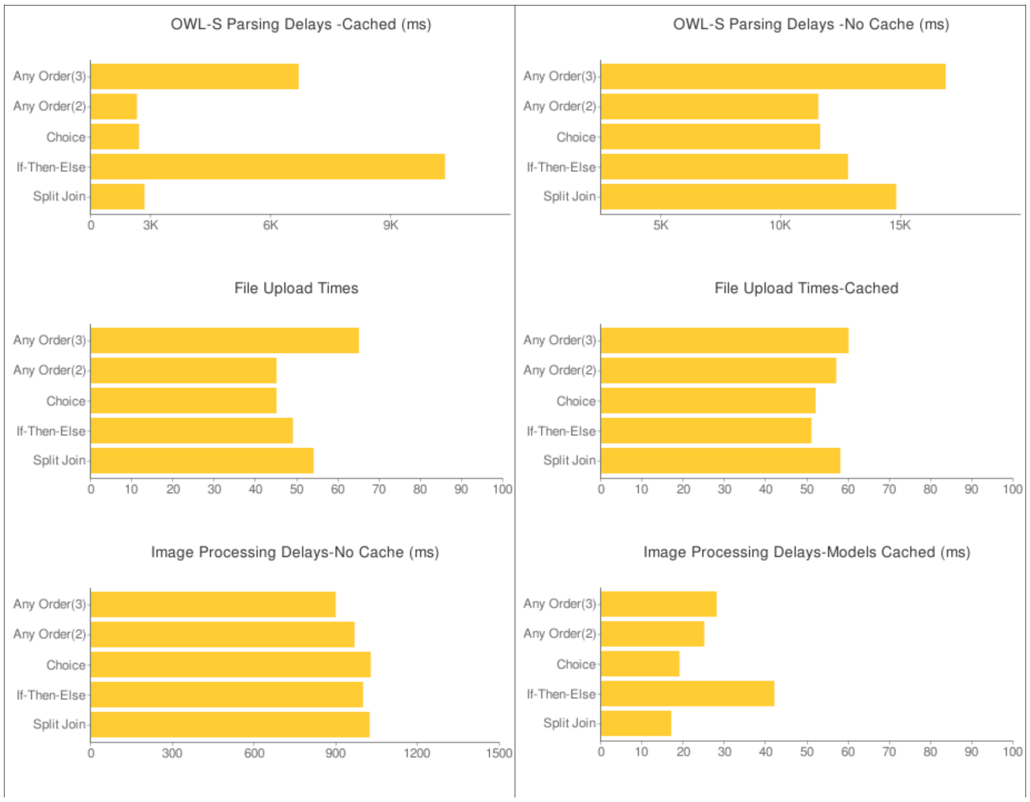
```
executable( dummy ).

abducible(dummy).
:- use_module(library(jpl)).

%abdemo([holds_at(pTravelProcessPlanned(ShouldRentACar, ReturnDate,
TravelDate, City), t)], R).


axiom(initiates(pTravelProcess(ShouldRentACar, ReturnDate, TravelDate,
City),pTravelProcessPlanned(ShouldRentACar, ReturnDate, TravelDate, City),
T), [ ] ).


axiom(happens(pTravelProcess(ShouldRentACar, ReturnDate, TravelDate, City),
T1, TN),
[
     happens(pFindRemoteTransportation(ReturnDate, TravelDate, City,
                    RemoteTransportationReservationNumber), T2, T3),
     happens(pFindHotel(ReturnDate, TravelDate, City,
                                   HotelReservationNumber), T4, T5),
     happens(pFindLocalTransportation(ReturnDate, TravelDate, City,
          ShouldRentACar, TransportationReservationNumber), T6, T7),
     before(T1, T2),
     before(T3, T4),
     before(T5, T6),
     before(T7, TN)
] ).


