NeOn: Lifecycle Support for Networked Ontologies

Integrated Project (IST-2005-027595)

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D6.9.1 Specification of NeOn architecture and API V2

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NeOn Consortium

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Change Log

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0.6	15-03-2008	Walter Waterfeld	Revised architecture, introduction, conclusion
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Executive Summary

This deliverable is the successor of the first deliverable D6.4.1 on the specification of the NeOn architecture and API. The intention is to incorporate first experiences with the NeOn toolkit in general and with its usage in the NeOn case studies.

In favour of a clear focus in the first realisation of the NeOn toolkit ontology usage has not been addressed specifically. Therefore this deliverable presents an enhanced architecture covering those runtime aspects. Based on this enlarged architectural scope API specification have been added. An additional focus was also the further utilization of the rich Eclipse infrastructure for the API and extension points of the NeOn toolkit.

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1 Introduction

Since the availability of the NeOn toolkit last year a lot of experiences and feedback are available now. Based on these experiences this deliverable enhances the NeOn architecture and API definitions. They have been gathered in a parallel update of the NeOn toolkit requirements [Aranda2008].

The NeOn project has concentrated in the first phase on the NeOn Toolkit as the Eclipse-based development infrastructure for Ontology engineering. Traditional IT applications have a very sharp distinction between development environment and the runtime environment. This is not the case for semantic applications. The functionality of many components is usable in the development and in the runtime environment. A major reason is that ontologies as the major modelling artefacts are directly executable by a reasoner. This contrasts with traditional IT applications where UML documents as modelling artefacts have to be transformed to source code, which has again to be transformed to binary components before it can be executed at runtime.

Due to different performance and architectural characteristics the runtime support of semantic application is still a very important aspect of the infrastructure.

1.1 Relationship to other NeOn Toolkit deliverables

This deliverable is an update of the deliverable D6.4.1 – specification of the NeOn reference architecture and NeOn APIs. It contains changes and additions to the NeOn architecture and API. Most of them were triggered from the first experiences with the available NeOn toolkit. A major issue is the extension of the NeOn platform to cover also the runtime phase.

These changes and additions are explained in a self-contained way, which requires some repetition from previous deliverables. However the deliverable does not repeat unchanged aspects and components of other deliverables. Therefore it is not a complete description of the NeOn architecture and APIs.

1.2 Experiences Use of NeOn Toolkit

In the following we sketch as a representative on specific application of the use cases from FAO. One of the use case partners of the NeOn Project, the FAO of the UN, leads work package WP7 where NeOn technology will be applied to several fisheries domains. In particular, an ontology-driven Fisheries Stock Depletion Assessment System (FSDAS) is planned. According to [Baldassarre2007] …

> “Users will experience FSDAS as a browse-able and query-able application that returns organized, quality-rated, linked results that can be used to make decisions about the state and trends of various fish stocks. Fisheries information resources will be exploited using ontologies to return time-series statistics on capture, production, commodities and fleets by stock, together with direct links to related documents, web pages, news items, images and multi-media.
>
> The user interface will support query refinement, assistance on query formulation (e.g. to avoid spelling errors) and multiple languages (e.g. Food and Agriculture

> Organization of the United Nations (FAO) languages: Arabic, Chinese, English, French and Spanish).
>
> Users will be able to perform ontology browse-based and query-based searches using a single ontology or the union, intersection or complement of various ontologies. They will also be able to navigate associated data instances."

Apparently, the FSDAS application has hardly any aspects for developing or updating ontologies. Instead it is about browsing, querying and analysing existing ontology or data. Nevertheless, the functionality of several NeOn plug-ins can provide a valuable basis for implementing FSDAS. Therefore, the FSDAS application will be realized as an Eclipse Rich Client Platform application, which allows using any NeOn plug-in as part of the runtime application. Current plans are to visualize and use the fisheries ontologies for search and query formulation. These ontologies were formulated in OWL-DL and can be hosted in the clients. Due to the features of the underlying Toolkit all means to manage and query those ontologies are present and can be adapted to the needs of the application.

For the actual search and query answering a centralized server is needed that provides integrated access to the different data sources, such as document like objects, XML fact sheets, databases etc. In order to access these non-ontological sources and to achieve an integrated view special means are needed, which are provided by the Inference Server (the server component of OntoBroker, cf. Section 3.3.1 *Reasoner Interface*) for queries formulated in FLogic. Thus, FSDAS will generate Flogic queries to send to the reasoning server. It will receive and interpret the results and display them to the application users, thus, demonstrating the full potential of the dual language approach pursued by NeOn.

As can be seen by this example, there is not strict separation of ontology engineering activities and ontology usage activities. In particular, on the technological level, numerous components can be used during both phases of the ontology life cycle.

2 Architecture

2.1 General Approach for Integrating Ontology Engineering and Runtime

We propose a generic architecture for integrating ontology engineering and runtime aspects.[1] We start with a discussion of the ontology lifecycle in ontology-based information systems (OIS). In Section 2.1.12, we present the generic architecture for OIS and illustrate how this architecture supports ontology lifecycle management. Finally, we discuss how the generic architecture is instantiated in the NeOn Toolkit.

2.1.1 Lifecycle Activities for Ontology Engineering and Runtime

In this section, we briefly present existing views on the *ontology lifecycle*. The concept has mainly been used in methodologies for ontology engineering [GomezPerez2003]. In the following, we give a compiled overview of these methodologies to present a simple lifecycle model (see Figure 1).

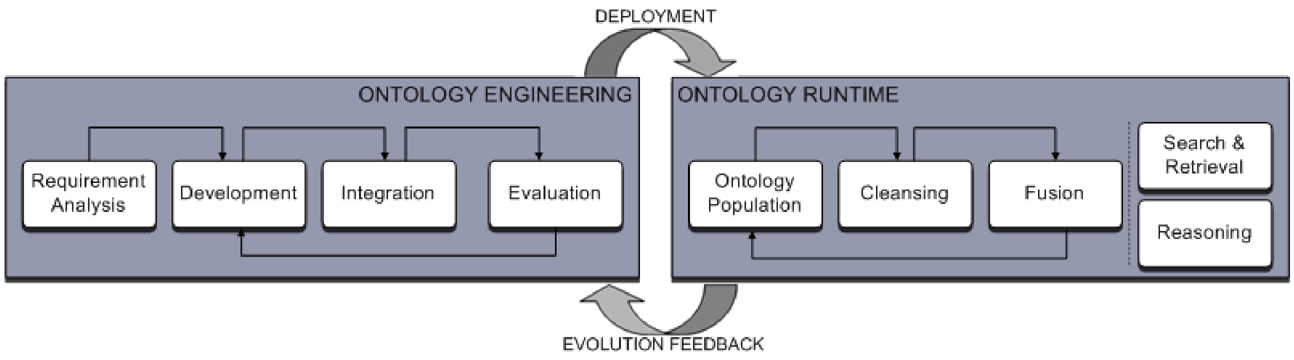


Figure 1: Lifecycle Model

It also encompasses the NeOn ontology development process and Ontology Lifecycle presented in the NeOn methodology deliverable D5.3.1 [Suarez2007]. D5.3.1 provides a much more fine-grained analysis of the development process; however it mainly targets the ontology engineering phase.

Our model considers not only engineering, but also the usage of ontologies at runtime as well as the interplay between usage and engineering activities.

2.1.1.1 Ontology Engineering

While the individual methodologies for ontology engineering vary, they agree on the main lifecycle activities, namely requirement analysis, development, evaluation, and maintenance, plus orthogonal activities such as project management.

[1] This architecture has originally been presented in parts in [Tran2007].

In the following, we focus on the first three engineering-related activities as described in the literature and then discuss maintenance in the context of usage-related activities.

Requirements Analysis: In this step, domain experts and ontology engineers analyze scenarios, use cases, and, in particular, intended retrieval and reasoning tasks performed on the ontology.

Development: This is the step in which the methodologies vary most. We therefore present an aggregated view on the different proposals for ontology development.

The initial step is the identification of already available reusable ontologies and other sources such as taxonomies or database schemas.

Once reusable ontologies are found, they have to be adapted to the specific requirements of the application. This may include both backward (understanding, restructuring, modifying) and forward (modifying, extending) engineering of these reusable ontologies w.r.t. some design patterns. Then, the ontologies are translated to the target representation language. Because of the expressivity-scalability trade-off involved in reasoning, it may be desirable to tweak the degree of axiomatization, e.g. for performance. An important aspect in development is collaboration. Existing proposals for reaching consensus knowledge involve the assignment of roles and the definition of interaction protocols for knowledge engineers.

Integration: Inspired by the componentization of software, recent approaches advocate the modularization of ontologies.

Accordingly, the result of the development step shall be a set of modularized ontologies rather than a single monolithic ontology. These modules have to be integrated, e.g. via the definition of import declarations and alignment rules. This integration concerns not only the modules that have been developed for the given use case.

For interoperability with external applications, they may be embedded in a larger context, e.g. integrated with ontologies employed by other OIS.

Evaluation: Similar to bugs in software, inconsistencies in ontologies impede their proper use. So the initial evaluation step is to check for inconsistencies, both at the level of modules and in an integrated setting.

Furthermore, ontologies also have to be assessed w.r.t. specific requirements derived from the use cases. Note that any deficiencies detected in this phase have to be addressed, i.e. lead back to development.

2.1.1.2 Ontology Runtime

Ontology runtime encompasses all activities related to the use of an ontology after it has been engineered. So far, the lifecycle as described in the literature is more of a static nature, just like the software lifecycle. Namely, if all requirements are met, the ontology will be deployed and the lifecycle continues with ontology evolution – also referred to as maintenance in literature. In this phase, new requirements may arise which are fed back into the loop, e.g. incorporated into the next release, which is then redeployed. Current lifecycle models however do not incorporate activities involved in the actual usage of ontologies. We will elaborate on these activities and based on them, show that the lifecycle can be dynamic.

Search, Retrieval, Reasoning: Once the ontologies have been created, they can be used to realize information access in the application, for example via search and retrieval. Typically an OIS involves a reasoner to infer implicit knowledge.

The schema can be combined with instance data to support advanced retrieval, e.g. schema knowledge exploited for query enhancement (refinement, expansion), and A-Box reasoning to retrieve also inferred knowledge.

Note these are two generic exemplary tasks that shall illustrate the use of ontologies. In the actual application, search and retrieval may be only two of the many ontology-related operations that are embedded in more complex (business) logic implementing a concrete use case. These usages of ontologies may require support by the following application-independent lifecycle activities that are also performed at runtime:

Ontology Population: To populate the Knowledge Base (KB), instances may be collected from the user, e.g. via forms. A substantial overhead may be imposed to the user when all instance data has to be created manually. This burden can be alleviated by a (semi)-automatic population of the KB. Part of this knowledge creation step is also the manipulation and deletion of instances.

Cleansing and Fusion: Automatically extracted knowledge cannot be assumed to have the desired quality. Enhancing instance data may include identification and merging of conceptually identical instances that are only differently labelled (object identification) as well as fusion at the level of statements, e.g. merging redundant statements.

Both the population and the fusion steps may lead to inconsistencies which have to be resolved. Consider a user requesting data that yet has to be crawled from external sources. Then, inconsistencies that may arise in the process have to be resolved at runtime for the user to be able to continue his work. Found inconsistencies are fed back to debugging and the development-phase of the ontology lifecycle. That is, ontology evolution – the loop from runtime back to engineering activities – is not only due to changing requirements but is also necessary for the runtime usage of ontologies.

2.1.2 A Generic Architecture for Ontology-based Information Systems with Lifecycle Support

We now present a generic architecture that aims to serve as a guideline for the development of any IS that involves ontologies. Hence, generic use cases that have to be considered may involve mere ontology engineering, mere ontology usage or a combination of both. Therefore, lifecycle activities discussed in the last section will be incorporated as functional requirements. Due to the possible dynamic nature of the lifecycle, it has to be supported in an integrated architecture that allows for a dynamic interaction of engineering and runtime activities.

We will start with an overview and continue with a detailed elaboration on the components for lifecycle support. Then, we show how this generic architecture can be adopted for the development of OIS with concrete functional requirements. While the presented architecture abstracts from specific application settings, we also discuss how concrete architecture paradigms can be applied to meet technological requirements.

2.1.2.1 Overview of the Architecture

The proposed architecture as shown in Figure 2: Abstract Architecture is organized in layers according to the control- and data flow (the control flow is indicated by the arrows) as well as the degree of abstraction of the constituent components. The former means that components at a higher layer invoke and request data from components at the lower layers. The latter means that components at the same abstraction level can be found on the same architecture layer. A single operation of components at a higher level of abstraction can trigger several low level operations. For example, a functionality provided by an ontology-based application front-end may invoke some ontology runtime services, each of them, in turn, making use of several ontology infrastructure services. These services rely on requests to specific data sources, which are accessed via connectors of the data abstraction layer.

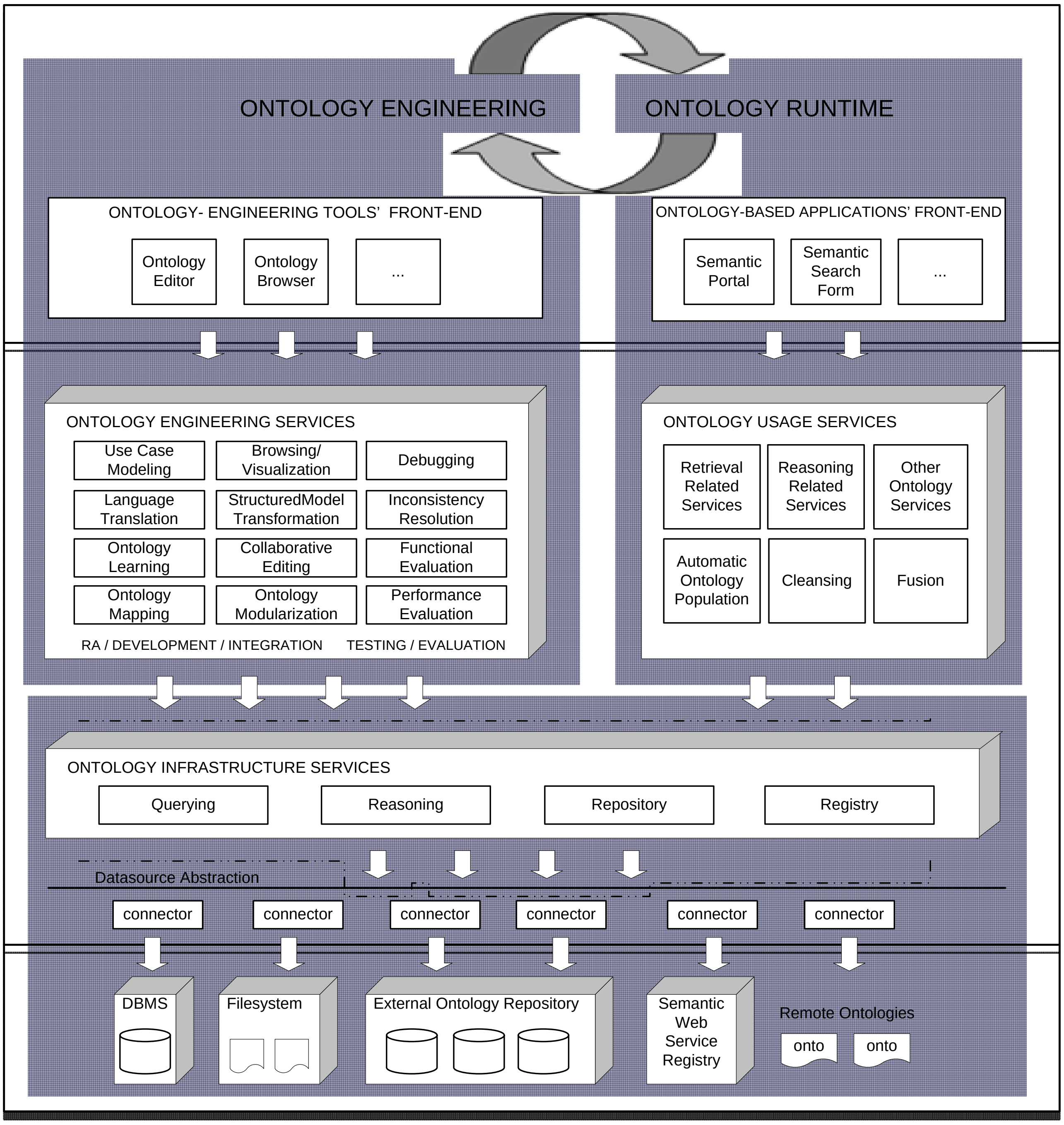


Figure 2: Abstract Architecture

Note that many of the concepts employed for this architecture proposal, i.e. the presentation components, platform services, data source abstraction and connectors follow J2EE and SOA best practices. Also, the organization in (three different) layers is inspired from the n-tier architecture – a well-known organization principle in software engineering. We now briefly discuss these concepts and the components at the different layers (see [Singh2002, McKenzie2006] for more information on J2EE and SOA best practices).

The Data Layer: This layer hosts any kind of *datasources*, including databases and *file systems*. This may also encompass ontological sources such as *external ontologies* hosted in repositories, *semantic web services* hosted in registries and any ontology on the web that can be retrieved via its URI.

Note that services external to the system can be regarded as a component of the data layer because their processing is transparent to the internal components. The processing can be considered a black-box that simply provides data for internal components:

The Logic Layer: At this layer, there are application-specific services that are implemented for a particular use case and operate on specific object models. The former encapsulate the processing logic and the latter capture the data. These services invoke *ontology lifecycle services* to manage and retrieve semantic data. Accordingly, object models may encapsulate data coming from conventional datasources like databases (data) or from ontological sources (semantic data), or both. In any case, the actual data comes from a persistent storage, most often a database. The data source abstraction can be used to hide specific datasource implementations by providing a uniform API and specific connectors.

While not shown in Figure 2: Abstract Architecture, services at the logic layer run on a specific platform, which provides orthogonal functionalities for the management, configuration, and identification (registry) of services as well as access control and security.

The Presentation Layer: This layer hosts presentation components that the user interacts with. These components could be simply *pages* or *interactive forms* of a web-based system or more sophisticated Uis of a desktop application that contains a variety of widgets. The engineering and runtime operations performed by the user on these components translate to calls to services situated at the logic layer. The data returned by these services is then presented by the components together with the static content.

We will now continue with a more detailed elaboration on ontology-related services.

2.1.2.2 Ontology Services

Ontology services are organized in one layer for ontology infrastructure services and one layer for the higher level ontology lifecycle services. While the control and data flow of lifecycle and core services are top-down as shown in Figure 2: Abstract Architecture, the interaction between the different lifecycle activities typically corresponds to the structure of the corresponding lifecycle activities, e.g. they follow a sequential flow. However, the actual interaction depends on the needs of a particular use case. That is, ontology lifecycle services can be invoked and controlled by application-specific services as needed.

Ontology Services: Functionalities offered by services at these layers are used by lifecycle services. An *ontology registry service* is used to find and publish ontologies. An *ontology repository service* provides access, manipulation and storage (persistence is supported by the lower level datastore) at the level of ontologies and at the level of ontology elements. That is, repository functionalities are also available for axioms, concepts, properties, individuals etc. The repository service also includes logging and versioning to ensure reversibility. Besides the common repository retrieval methods, a *query service* offers a generic mechanism for retrieval.

Finally, an *inference service* is available for standard reasoning tasks such as consistency checking, classification etc.

Ontology Engineering Services: The architecture contains services for the requirement analysis that has functionalities similar to the ones supported in an IDE for software development, e.g. for requirements elicitation, **modelling of use cases** and specification of reasoning and retrieval tasks involved in the use cases.

In the actual development, services are provided for ontology browsing, visualization, editing and integration. In particular, *browsing* and *visualization* supporting ontologies as well as non-ontological artefacts such as interface signatures, data base schema, and UML models to help in identifying reusable artefacts. To enable reuse, there are services for the *translation* of existing ontologies to the target representation formalism. Services for (semi)-automatic *transformation* of non-ontological sources to ontologies are also incorporated into the architecture to facilitate reuse. This transformation is possible in both directions to ensure the interoperability of ontology data w.r.t. these data sources. Services for *ontology learning* are also provided to accelerate the development process by the generation of a base version that can be further refined.

Implementations of specific interaction protocols enable a *collaborative editing* process. The *mapping service* includes support for the identification and specification of ontology modules as well as their relations and dependencies. Also, it includes the specification of concept mappings required for the alignment of ontologies.

After the base ontologies have been further developed, adapted to requirements and integrated, they have to be tested and evaluated. For these tasks, there are services for *debugging* (identification of axioms that are responsible for or affected by the inconsistency) and for the *inconsistency resolution* of the conflicts [Haase2007]. Also, there are services that evaluate the coverage of the ontology w.r.t. the representative set of retrieval and reasoning tasks envisaged for the use cases (*functional evaluation*).

Finally, *performance evaluation* services are essential to meet the requirements and are incorporated into the architecture. In order to meet performance targets for particular scenarios, different configurations for ontology axiomatization may be considered.

Ontology Runtime Services: In Figure 2: Abstract Architecture some application-specific services are shown to illustrate that ontologies may be used as a technology to implement use cases of a particular OIS. This can involve *reasoning*, *retrieval*, but also *other tasks* enabled by ontologies. In order to support these ontology-based services, the architecture contains the following runtime services that are rather independent from specific use cases.

Services that can automatically *populate* the KB reduce the effort needed for the manual creation of instance data. These services are performed by agents that request external ontology data as well knowledge extractors that crawl external non-ontological sources. They implement learning algorithms to extract instances from text and multimedia contents. Some of these population services (and ontology learning services) may incorporate procedures for natural language processing [Valarakos2004] as subcomponents.