axiom(happens(pFindRemoteTransportation(ReturnDate, TravelDate, City,
RemoteTransportationReservationNumber), T1, TN),
[
     happens(pFindFlight(ReturnDate, TravelDate, City,
                    RemoteTransportationReservationNumber), T2, T3),
     before(T1, T2),
     before(T3, T4),
     before(T3, TN)
] ).


axiom(happens(pFindRemoteTransportation(ReturnDate, TravelDate, City,
RemoteTransportationReservationNumber), T1, TN),
[
     happens(pFindBus(ReturnDate, TravelDate, City,
               RemoteTransportationReservationNumber), T2, T3),
     before(T1, T2),
     before(T3, T4),
     before(T3, TN)
```

```
] ).


axiom(happens(pFindLocalTransportation(ReturnDate, TravelDate, City,
ShouldRentACar, TransportationReservationNumber), T1, TN),
[
     jpl_pFindLocalTransportationIfcondition('1', ShouldRentACar),
     happens(pFindCar(ReturnDate, TravelDate, City,
                         TransportationReservationNumber),T2, T3),
     before(T1,T2),
     before(T3,TN)
] ).

axiom(happens(pIfCondition(ReturnDate, TravelDate, City, ShouldRentACar,
TransportationReservationNumber), T1, TN),
[

     jpl_pFindLocalTransportationIfcondition('1', ShouldRentACar),
]).

axiom(happens(pFindLocalTransportation(ReturnDate, TravelDate, City,
ShouldRentACar, TransportationReservationNumber), T1, TN),
[
     jpl_pFindLocalTransportationElsecondition('1', ShouldRentACar),
     happens(pFindBicycle(ReturnDate, TravelDate, City,
                TransportationReservationNumber), T2, T3),
     before(T1,T2),
     before(T3,TN)
] ).

axiom(happens(pElseCondition(ReturnDate, TravelDate, City, ShouldRentACar,
TransportationReservationNumber), T1, TN),
[

     not(jpl_pFindLocalTransportationIfcondition('1',
                                          ShouldRentACar)),
]).

%Composite Process Prolog:FindRemoteTransportation
%Atomic Process Prolog:FindFlight
%Atomic Process Prolog:FindBus
%Atomic Process Prolog:FindHotel
%Composite Process Prolog:FindLocalTransportation
%Atomic Process Prolog:FindCar
%Atomic Process Prolog:FindBicycle

%%% INDIVIDUAL AXIOMS %%%
axiom(happens(pFindFlight(ReturnDate, TravelDate, City,
RemoteTransportationReservationNumber), T1, TN),
[
     jpl_pFindFlight(ReturnDate, TravelDate, City,
RemoteTransportationReservationNumber)
]).

axiom(happens(pFindBus(ReturnDate, TravelDate, City,
RemoteTransportationReservationNumber), T1, TN),
[
     jpl_pFindBus(ReturnDate, TravelDate, City,
RemoteTransportationReservationNumber)
]).

axiom(happens(pFindHotel(ReturnDate, TravelDate, City,
HotelReservationNumber), T1, TN),
[
     jpl_pFindHotel(ReturnDate, TravelDate, City, HotelReservationNumber)
]).

axiom(happens(pFindCar(ReturnDate, TravelDate, City,
TransportationReservationNumber), T1, TN),
[
     jpl_pFindCar(ReturnDate, TravelDate, City,
TransportationReservationNumber)
]).

axiom(happens(pFindBicycle(ReturnDate, TravelDate, City,
TransportationReservationNumber), T1, TN),
[
     jpl_pFindBicycle(ReturnDate, TravelDate, City,
TransportationReservationNumber)
]).



%%% EX_WEBSERVICE DECLARATIONS %%%
ex_WebService(jpl_pFindFlight(_,_,_,_)).
ex_WebService(jpl_pFindBus(_,_,_,_)).
ex_WebService(jpl_pFindHotel(_,_,_,_)).
ex_WebService(jpl_pFindLocalTransportationIfcondition(_,_)).
ex_WebService(jpl_pFindLocalTransportationElsecondition(_,_)).
ex_WebService(jpl_pFindCar(_,_,_,_)).
ex_WebService(jpl_pFindBicycle(_,_,_,_)).