Finally, the quality of the acquired instance data has to be ensured. *Cleansing* services are available to adapt the format and labels to the application requirements. The same instances extracted from different sources may have different labels. Knowledge *fusion* services identify and resolve such occurrences. Similarly, knowledge acquired from different sources may be redundant and often contradictory. This is also addressed by the fusion services. These services may implement a semi-automatic process, which involves the user and engineering services such as debugging and editing. The arrows in Figure 2: Abstract Architecture illustrate this interaction between runtime and engineering services. This interaction is supported by the evolution support, a feature part of these runtime services.

2.1.2.3 Designing OIS with the Generic Architecture

We now discuss how this architecture can act as a reference that can be adapted to match functional and technological requirements of a particular ontology-based information system.

Matching Functional Requirements: The presented architecture is very generic and targets the management of the entire ontology lifecycle. Implementing the whole architecture would result in a fully-fledged integrated system that supports both the engineering and the application of ontologies. However, a particular application often requires only a subset of the envisaged services.

Applications may feature only engineering, or only usage of ontologies that already have been engineered using another system. Then only engineering and runtime services, respectively, have to be incorporated into the concrete architecture of the final application. In general, the functional requirements of the system have to be analyzed. Then these requirements have to be mapped to services of the architecture. Finally, for each of the identified services, more fine-grained functionalities have to be derived w.r.t. the use cases to be supported by the application.

For instance, an application that only uses RDF(S) ontologies may not need any lifecycle services at all. Imagine a web application, which simply presents FOAF profiles manually imported from external sources. Then only core ontology services are needed to import, store and retrieve information from the profiles. A more sophisticated version may employ agents to crawl profiles from the web. Even then, only population and basic cleansing is needed, because due to the use of RDF(S), no inconsistencies can arise that would require engineering services. Now, imagine an application using OWL ontologies to manage resources of a digital library. Resources are annotated with ontology concepts that can be defined by the user. Most annotations are extracted automatically and even new concept descriptions are suggested by the system to capture the knowledge contained in new library resources. Clearly, this application would need a wide range of runtime and engineering services and hence, an integrated application with lifecycle support.

Matching Technological Requirements: The presented architecture is of abstract nature and free of assumptions about specific technological settings. For the development of a specific application, it can be used as a reference to identify the components (as discussed previously) and to organize them with the suggested abstraction layers and control-flow. Then, given specific technological constraints, a concrete architecture paradigm can be chosen and applied to the abstract architecture.

These paradigms capture best practices in different application settings and can also give additional guidance for OIS engineering. We will now outline standard paradigms in software engineering and discuss for which exemplary settings they are most appropriate.

Architecture paradigms can be distinguished along three dimensions, namely the degree of distribution, coupling and granularity of components. Distribution can range from non-distributed rich client, over client-server, three-tier, multi-tier to fully-distributed P2P architectures. The last two dimensions make up the differences of two more concrete architecture paradigms with specific platform assumptions, namely the component-oriented multi-tier J2EE architecture [Singh2002] and the Service-oriented Architecture (SOA) [McKenzie2006]. While J2EE comprises of tightly-coupled and relatively fine-grained components, SOA advocate the use of loosely-coupled and coarse-grained services.

The main idea behind multi-tier architectures is the encapsulation of each tier, meaning any tier can be upgraded or replaced without affecting the other tiers. While this organization principle has been adopted (where layer stands for tier), the proposed architecture does not make any assumptions about how components may be distributed. In fact, the layered organization can be seen as an orthogonal principle that can be combined with any of the mentioned paradigms.

For instance, elements of the architecture can be implemented as components of a desktop application, e.g. the backend maps to a file system, services and control-flow map to Plain Old Java Objects (POJOs) and their call hierarchy and GUI components map to Swing widgets. In another use case, more flexible access may be required, the application logic may call for more processing capabilities, and the amount of data cannot be managed efficiently by a file system. Then, a database can be employed as backend, data access can be provided by Data Access Objects (DAO) and lifecycle services are realized as Enterprise Java Beans (EJB) of a J2EE platform, and front-ends are implemented as Java Server Pages (JSP) to deliver contents over the web.

In some cases lifecycle components could be tightly integrated with other internal systems via J2EE connectors [Sharma2001]. In other cases external parties may want to choose from different offerings and therefore demand a more flexible way to discover ontology services at runtime and to interact with them on the basis of a standardized protocol. Here, SOA may be the choice: The fine-grained functionalities of some lifecycle components are encapsulated in form of coarse-grained services exposed to consumers via WSDL and SOAP. Instead of using a completely new SOA platform, one may go a more evolutionary way advocated by major J2EE vendors, i.e. switch to a Service Component Architecture (SCA) that implements SOA. SCA provide guidelines for decoupling service implementation and service assembly from the details of underlying infrastructure capabilities. Components can then offer their functionalities as services that can also be consumed externally. However for internal consumption, they do not necessarily have to be loosely coupled---since tight coupling can avoid the overhead of creating, parsing and transporting messages over the network.

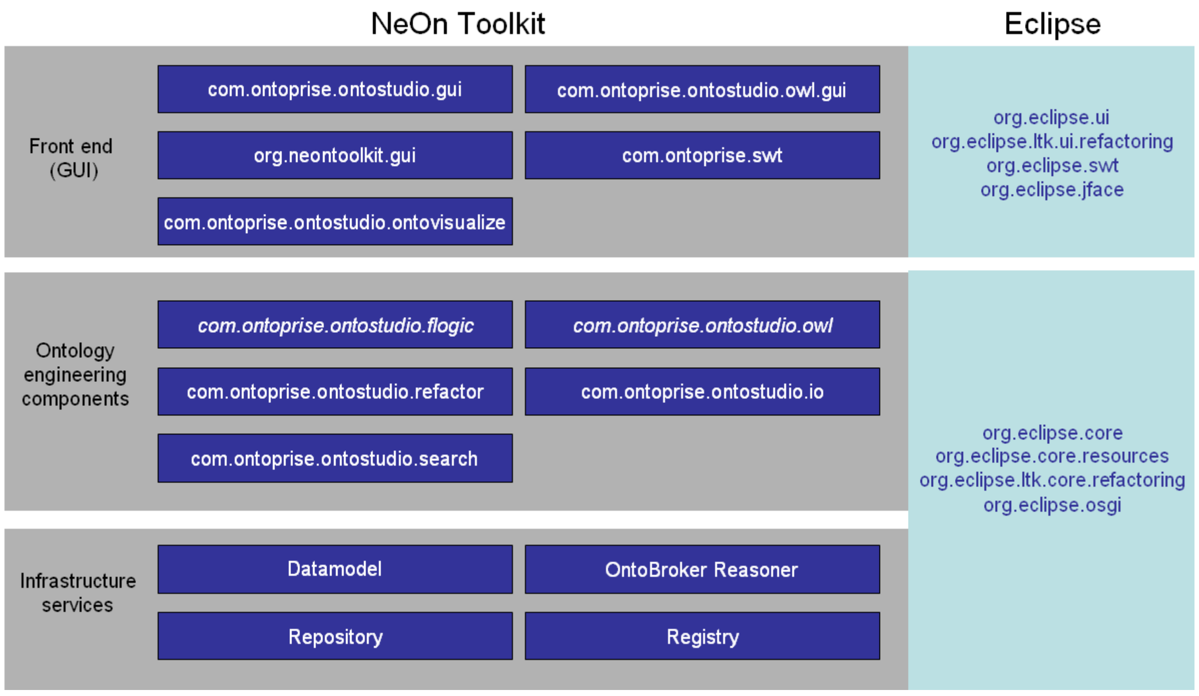
In all, the generic architecture gives guidelines for the identification and organization of components. The examples above illustrate that there are many other aspects that have to be considered given concrete requirements. After the choice for a concrete platform and the paradigm to be applied on the architecture, guidance can then be found in the respective reference architectures, e.g. see [Sharma2001] for J2EE, for SOA and SCA.

2.2 NeOn Toolkit for Ontology Engineering

In this section we provide an overview of the NeOn toolkit core components that represent an implementation of the NeOn reference architecture to support the ontology engineering phase. Thus, its components can be roughly separated into

- front end (GUI),
- ontology engineering services, and
- ontology infrastructure services.

Additionally, Eclipse components play an essential role in the architecture. They provide the basis for different functionalities on all three layers of the architecture. In the following figure we assign the main plug-ins from the basic NeOn Toolkit to the three layers of the architecture.


NeOn Toolkit
Eclipse
Front end (GUI)
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com.ontoprise.ontostudio.owl.gui
org.neontoolkit.gui
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com.ontoprise.ontostudio.search
org.eclipse.core
org.eclipse.core.resources
org.eclipse.ltk.core.refactoring
org.eclipse.osgi
Infrastructure services
Datamodel
OntoBroker Reasoner
Repository
Registry

Figure 3: The plug-ins of the basic NeOn toolkit

These three layers have been introduced in the NeOn architecture [WaterfeldWeiten2007]. The figure presented above provides a refinement of the ontology engineering (or "design time") aspects of the ontology lifecycle by instantiating the abstract components with actual plug-ins of the NeOn toolkit core. Not all core plug-ins are shown in the figure to not blur the overall picture. Plug-ins dealing with the *branding* of the toolkit, with the online *help system*, or that provide generic *utility* functionality or third party *libraries* are left out.

In the next section we will provide some details about the functionality of the different plug-ins and also describe the important dependencies between them. This should illustrate how they can be reused when developing other plug-ins.

2.2.1 Ontology Infrastructure Services

The built-in infrastructure components of the core NeOn Toolkit provide services for basic ontology management, storage and querying/reasoning functionality. The following list contains all plug-ins that implement these infrastructure capabilities:

- `datamodel`
- `datamodelBase`
- `flogic-parser`
- `ontobroker-ng_kernel-g3`
- `ontobroker-ng_ontobroker-core`
- `ontobroker-ng_server`
- `ontoprise-licensechecker`
- `touchgraph`
- `util`

These plug-ins support both Flogic and OWL-DL and subsume the datamodel and reasoner components. The ontology management aspects for both language use a common API. Since the two languages differ in many respects, of course, the objects that are passed through this API are very different. Nevertheless, the basic infrastructure and access methods are shared between both languages. For query answering and reasoning two inference engines are contained in the set of infrastructure components. For processing Flogic models and queries we exploit OntoBroker [Ontobroke 2007b]. For reasoning about OWL-DL models and processing SPARQL queries we exploit the KAON-2 disjunctive datalog engine [Motik 2006].

Currently the functionality of the mentioned plug-ins is made accessible by the engineering level plug-ins, mainly `com.ontoprise.ontostudio.flogic`[2] for access to Flogic models and `com.ontoprise.ontostudio.owl`[3] for accessing OWL models.

As described in the NeOn Registry and Repository deliverable [WaterfeldPalma2007] the NeOn Registry and Repository infrastructure services are defined as web services. There are currently two realisations of those services with different characteristics. It is planned to offer on top of these web services a common Java API, which will be provided as a NeOn toolkit plug-in.

2.2.2 Ontology Engineering Services

On the level of ontology engineering services we can distinguish between

- plug-ins providing general functionality like search, writing and reading models, or refactoring,
- plug-ins providing support for managing OWL ontologies, and
- plug-ins providing support for managing Flogic ontologies.

`Com.ontoprise.ontostudio.io`:

Provides functionality to importing and exporting ontologies in different formats from and to the local file system or a WebDAV server (Web-based Distributed Authoring and Versioning).

`Com.ontoprise.ontostudio.search`:

This plug-in provides some search functionalities for ontological entities like concepts, attributes, relations and instances.

`Com.ontoprise.ontostudio.refactor`:

This plug-in provides extension points and associated Java interfaces and classes to extend the refactoring functionality of the toolkit. This is based on the Eclipse refactoring framework and supports things like renaming entities, or moving a class/concept from one place in the taxonomy to another.

`Com.ontoprise.ontostudio.owl`:

This plug-in is intended to simplify access to OWL models for all NeOn Toolkit plug-ins, esp. plug-ins developed by NeOn partners or external developers. It simplifies certain aspects of the underlying Kaon-2 API but also reuses some of the classes and interfaces defined in Kaon-2. This plug-in is not yet implemented. Currently its functionality is part of the OWL GUI plug-in because the GUI level support for modelling OWL ontologies is *work-in-progress*.

[2] Currently this plug-in is still named `com.ontoprise.ontostudio.datamodel`, which is slightly too general.

[3] Currently this plug-in is still merged with the OWL gui plug-in.

`Com.ontoprise.ontostudio.flogic`:

> This plug-in represents the Flogic modelling capabilities of the NeOn Toolkit. It provides abstractions to the underlying *internal* datamodel and thus makes it easier for other plug-ins to the knowledge representation aspect of the application. It provides access to the underlying datamodel via an API. The datamodel is realized by OntoBroker's storage functionality.

2.2.3 GUI Level Components

The last group of plug-ins from the basic configuration of the NeOn Toolkit consists of GUI level plug-ins that provide very different functionalities. Some of them are self-contained and only rely on the plug-ins on the lower levels, others spread over multiple plug-ins.

`Com.ontoprise.ontostudio.gui`:

> This plug-in contains the core UI components like the EntityPropertyView and the ontology navigator that are shared between Flogic and OWL. Additionally it contains the GUI features for modelling Flogic ontologies.

`Org.ontoprise.ontostudio.owl.gui`:

> In this plug-in we are currently implementing the functionality to display, navigate and manipulate OWL-DL ontologies.

`Com.ontoprise.ontostudio.ontovisualize`:

> The ontovisualize plug-in contains a view to graphically visualize Flogic ontologies using the JpowerGraph library which is customized in the `com.ontoprise.jpowergraph` plug-in.

The following plug-ins represent framework classes and interfaces to support a common look-and-feel and to enable extensibility and communication means between the components.

`Com.ontoprise.ontostudio.swt`:

> Here, the basic Eclipse SWT (Standard Widget Toolkit) classes are extended and customized to support the other GUI plug-ins of NeOn Toolkit.

`Org.neontoolkit.gui`:

> In this plug-in the extension points and associated Java interfaces are specified that allow for extending the NeOn toolkit with additional functionality, in particular to add new nodes into the ontology navigator and to extend the entity property views for existing and new entity types.

2.2.4 Other components

Supporting plug-ins which do not nicely fit into the three layer architecture such as "Help" or "Branding" complete the set of core components of the NeOn Toolkit.

`Org.neontoolkit.help`:

> In this plug-in we define the on-line documentation for the basic features of the NeOn Toolkit as specified in [NeOn D6.7.1]. The documentation is available via the Help Contents entry of the Help menu.

`Org.neontoolkit.plugin`:

> This is the branding plug-in. With this plug-in the toolkit can be customized regarding the splash-screen, the about-dialog etc.

2.2.5 Essential Eclipse Plug-ins

Since the NeOn Toolkit is based on the Eclipse framework, which provides a vast variety of functionalities, we will describe the most important Eclipse plug-ins [Shavor2003] that are used or extended by the NeOn Toolkit

2.2.5.1 Deployment, Eclipse Framework

`org.eclipse.core.resources`

This `org.eclipse.core.resources` plug-in manages the resources in the user-workspace. It provides handles to create, modify and delete all kinds of resources in the workspace (such as projects, files and folders). The NeOn Toolkit uses theses resources to manage the content of the ontology navigator component. It has the notion of an *ontology project*, which supports specific functionalities like hosting multiple *ontology* resource.

`Org.eclipse.core.runtime`

The runtime platform is implemented in the `org.eclipse.core.runtime` plug-in. It includes the basic plug-in super-class, plug-in preferences, logging objects, etc. We also find core utility methods (such as ProgressMonitors, IsafeRunnable, Ipath, etc.) and the extension registry, which manages the extension points and their extensions, in this plug-in. All plug-ins in the NeOn Toolkit depend on this plug-in because every plug-in containing an activator class controlling the plug-in's lifecycle must have a dependency to the runtime plug-in.

2.2.5.2 User Interface

`org.eclipse.swt`

The `org.eclipse.swt` plug-in contains the classes of the Standard Widget Toolkit (SWT). This is the graphics toolkit of eclipse containing all basic UI elements, such as trees, tables, labels, comboboxes, etc. All plug-ins that provide a user interface in the NeOn Toolkit need to access the SWT classes. For example, the Entity Properties View consists of some composites (`org.eclipse.swt.widgets.Composite`) and a tabbed container (`org.eclipse.swt.custom.CtabFolder`) containing the different property pages. Every property page is using several SWT classes to implement the GUI features.

`Org.eclipse.jface`

Jface is a UI toolkit that helps solving common UI programming tasks. Jface also acts as a bridge between low-level SWT widgets and your domain objects, e.g. by providing viewers that implement the MVC (model-view-controller) pattern using

- content providers which retrieve the domain objects and
- label providers the determine the representation of the domain objects.

The basic wizard classes are also implemented in the Jface plug-in. The OntologyNavigator is implemented as a TreeViewer with a content provider and label provider that delegate their calls to the extensions of the `extendableTreeProvider` extension point from the `org.neontoolkit.gui` plug-in.

`org.eclipse.ui.views`

This plug-in provides extension-points to extend the basic eclipse views such as content outline and property pages. The plug-in for textual editing of F-Logic source code is implementing an outline page to show the entities contained in the ontology for easier navigation in the (potentially large) text file.

`Org.eclipse.ui.workbench`

In this plug-in we find the implementation of the Eclipse workbench (including the basic interfaces for views, editors and perspectives) and many UI utilities, such as basic actions, commands, dialogs, auto-completion functionalities, and many more. The OntologyNavigator and the `EntityPropertiesView` are views in Eclipse and implement the view interface `IviewPart`. The actions contained in the context menus implement the action interfaces `IobjectActionDelegate` and `IviewActionDelegate` which are also contained in the workbench plug-in.

2.2.5.3 Refactoring

`org.eclipse.ltk.core.refactoring` and `org.eclipse.ltk.ui.refactoring`

Another example of basic functionality that the NeOn Toolkit inherits and extends from the Eclipse framework is concerned with refactoring models. Refactoring is a technical term from the realm of programming languages. Whenever simple (or complex) modifications must be executed in a lot of places with in a large set of source code files, an automatic mechanism to ensure proper and consistent updates is of invaluable help for the developer. For Java this includes renaming classes or methods, or moving classes or methods between packages or classes respectively. For ontologies this refers to e.g. removing classes (how to handle existing instances of this class?) or renaming properties. The Eclipse basic implementation support the refactoring process by providing means to test preconditions, to display (hypothetical) results of the refactoring etc. (cf. [Frenzel 2006]).

2.3 NeOn Toolkit Plug-ins

While basic ontology management and editing functionalities are provided by the core NeOn Toolkit, additional plug-ins can extend the core NeOn Toolkit with additional functionalities supporting specific lifecycle activities, as they have been discussed in Section 2.1.1.

These plug-ins may implement functionalities on all layers of the NeOn reference architecture. In deliverable D6.10.1 [Haase2008] we have provided a comprehensive description of the plug-ins that been developed thus far, including a mapping to the ontology lifecycle activities they support. Additionally, up-to-date and “live” information about the plug-ins can be found in the NeOn Toolkit plugin wiki at http://www.neon-toolkit.org/. We therefore refer the reader to these sources for further information.

Runtime Infrastructures

In this section we discuss a number of technologies that may be used for developing runtime applications based on the NeOn platform. We present a range of technologies for different runtime infrastructures that may match different technological requirements of the intended application.

As an example, the requirements may concern the realization of the client side of the application, which may need to be realized as a rich client application in one case or as a pure web client application in another one.

While allowing for different target infrastructures, we intend to provide standard technologies that enable use and reuse of NeOn components across different platforms.

2.3.1 WTP based

2.3.1.1 Overview

The Eclipse Web Tools Platform (WTP) project extends the Eclipse platform with tools for developing J2EE and Web applications. It includes source and graphical editors for a variety of languages, wizards and built-in applications to simplify development, and tools and APIs to support deploying, running, and testing applications.

WTP has the dual goals of providing a core set of tools J2EE *tools* for Web application developers and for tool vendors. WTP is divided into two main subprojects, as shown in Figure 4.

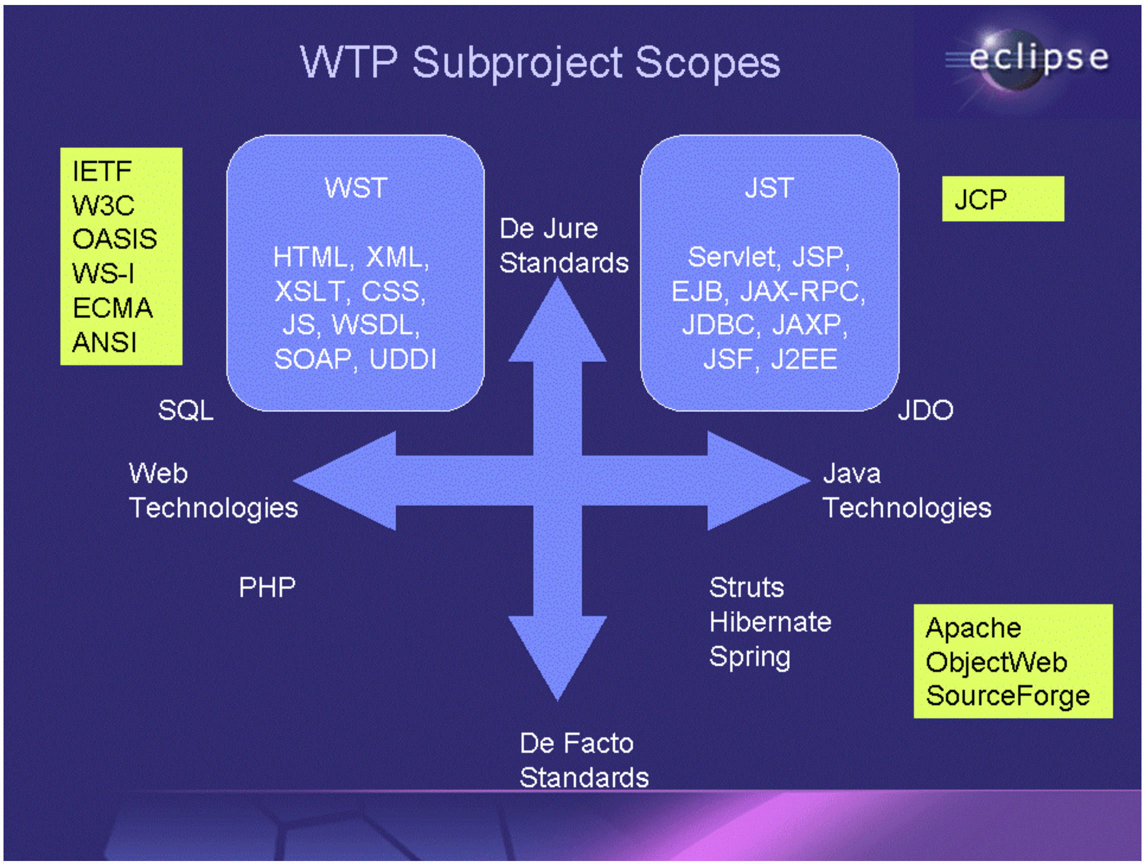


Figure 4: WTP Subproject Scopes[4]

[4] Figure taken from http://www.eclipse.org/webtools/releases/0.7/whatsnew.html

The Web Standard Tools project provides a common infrastructure available to Eclipse-based development environment targeting multi-tier Web-enabled applications. It includes server tools which extend the Eclipse platform with servers as first-class execution environments. Server tools provide an extension point for generic servers to be added to the workspace, and to be configured and controlled. For example, generic servers may be assigned port numbers, and may be started and stopped. The WTP extension for Web servers, which builds on the generic server extension point, includes exemplary adapters for popular commercial and Open Source servers, e.g. Apache Tomcat.