%%% JPL METHOD DEFINITIONS %%%
jpl_pFindFlight(ReturnDate, TravelDate, City,
RemoteTransportationReservationNumber) :-
     jpl_new('tr.edu.metu.prolog.WebServiceInvocation', [], WSI),
     jpl_list_to_array([ReturnDate, TravelDate, City], InputArray),
     jpl_call(WSI, invokeService, ['pFindFlight', InputArray],
OutputArray),
     (OutputArray == @(null) ->  OutputList = [] ;
     jpl_array_to_list(OutputArray, OutputList)),
     length(OutputList,Length),
     (
     Length==1 ->
     [A] = OutputList,
     (A == @(null) ->  TempList1 = [] ;
     jpl_array_to_list(A, TempList1)),
     WholeList = [TempList1];
          (
          Length==2 ->
          [A,B] = OutputList,
          (A == @(null) ->  TempList1 = [] ;
          jpl_array_to_list(A, TempList1)),
          (B == @(null) ->  TempList2 = [] ;
          jpl_array_to_list(B, TempList2)),
          WholeList = [TempList1, TempList2];
               (
               Length==3 ->
               [A,B,C] = OutputList,
               (A == @(null) ->  TempList1 = [] ;
               jpl_array_to_list(A, TempList1)),
               (B == @(null) ->  TempList2 = [] ;
               jpl_array_to_list(B, TempList2)),
               (C == @(null) ->  TempList3 = [] ;
               jpl_array_to_list(C, TempList3)),
               WholeList = [TempList1, TempList2, TempList3];
                    (
                    Length==4 ->
                    [A,B,C,D] = OutputList,
                    (A == @(null) ->  TempList1 = [] ;
                    jpl_array_to_list(A, TempList1)),
                    (B == @(null) ->  TempList2 = [] ;
                    jpl_array_to_list(B, TempList2)),
                    (C == @(null) ->  TempList3 = [] ;
                    jpl_array_to_list(C, TempList3)),
                    (D == @(null) ->  TempList4 = [] ;
                    jpl_array_to_list(D, TempList4)),
                    WholeList = [TempList1, TempList2, TempList3,
TempList4];
                    true
                    )
               )
          )
     ),
     member([RemoteTransportationReservationNumber], WholeList),
     true.

jpl_pFindBus(ReturnDate, TravelDate, City,
RemoteTransportationReservationNumber) :-
     jpl_new('tr.edu.metu.prolog.WebServiceInvocation', [], WSI),
     jpl_list_to_array([ReturnDate, TravelDate, City], InputArray),
     jpl_call(WSI, invokeService, ['pFindBus', InputArray], OutputArray),
     (OutputArray == @(null) ->  OutputList = [] ;
     jpl_array_to_list(OutputArray, OutputList)),
     length(OutputList,Length),
     (
     Length==1 ->
     [A] = OutputList,
     (A == @(null) ->  TempList1 = [] ;
     jpl_array_to_list(A, TempList1)),
     WholeList = [TempList1];
          (
          Length==2 ->
          [A,B] = OutputList,
          (A == @(null) ->  TempList1 = [] ;
          jpl_array_to_list(A, TempList1)),
          (B == @(null) ->  TempList2 = [] ;
          jpl_array_to_list(B, TempList2)),
          WholeList = [TempList1, TempList2];
               (
                    Length==3 ->
                    [A,B,C] = OutputList,
                    (A == @(null) ->  TempList1 = [] ;
                    jpl_array_to_list(A, TempList1)),
                    (B == @(null) ->  TempList2 = [] ;
                    jpl_array_to_list(B, TempList2)),
                    (C == @(null) ->  TempList3 = [] ;
                    jpl_array_to_list(C, TempList3)),
                    WholeList = [TempList1, TempList2, TempList3];
                          (
                          Length==4 ->
                          [A,B,C,D] = OutputList,
                          (A == @(null) ->  TempList1 = [] ;
                          jpl_array_to_list(A, TempList1)),
                          (B == @(null) ->  TempList2 = [] ;
                          jpl_array_to_list(B, TempList2)),
                          (C == @(null) ->  TempList3 = [] ;
                          jpl_array_to_list(C, TempList3)),
                          (D == @(null) ->  TempList4 = [] ;
                          jpl_array_to_list(D, TempList4)),
                          WholeList = [TempList1, TempList2, TempList3,
TempList4];
                          true
                          )
                    )
              )
        ),
        member([RemoteTransportationReservationNumber], WholeList),
        true.