The scope of the J2EE Standard Tools project is to provide a basic Eclipse plug-in for developing applications based on standards-based application servers, as well as a generic tooling infrastructure for other Eclipse-based development products. Included is a range of tools simplifying development with J2EE APIs including EJB, Servlet, JSP, JCA, JDBC, JTA, JMS, JMX, JNDI, and Java Web Services. This infrastructure is architected for extensibility for higher-level development constructs providing architectural separations of concern and technical abstraction above the level of the J2EE specifications. The J2EE Standard Tools Project builds on the Server Tools provided by the Web Standard Tools Project to provide support for application servers, including both servlet engines and EJB containers.

Figure 5 depicts a high level conceptual architecture of WTP. WTP is built from a collection of plug-ins, organized in layers that depend on each other in a very controlled way: only upper layers depend on lower layers.

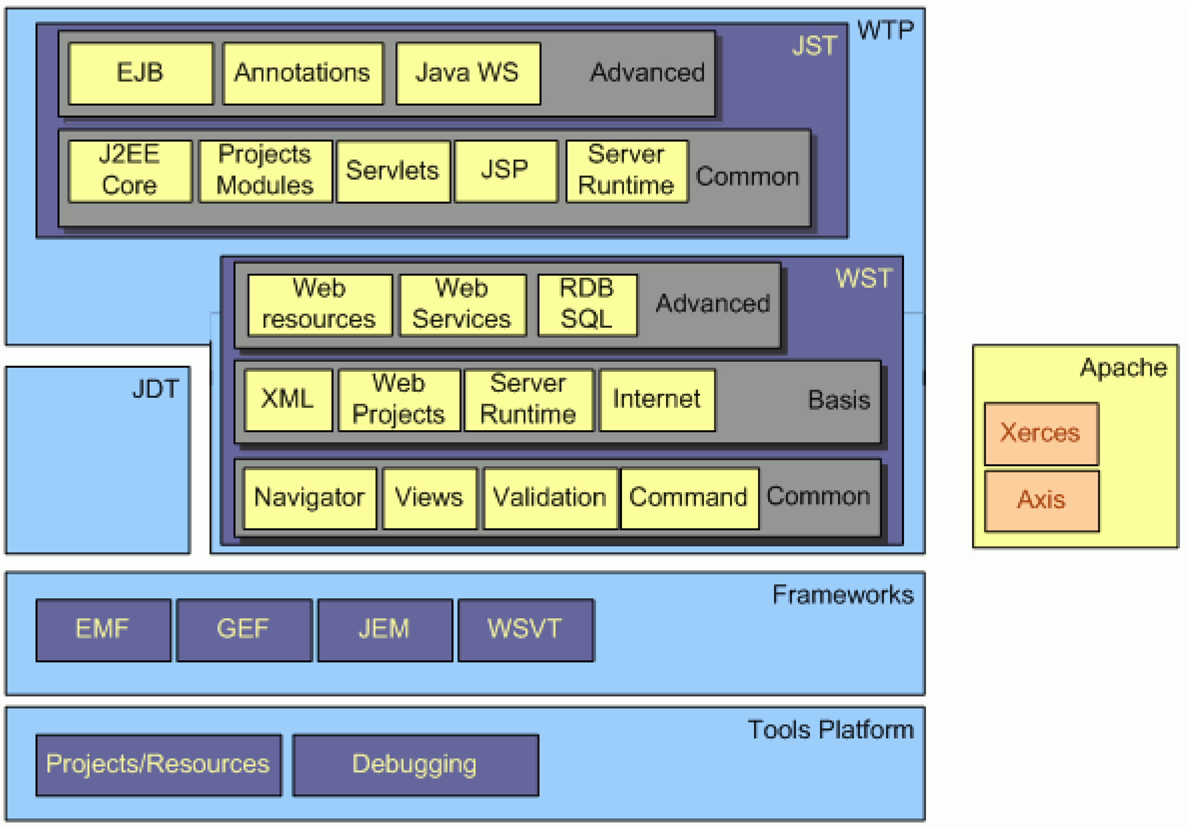


Figure 5: WTP Architecture[5]

[5] Figure taken from http://www.eclipse.org/webtools/releases/0.7/whatsnew.html

2.3.1.2 How can NeOn Benefit from WTP?

The WTP focuses on providing infrastructure for application development, in contrast to infrastructure related to the application run-time. As such, WTP is relevant for NeOn primarily as a development technology that allows creating NeOn applications for a variety of different target runtime infrastructures. It is in principle adequate for developing NeOn applications following any of the target infrastructures following the J2EE architectural model.

Being itself based on Eclipse, WTP as a development platform for NeOn applications integrates well with components of the NeOn Toolkit as platform for ontology development.

2.3.2 RAP Based Runtime Infrastructure

2.3.2.1 Overview

RAP stands for Rich AJAX Platform[6]. The name should resemble RCP (Rich Client Platform), the technology that is used to build desktop applications with Eclipse, e.g. the NeOn Toolkit. The goal of RAP is, to move RCP applications with minimal effort into a web browser. Thus, they can be used from everywhere over the web without the need of a local installation. A standard web browser is sufficient. RAP is very similar to Eclipse RCP, but instead of being executed on a desktop computer RAP applications run on a server and standard browsers are used on the client-side to display the GUI.

One central part of RAP is AJAX (Asynchronous JavaScript and XML). A browser can communicate with a server via AJAX requests. This allows changing small parts of a web page without the need to reload it completely. With this ability it is possible to build complete applications that seem to be executed within a browser. To be precise, this means that the major part of the application runs on the web server. The data structures are stored, accessed and modified on the server. Furthermore, the server controls the logic of the user interface on the client. The client has the look and feel of an application but it displays only the GUI and renders the data it receives from the server.

2.3.2.2 How can NeOn Benefit from RAP?

In the NeOn context, it is desirable to create AJAX-based web application that can access parts of the NeOn architecture (e.g. the data model and the ontology) that are hosted on a server. The NeOn Toolkit is concerned with the creation and modification of ontologies during design-time. At run-time applications use knowledge bases and ontologies to provide added value. Often, these applications are not as full-fledged as the NeOn Toolkit and their use cases are likely to be found in a web context, i.e. users want to access a remote knowledge base via a web interface. Thus, a seamless integration of web applications with the Eclipse-based NeOn Toolkit implementation or at least some code-reuse is desirable.

RAP is ideal for this scenario, as the RAP project enables developers to build rich, AJAX-enabled web applications by using the Eclipse development model, plug-ins with the well known Eclipse workbench extension points, Jface, and a widget toolkit with SWT API. Developers of a web application implement the GUI with the Java interface of the SWT (Standard Widget Toolkit) as they would do for an Eclipse application. In RAP the implementation of SWT is replaced by RWT

[6] http://www.eclipse.org/rap/

that uses Qooxdoo for the client-side GUI presentation. Qooxdoo[7] is an Open Source project that aims at creating application-like GUIs in web browsers with the help of JavaScript and Ajax.

The backend, i.e. the access to the data structures in Java (e.g. NeOn's datamodel), does not have to be changed at all. There is no need to translate Java objects into streams for Ajax requests or whatever.

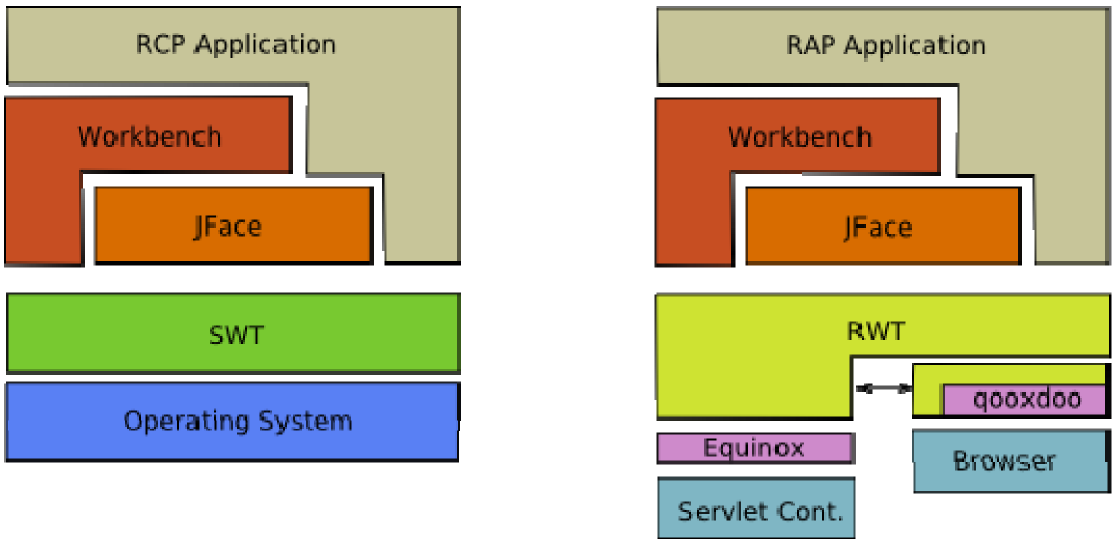


Figure 6. RAP Architecture (right) compared to traditional RCP architecture (left) [8]

RAP takes advantage of the Java development tools and the plug-in development tools provided by Eclipse. The applications are entirely developed in Java as bundles (plug-ins). Everything from development to launching, debugging and exporting to standard .war files works right out of the Eclipse IDE (a Web archive (WAR) file is a packaged web application[9]). RAP enables application developers familiar with RCP to create web application using the RCP programming model. They do not need to know anything about JavaScript, HTML and server-side scripting languages like PHP.

2.3.2.3 Multi-user vs. single-user applications

However, there is one important difference between RCP and RAP applications. In most cases an RCP application performs operations on its own data set. For instance, a user opens their own files with exclusive write access.

In a RAP application a user normally does not have a private, exclusive data set. With a web application, users do usually access the same database. This is no problem, as long as all users have only read access. Special care has to be taken, if the users are allowed to modify their common data. For instance, it might be required to update the data representation in the web application of all users that are logged in, when one user changes something.

2.3.2.4 Advantages of a RAP

- The implementation looks like a real application that runs in a browser. It does not have to be installed. This is particularly interesting for the casual user.
- It is platform independent.

[7] http://qooxdoo.org/

[8] Figure taken from http://www.eclipse.org/rap/about.php

[9] http://help.eclipse.org/help32/index.jsp?topic=/org.eclipse.wst.webtools.doc.user/topics/cwwarovr.html

- There are benefits for collaborative work as several users can share the same data basis that is located on the server.
- The same Java code base is shared for RCP and RAP applications and the development is completely in Java. This is a huge benefit for the developers and the code quality of the application.
- Most existing NeOn plug-ins can be reused. They only need to be connected to the GUI of the RAP application.

2.3.2.5 Disadvantages of a RAP

- Nearly every event in the GUI triggers an Ajax call to the server, e.g. opening a (context) menu. Depending on the speed of the network and the responsiveness of the server the workflow can be slowed down considerably. This might affect the user's motivation.
- Working without an internet connection is impossible.
- Slow client machines will be overloaded.

However, all of these disadvantages apply to all kinds of web applications. They are not specific for RAP.

2.3.3 Interoperability of NeOn Engineering Plug-ins and (Ontology) Web Services

As already explained the distinction between development and runtime environment is much smaller for semantic applications. Thus, due to the existence of Eclipse-based engineering plug-ins there is a need to have their functionality at runtime. Therefore interoperability between engineering plug-ins and runtime services is required. The establishing architecture for runtime services is based on web services according to SOA principles.

OSGI is a core functionality in order to reach this interoperability. The reason is that the Eclipse runtime itself is completely based on OSGI. OSGI is a light-weight and fully dynamic component model. It allows running isolated components within a single JVM process. Therefore it is quite efficient. All Eclipse plug-ins are realized on top of the OSGI component model as bundles. Although OSGI represents a full fledged component model it is used in Eclipse only within a single JVM process. There are however several approaches to access OSGI bundles and thus Eclipse plug-ins also remotely. This forms the basis to realize a larger degree of interoperability with web services in the following two approaches:

There are two major scenarios where interoperability between NeOn plug-ins and web services is required.

2.3.3.1 Publish NeOn engineering plugin as Web Service

The first step is to use a NeOn engineering plugin, which has no GUI interactions, as an OSGI bundle. This bundle is deployed on an OSGI server, which can be accessed remotely.

In order to publish the functionality of the bundle as a web service the interfaces of the bundles has to be transferred to SOAP request. We use the AXIS2 mechanism to publish ordinary Java interfaces as web services. Thus in principle arbitrary Java interfaces of the bundle can be chosen. However usually the exported interface packages for OSGI bundles are the starting point. A manual step is required, where for the appropriate Java interface adapter classes are generated. This generation tool (Java2WSDL) is part of the WTP (web tools platform) of Eclipse and thus is integrated with the NeOn Toolkit.

The generated classes on top of the OSGI bundle will be deployed in an Axis2 server. The Axis2 runtime will run in a servlet container like Tomcat. In order to rely on a common infrastructure the OSGI server must also run in a servlet container.

2.3.3.2 Loosely coupled engineering plug-ins: NeOn engineering plugin for Web Service

The other side of the interoperability between engineering plug-ins and web services are the loosely coupled engineering plug-ins. As already explained in the first version of the NeOn architecture we generate here for existing web services a NeOn engineering plugin.

We use here the same Axis2 infrastructure. In this case however a Java client has to be generated from the WSDL of the web service. Thus, the WSDL2Java mapping has to be used from WTP. This time the generated classes are only part of the engineering plug-in at the Eclipse client side. Thus it is independent of the Axis2 web service runtime. However one usually experience less subtle compatibility problems if the same infrastructure is used at the server and the client side for web services.

3 NeOn Toolkit API

3.1 Core NeOn Toolkit Plug-ins

In this section we will provide an overview of the important aspects for the NeOn Toolkit API, i.e. we will introduce relevant extension points, interfaces and classes that plug-in developers will refer to when implementing additional NeOn Toolkit plug-ins. This section will discuss infrastructure, ontology engineering, and GUI-level APIs. We use the term “*core* plug-ins” or “*core* component” to indicate that these components represent the basis for all other plug-ins of the NeOn Toolkit. They are central and provide the core functionality that can be used and extended by others.

3.1.1 Infrastructure Level APIs

3.1.1.1 Datamodel and Reasoner

The datamodel and the reasoner are implemented by OntoBroker implementing the Kaon2 API. Refer to the Kaon2 API[10] for more details and example code. The most relevant classes are

The class `org.semanticweb.kaon2.api.KAON2Connection`[11] encapsulates several ontologies that import each other.

The interface `org.semanticweb.kaon2.api.Ontology` represents all axioms of an OWL-Ontology. It provides numerous means of modifying an ontology, by adding, removing axioms, or imports statements. It can also persist itself and can provide a reasoner object and also request objects for different levels of querying the model.

The interface `org.semanticweb.kaon2.api.owl.axioms.OWLAxiom` and its subclasses `ClassMember`, `SubClassOf`, `SubPropertyOf`, `EquivalentObjectProperty`, `SameIndividualAs` represent OWL axioms that are the underlying means for modelling in OWL. Axioms can be added and removed from ontologies and can be used for requests to locate certain information in a model.

The interface `org.semanticweb.kaon2.api.owl.elements.OWLEntity` and its subclasses `OwlClass`, `AnnotationProperty`, `ObjectProperty`, `DataProperty`, `Individual`. These classes are “proxy classes” that provide appropriate methods for manipulating the objects but always write-through and read-through to the underlying ontology.

A `org.semanticweb.kaon2.api.Request` allows retrieval of a set of objects from the KAON2 API. Kaon2 distinguishes between `EntityRequests` and `AxiomRequests`. Request objects are obtained from the ontology instance.

[10] http://kaon2.semanticweb.org

[11] This interface will be renamed to `org.semanticweb.kaon2.api.OntologyManager` to better reflect the actual semantics of this class.

Ontologies can also provide reasoner objects of the type `org.semanticweb.kaon2.api.reasoner.Reasoner`. A reasoner provides methods to answer questions over (the entailments of) an ontology.

3.1.1.2 com.ontoprise.ontostudio.datamodel

This plug-in provides interfaces and implements classes supporting the generic access to the underlying datamodel, i.e. provides abstractions for the GUI oriented NeOn Toolkit plug-ins and also organizes multiple ontologies into *projects*.

Currently, this component additionally instantiates the Flogic functionality of the Toolkit. This Flogic (and engineering) oriented pieces of code should actually be moved to a separate plug-in `com.ontoprise.ontostudio.flogic` (see below).

The class `com.ontoprise.ontostudio.datamodel.DatamodelPlugin` is the activator class for the datamodel plug-in. It manages the various ontology containers, manages access to ontology projects, etc.

The eclipse nature `com.ontoprise.ontostudio.datamodel.natures.OntologyProjectNature` identifies projects in the workspace as being ontology projects. All projects marked in this way will be displayed in the ontology navigator. This nature stores the properties of an ontology project, such as the ontologies loaded in the project, the ontology language supported or the data storage used.

The Java interface `com.ontoprise.ontostudio.datamodel.api.IontologyContainer` is the interface for all ontology containers. It is used to provide access to the datamodel.

For the auto-completion functionality of the NeOn Toolkit the class `com.ontoprise.ontostudio.datamodel.autocomplete.CompletionElement` implements the result elements of auto-complete operations.

The Java package `com.ontoprise.ontostudio.datamodel.event` contains listener interfaces for rename and change operations in the datamodel and also the classes relevant for the events.

The class `com.ontoprise.ontostudio.exception.OntoStudioExceptionHandler` is a utility class to uniformly display exception dialogs to the user and to log these events to the eclipse log files.

3.1.2 Engineering Level APIs

3.1.2.1 com.ontoprise.ontostudio.owl[12]

This NeOn Toolkit level plug-in is intended to provide a bridge between the low-level datamodel provided by Kaon2 and the needs of engineering and GUI level components with respect to accessing and modifying OWL models. The two important classes in this plug-in are

- `com.ontoprise.ontostudio.owl.datamodel.OWLModel`: An `OwlModel` instance represents a Kaon2 ontology within a specific `Kaon2Connection` (equivalent to NeOn Toolkit ontology project). This class provides convenience methods for getting all classes of an ontology, for getting the super and subclasses of an `OWLClass`, for getting the all annotations associated with an `OWLEntity`, for adding new axioms to the ontology etc.

[12] Currently this functionality is still part of the `com.ontoprise.ontostudio.owl.gui` plug-in.

- `com.ontoprise.ontostudio.owl.datamodel.OWLModelFactory`: This class provides means for creating (and forgetting) `OwlModel` instances and for retrieving ontology objects given an ontology project.

3.1.2.2 com.ontoprise.ontostudio.flogic[13]

This plug-in implements the basic means for creating Flogic models within the NeOn Toolkit. It mainly provides an API to access the underlying datamodel. The abstract class `com.ontoprise.ontostudio.datamodel.api.Statement` represents the main mechanism for communicating with the underlying datamodel in the Flogic half of the NeOn Toolkit. Each statement represents a modelling primitive that provides means to create Flogic statements and on a conceptual level access the statements properties independent of the underlying actual knowledge representation. The long list of subclasses of `Statement` includes `Concept` (to create and retrieve Flogic concepts from an ontology), `DirectInstanceOf` (to create and retrieve instances of a given concept), `DirectSubclassOf` (for the class hierarchy), or `InstanceProperty` to represent attribute values of instances. Statements are created by passing appropriate `Term` objects to their constructor. They can be used to modify the model via the `ModuleContainer`'s `addStatement()` and `removeStatement()` methods, and they are used in events sent to `OntologyListeners`.

Some additional utility classes are implemented in this plug-in, e.g. the abstract Java class `com.ontoprise.ontostudio.datamodel.DatamodelControl` provides static methods to handle terms, the basic building block of all Flogic “axioms”.

3.1.2.3 com.ontoprise.ontostudio.io

The IO plug-in provides means to import and export models with the NeOn Toolkit. The central class for this functionality is Java class `com.ontoprise.ontostudio.io.ImportExportControl`. It provides methods to load ontologies into a specified ontology project

```
String[] importFileSystem(String projectName, String physicalUri,
ProgressListener listener)
```

And to serialize a specific ontology in a given format to some location:

```
void exportFileSystem(String fileFormat, String projectName, String
moduleId, String physicalUri) throws Exception
```

To implement your own import wizard you can use the abstract Java class `com.ontoprise.ontostudio.io.wizard.AbstractImportWizard`. As examples for import wizards you can refer to the implementation of `com.ontoprise.ontostudio.io.wizard.filesystem.FileSystemImportWizard`. For exports there exists the `AbstractExportWizard` class.