jpl_pFindHotel(ReturnDate, TravelDate, City, HotelReservationNumber) :-
        jpl_new('tr.edu.metu.prolog.WebServiceInvocation', [], WSI),
        jpl_list_to_array([ReturnDate, TravelDate, City], InputArray),
        jpl_call(WSI, invokeService, ['pFindHotel', InputArray], OutputArray),
        (OutputArray == @(null) ->  OutputList = [] ;
        jpl_array_to_list(OutputArray, OutputList)),
        length(OutputList,Length),
        (
        Length==1 ->
        [A] = OutputList,
        (A == @(null) ->  TempList1 = [] ;
        jpl_array_to_list(A, TempList1)),
        WholeList = [TempList1];
              (
              Length==2 ->
              [A,B] = OutputList,
              (A == @(null) ->  TempList1 = [] ;
              jpl_array_to_list(A, TempList1)),
              (B == @(null) ->  TempList2 = [] ;
              jpl_array_to_list(B, TempList2)),
              WholeList = [TempList1, TempList2];
                    (
                    Length==3 ->
                    [A,B,C] = OutputList,
                    (A == @(null) ->  TempList1 = [] ;
                    jpl_array_to_list(A, TempList1)),
                    (B == @(null) ->  TempList2 = [] ;
                    jpl_array_to_list(B, TempList2)),
                    (C == @(null) ->  TempList3 = [] ;
                    jpl_array_to_list(C, TempList3)),
                    WholeList = [TempList1, TempList2, TempList3];
                          (
                          Length==4 ->
                          [A,B,C,D] = OutputList,
                          (A == @(null) ->  TempList1 = [] ;
                          jpl_array_to_list(A, TempList1)),
                          (B == @(null) ->  TempList2 = [] ;
                          jpl_array_to_list(B, TempList2)),
                          (C == @(null) ->  TempList3 = [] ;
                          jpl_array_to_list(C, TempList3)),
                          (D == @(null) ->  TempList4 = [] ;
                          jpl_array_to_list(D, TempList4)),
                          WholeList = [TempList1, TempList2, TempList3,
TempList4];
                          true
                          )
                    )
              )
        ),
        member([HotelReservationNumber], WholeList),
        true.

jpl_pFindLocalTransportationIfcondition(I1, IShouldRentACar) :-
        atom_number(I1, Arg1),
atom_number(IShouldRentACar, Arg2),
Arg1==Arg2,
        true.

jpl_pFindLocalTransportationElsecondition(I1, IShouldRentACar) :-
        atom_number(I1, Arg1),
atom_number(IShouldRentACar, Arg2),
not(Arg1==Arg2),
        true.

jpl_pFindCar(ReturnDate, TravelDate, City, TransportationReservationNumber)
:-
        jpl_new('tr.edu.metu.prolog.WebServiceInvocation', [], WSI),
        jpl_list_to_array([ReturnDate, TravelDate, City], InputArray),
        jpl_call(WSI, invokeService, ['pFindCar', InputArray], OutputArray),
        (OutputArray == @(null) ->  OutputList = [] ;
        jpl_array_to_list(OutputArray, OutputList)),
        length(OutputList,Length),
        (
        Length==1 ->
        [A] = OutputList,
        (A == @(null) ->  TempList1 = [] ;
        jpl_array_to_list(A, TempList1)),
        WholeList = [TempList1];
              (
              Length==2 ->
              [A,B] = OutputList,
              (A == @(null) ->  TempList1 = [] ;
              jpl_array_to_list(A, TempList1)),
              (B == @(null) ->  TempList2 = [] ;
              jpl_array_to_list(B, TempList2)),
              WholeList = [TempList1, TempList2];
                   (
                   Length==3 ->
                   [A,B,C] = OutputList,
                   (A == @(null) ->  TempList1 = [] ;
                   jpl_array_to_list(A, TempList1)),
                   (B == @(null) ->  TempList2 = [] ;
                   jpl_array_to_list(B, TempList2)),
                   (C == @(null) ->  TempList3 = [] ;
                   jpl_array_to_list(C, TempList3)),
                   WholeList = [TempList1, TempList2, TempList3];
                        (
                        Length==4 ->
                        [A,B,C,D] = OutputList,
                        (A == @(null) ->  TempList1 = [] ;
                        jpl_array_to_list(A, TempList1)),
                        (B == @(null) ->  TempList2 = [] ;
                        jpl_array_to_list(B, TempList2)),
                        (C == @(null) ->  TempList3 = [] ;
                        jpl_array_to_list(C, TempList3)),
                        (D == @(null) ->  TempList4 = [] ;
                        jpl_array_to_list(D, TempList4)),
                        WholeList = [TempList1, TempList2, TempList3,
TempList4];
                        true
                        )
                   )
              )
        ),
        member([TransportationReservationNumber], WholeList),
        true.

jpl_pFindBicycle(ReturnDate, TravelDate, City,
TransportationReservationNumber) :-
        jpl_new('tr.edu.metu.prolog.WebServiceInvocation', [], WSI),
        jpl_list_to_array([ReturnDate, TravelDate, City], InputArray),
        jpl_call(WSI, invokeService, ['pFindBicycle', InputArray],
OutputArray),
        (OutputArray == @(null) ->  OutputList = [] ;
        jpl_array_to_list(OutputArray, OutputList)),
        length(OutputList,Length),
        (
        Length==1 ->
        [A] = OutputList,
        (A == @(null) ->  TempList1 = [] ;
        jpl_array_to_list(A, TempList1)),
        WholeList = [TempList1];
              (
              Length==2 ->
              [A,B] = OutputList,
              (A == @(null) ->  TempList1 = [] ;
              jpl_array_to_list(A, TempList1)),
              (B == @(null) ->  TempList2 = [] ;
              jpl_array_to_list(B, TempList2)),
              WholeList = [TempList1, TempList2];
                   (
                   Length==3 ->
                   [A,B,C] = OutputList,
                   (A == @(null) ->  TempList1 = [] ;
                   jpl_array_to_list(A, TempList1)),
                   (B == @(null) ->  TempList2 = [] ;
                   jpl_array_to_list(B, TempList2)),
                   (C == @(null) ->  TempList3 = [] ;
                   jpl_array_to_list(C, TempList3)),
                   WholeList = [TempList1, TempList2, TempList3];
                        (
                        Length==4 ->
                        [A,B,C,D] = OutputList,
                        (A == @(null) ->  TempList1 = [] ;
                        jpl_array_to_list(A, TempList1)),
                        (B == @(null) ->  TempList2 = [] ;
                        jpl_array_to_list(B, TempList2)),
                        (C == @(null) ->  TempList3 = [] ;
                        jpl_array_to_list(C, TempList3)),
                        (D == @(null) ->  TempList4 = [] ;
                        jpl_array_to_list(D, TempList4)),
                        WholeList = [TempList1, TempList2, TempList3,
TempList4];
                        true
                        )
                   )
              )
        ),
        member([TransportationReservationNumber], WholeList),
        true.
```

APPENDIX C

PERFORMANCE CHARTS

Some system performance analysis charts are provided below.