3.1.3 GUI Level APIs

3.1.3.1 com.ontoprise.ontostudio.gui

The GUI plug-in contains the major components of the user interface of the NeOn Toolkit, such as the Ontology Navigator and the Entity Properties View. Additionally, some basic classes supporting the extension of the Ontology Navigator and the definition of property pages to be shown in the Entity Properties View are contained in this plug-in. The core classes of this plug-in are:

[13] The classes described here are currently still located in the `com.ontoprise.ontostudio.datamodel` plug-in.

The class `com.ontoprise.ontostudio.gui.GuiPlugin` is the activator class for the GUI plug-in. It controls the life cycle of this plug-in and manages the extensions of the extension-points

- `org.neontoolkit.gui.entityProperties` and
- `org.neontoolkit.gui.extendableTreeProvider`.

The abstract class `com.ontoprise.ontostudio.gui.LoggingUIPlugin` is an extension of the `AbstractUIPlugin` provided by Eclipse. It additionally contains logging methods to log errors and warnings, etc.

The class `com.ontoprise.ontostudio.gui.navigator.MtreeView` is the implementation of the Ontology Navigator.

The abstract class `com.ontoprise.ontostudio.gui.navigator.DefaultTreeDataProvider` is a default implementation for extensions of the `org.neontoolkit.gui.extendableTreeProvider` extension point.

The abstract class `com.ontoprise.ontostudio.gui.navigator.TreeElement` is a default implementation of the `org.neontoolkit.gui.navigator.ItreeElement` interface. For elements shown in the Ontology Navigator it is recommended to extend this class.

The class `com.ontoprise.ontostudio.gui.properties.EntityPropertiesView` is the implementation of the Entity Properties View.

The abstract class `com.ontoprise.ontostudio.gui.properties.BasicEntityPropertyPage` contains a default implementation of the `org.neontoolkit.gui.properties.IentityPropertyPage` interface. It can be used as a template for property pages for entities having a URI as identifier.

3.1.3.2 org.neontoolkit.gui

This GUI plug-in provides the basic extension points for adding functionality to the Ontology Navigator and the Entity Property View of different ontology entities [Erdmann2007].

The *Ontology Navigator* can be extended to support additional elements in its hierarchical structure and to support additional drag-and-drop actions.

- `org.neontoolkit.gui.extendableTreeProvider` and
- `org.neontoolkit.gui.extendableDropHandler`.

Note: New context menu entries can be defined by using the `org.eclipse.ui.popupMenus extension-point`.

The *Entity Properties View* can be extended to support the display and modification of additional entity types.

- `org.neontoolkit.gui.entityProperties`.

In addition to the extension points above that have been described in [Erdmann 2007] a new feature of the NeOn Toolkit exist which makes it possibility to add multiple property pages to the Entity Property View. In this way the view can separate different aspects of a single entity and new plug-ins can provide their own property pages to existing entities. *Entity Property Pages* now can have sub-pages. Each page extends the `entityProperties` extension point and now has some new attributes.

- `id`: unique identifier of the property page
- `name`: label of the property page displayed in the tab of the entity property view

- `subContributorOf` subelement with `superContributorId` and `priority` attributes: the `superContributorId` identifies the Entity Property View that this property page will be displayed (this id must match the `id` attribute of another Entity Property Page. The `priority` attribute is used to order the different tabs in a sequential order, lower numbers being moved to the right.

3.1.3.3 com.ontoprise.ontostudio.swt

This plug-in contains some NeOn Toolkit-specific extensions of the SWT classes of Eclipse. If contains extensions of the *field assist* classes (used for the auto-complete functionality) and some other utilities.

The class `com.ontoprise.fieldassist.ContentAssistTextCellEditor` is an extension of the `TextCellEditor` provided by Eclipse, offering an auto-complete popup menu.

The class `com.ontoprise.fieldassist.ContentAssistTextField` provides a Text widget with auto-complete functionalities.

3.2 Support for developing NeOn plug-ins

3.2.1 Using the NeOn Metamodel with the EMF, GEF and GMF Frameworks in Plugin Development

In this section, we illustrate how to make use of the Eclipse EMF and GMF frameworks in plugin development. As example, we discuss a plug-in called OntoModel, which is based on the NeOn metamodel and corresponding UML profile to support the graphical development of OWL ontologies and ontology mappings.

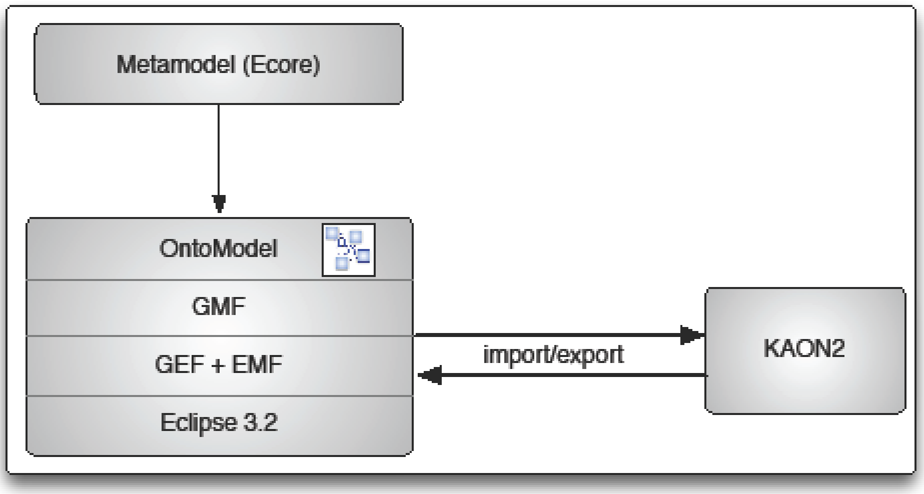


Figure 7: Ontomodel Plugin Architecture

Figure 7: Ontomodel Plugin Architecture shows how OntoModel builds on Eclipse and some of its available plug-ins: it builds on the Graphical Modeling Framework (GMF[14]), which in turn builds on the Graphical Editing Framework (GEF[15]) and the Eclipse Modeling Framework (EMF[16]).

[14] http://www.eclipse.org/gmf/

EMF is a code generation facility for building applications based on a structured model. It helps to turn models into efficient, correct, and easily customizable Java code. Out of our Ecore metamodel, we created a corresponding set of Java classes using the EMF generator. The generated classes can be edited and the code is unaffected by model changes and regeneration. Only when the edited code depends on something that changed in the model, that code has to be adapted to reflect these changes.

EMF consists of two fundamental frameworks: the core framework and EMF.Edit. The core framework provides basic generation and runtime support to create Java classes for a model, whereas EMF.Edit extends and builds on the core framework, adding support for generating a basic working model editor as well as adapter classes that enable viewing and editing of a model.

EMF started out as an implementation of the MOF specification. It can be thought of as a highly efficient Java implementation of MOF, and its MOF-like metamodel is called Ecore.

The EMF adapter listens for model changes. When an object changes its state, GEF becomes aware of the change, and performs the appropriate action, such as redrawing a figure due to a move request. GEF provides the basic graphical functionality for GMF.

GMF is the layer connecting OntoModel with GEF and EMF. It defines and implements many functionalities of GEF to be used directly in an application and complements the standard EMF generated editor.

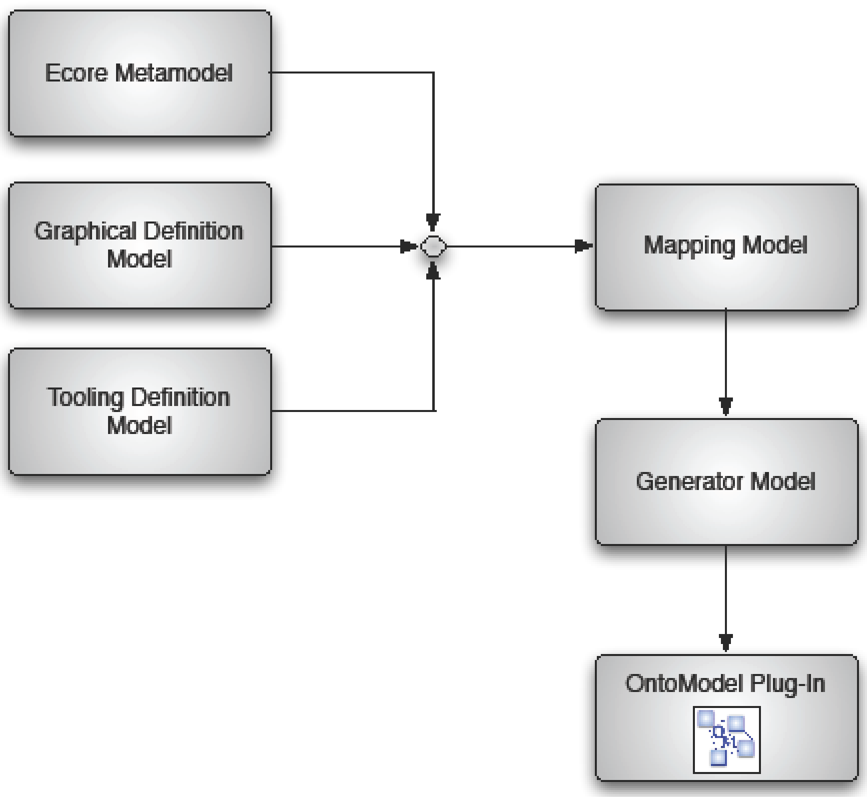


Figure 8: Components and models used during the GMF-based development of OntoModel

[15] http://www.eclipse.org/gef/

[16] http://www.eclipse.org/modeling/emf/

Figure 8: Components and models used during the GMF-based development of OntoModel illustrate the main components and models used during the GMF-based development of OntoModel.

The graphical definition model is the core concept of GMF. It contains the information related to the graphical elements that are used in our ontology models. However, they do not have any direct connection to our metamodel. The graphical definition model is generated semi-automatically from our Ecore metamodel. (Note that, although our editor is UML-based, GEF also provides other graphical elements.)

Similarly, the tooling definition model is generated semi-automatically from the metamodel to design the palette and other periphery (menus, toolbars, etc).

A goal of GMF is to allow the graphical definition to be reused for several domains. This is achieved by using a separate mapping model to link the graphical and tooling definitions to the selected domain metamodel. This semi-automatically generated model is a key model to GMF development and is used as input to a transformation step producing the generator model.

The generator model generates the OntoModel plug-in which is then refined with dialogs and other application-specific user interface aspects. The plug-in bridges the graphical notation and the domain metamodel when a user is working with a diagram, and also provides for the persistence and synchronization of both. An important aspect of GMF-based application development is that a service-based approach to EMF and GEF functionality is provided which can be leveraged by non-generated applications.

3.3 Core Infrastructure Services

3.3.1 Reasoner Interface

For the runtime or ontology-usage time of the ontology lifecycle one main functionality usually is the possibility to access the knowledge base in terms of queries. The query answering component of the NeOn Architecture is comprised of the *Inference Server* based on the OntoBroker reasoner.