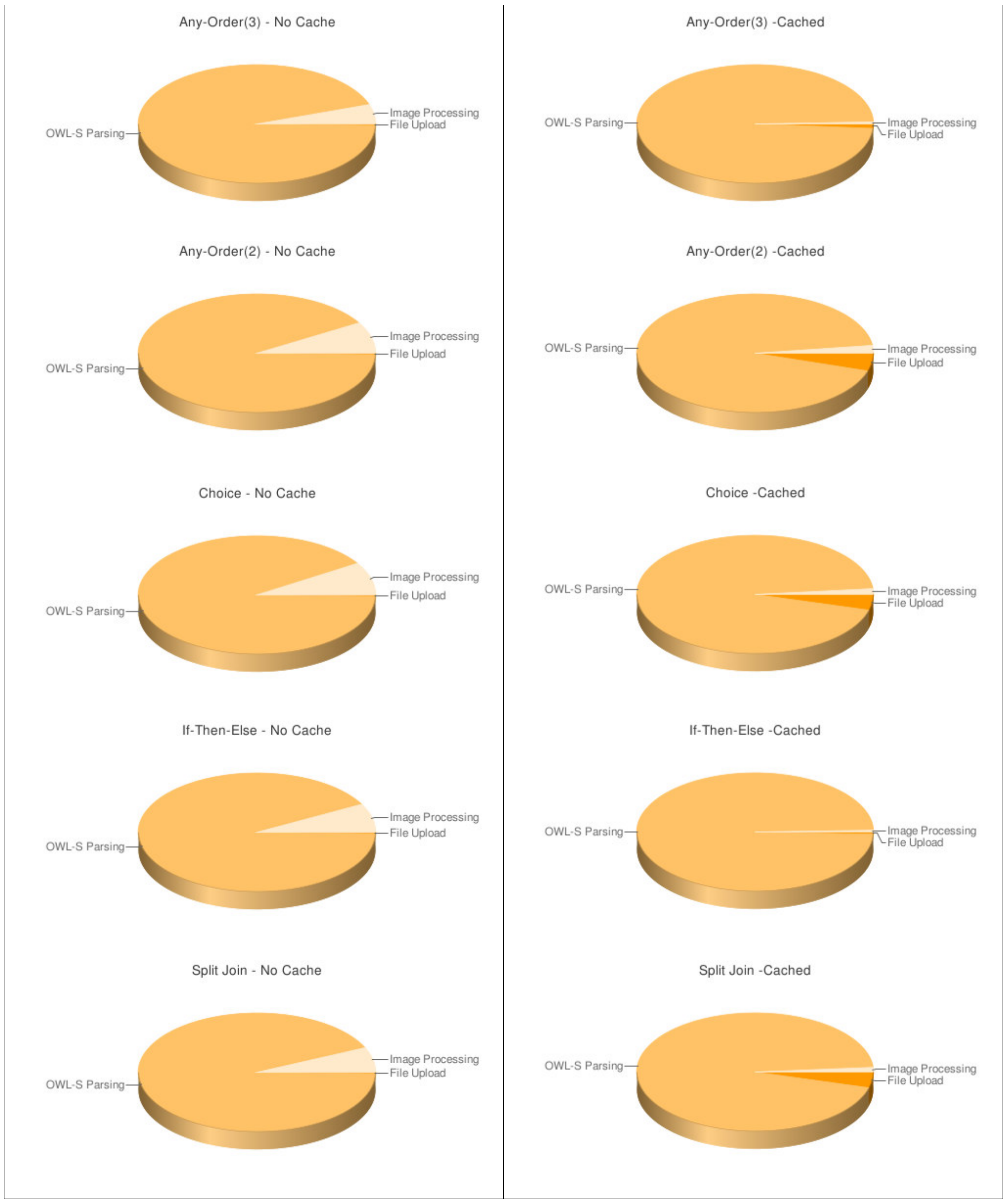


Figure C.1 Performance Charts