Currently the reasoning component built-in the NeOn Toolkit cannot be accessed from other processes outside of the toolkit or from other remote clients. The NeOn Toolkit represents a single-user desktop application for managing and modifying ontologies. This use case is drastically different from hosting a service which provides query functionality to a knowledge base for remote access by external client applications.

3.3.1.1 Setup

In order to setup such a service we can follow the installation instructions from the OntoBroker manual [Ontoprise 2007][17]. The Inference Server can be started from the command line by using the start script.

```
Start-ontobroker [-p <port>] [-ip <ipadress>]
                 {[-m][<lang>][-fenc <encoding>] <file>|<url>}+
```

The following list shows the most relevant command line arguments

[17] Currently we develop a web-service based API for accessing the reasoning engine which will be released with the OntoBroker 5.1 release in April 2008. For NeOn partners a project-license for OntoBroker server is available upon request from ontoprise.

- `-p` represents the port number of the server for receiving queries and commands. Different port numbers can be used to run different Inference Servers on the same machine. If no value is given the default port 2267 will be used. This port is registered at IANA.
- `-ip` allows specifying the IP address of the host where the server is running. This is only needed if the server has multiple IP addresses. If no value is given <localhost> is the default value.
- `-m` Materialize the rules from the following file. This improves performance but decreases loading time and increases memory consumption. Materialization of rules means, that rules are evaluated entirely at loading time and all inferred facts are added to the KB. The rules can be later excluded from further inferencing processes.
- `<lang>` is one of:
  - `–flo` file contains an Flogic KB (the default)
  - `–oxml` file contains an Flogic KB encoded in OXML
  - `–rdf` file contains an RDF(S) ontology
  - `–owl` file contains an OWL ontology

  This option identifies the language of the following file. For the 5.0 version of the Inference Server it is recommended to use FLO or OXML since OWL and RDF files are transformed into the Flogic model at loading time, which implies that some information from the original models will be lost.
- `-fenc` By using this parameter it is possible to set the file encoding used to read the files This is necessary when the file encoding of a concrete file differs from the default of your operating system. XML-based files typically provide encoding information in the header.
- `-webservice` By passing this switch, the Inference Server will be available as a web service. The WSDL for the service can be located at

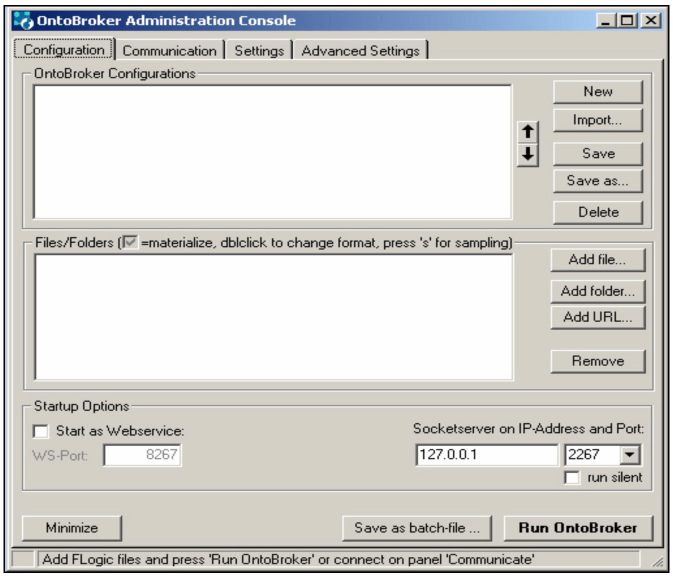
  ```
  http://<host>:<port>/services/ontobroker?wsdl
  ```

  Where host and port are set appropriately. By default, the web service is started at port 8267. For testing purposes you can use the HTTP-client by opening a browser with the following address:

  ```
  http://<host>:<port>/services/
  ```

3.3.1.2 Administration Console

The OntoBroker Administration Console is an easy-to-use graphical user interface to configure and execute the Inference Server as a server and can also be used on the client side for accessing and testing the server.



WS-Port: 8267

127.0.0.1 2267

Add FLogic files and press 'Run OntoBroker' or connect on panel 'Communicate'

Figure 9: The configuration tab of the administration console.

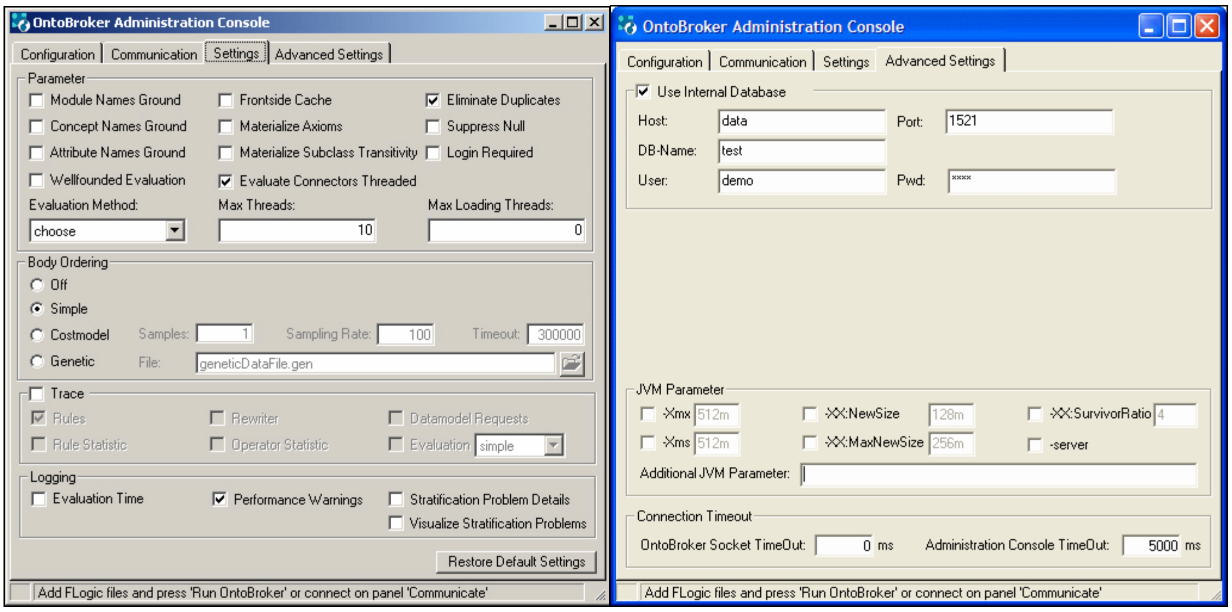
In the *configuration tab* you can add files or folders containing ontologies that represent the knowledge base. These files must contain facts and rules in one of the input formats. A combination of different files or folders can be saved and later imported as a configuration with a short description. By clicking *<Add file...>* (*<Add folder...>*) you can select a file (folder), that the Inference Server should load (when adding a folder all files with the given input format in this folder are loaded). According to the file extensions [FLO, RDF(S), OXML, OWL, n3, nt], the file's input format is determined. The definition of its input format can be changed by double clicking the file/folder-name. By marking the checkbox of a file/folder the Inference Server will materialize the contained facts and rules when executed.

After the configuration is complete, you can choose the port-number (standard port is <2267>) the Inference Server should run on. If there are multiple IP-addresses on your local host, you can specify, which one to take to be available in the network. For this, enter the IP-address into the appropriate field. The Inference Server can also be started as a WebService on the given port, when "Start as WebService" is activated. When "Run silent" is activated there will be no output on the OntoBroker console. To start the OntoBroker inference serve just click "Run OntoBroker".

Your configurations can be saved by clicking "Save" or "Save as...". You can add new configurations or delete existing ones by clicking on the appropriate buttons. To create a batch-file OntoBroker can be started with, click the button "Save as batch-file …".

After starting OntoBroker a command line box will show up. After all files are successfully loaded, the OntoBroker Administration Tool shows the message "Connected to ..." and a green check mark in its status bar. The Administration Console checks OntoBroker after 5 seconds if it has start-up.

In the *Settings and Advanced Settings tab* several advanced options for OntoBroker can be set. This includes various possibilities to tweak the internal knowledge representation, to enable/disable logging and tracing or to change Java options. Additionally, an internal database can be chosen, if available. Furthermore, timeouts for the OntoBroker socket communication and for the Administration Console trying to connect to OntoBroker on start-up can be set.



Parameter
- Module Names Ground ☐
- Concept Names Ground ☐
- Attribute Names Ground ☐
- Wellfounded Evaluation ☐
- Frontside Cache ☐
- Materialize Axioms ☐
- Materialize Subclass Transitivity ☐
- Evaluate Connectors Threaded ✓
- Eliminate Duplicates ✓
- Suppress Null ☐
- Login Required ☐
- Evaluation Method: choose
- Max Threads: 10
- Max Loading Threads: 0

Body Ordering
- Off
- Simple ●
- Costmodel — Samples: 1 — Sampling Rate: 100 — Timeout: 300000
- Genetic — File: geneticDataFile.gen

Trace ☐
- Rules ✓
- Rule Statistic ☐
- Rewriter ☐
- Operator Statistic ☐
- Datamodel Requests ☐
- Evaluation ☐ simple

Logging
- Evaluation Time ☐
- Performance Warnings ✓
- Stratification Problem Details ☐
- Visualize Stratification Problems ☐

Add FLogic files and press 'Run OntoBroker' or connect on panel 'Communicate'

Use Internal Database ✓
- Host: data
- Port: 1521
- DB-Name: test
- User: demo
- Pwd: ****

JVM Parameter
- -Xmx ☐ 512m
- -Xms ☐ 512m
- -XX:NewSize ☐ 128m
- -XX:MaxNewSize ☐ 256m
- -XX:SurvivorRatio ☐ 4
- -server ☐
- Additional JVM Parameter:

Connection Timeout
- OntoBroker Socket TimeOut: 0 ms
- Administration Console TimeOut: 5000 ms

Add FLogic files and press 'Run OntoBroker' or connect on panel 'Communicate'

Figure 10: The Setting tabs of the Administration console

3.3.1.3 Inference Server Commands

In this section we present the most frequently used commands for communicating with the Inference Server. For a complete list of available server commands, confer Section 10 of [Ontoprise 2007a].

`add`	Adds a fact to the knowledge base
	Syntax: `add <F-Logic fact> e.g.: add mike:man@module1.`
	Return values: `fact(s) added`
	Side effects: Causes the cache to be cleared.
`Busy`	Returns the server status.
	Syntax: `Busy`
	Return values: `yes, no`
	Side effects: None
`commands`	Returns a list of all available commands in the server
	Syntax: `Commands`
	Return values: *a list of all available commands in the server*
	Side effects: None
`del`	Deletes a fact from the knowledge base

	Syntax: `del <F-Logic fact> e.g.: del mike:man@module2.`
	Return values: `fact(s) deleted`
	Side effects: Causes the cache to be cleared.
`Isalive`	Checks whether the server is up and running
	Syntax: `Isalive`
	Return values: `inference server on port 1234 is up an running…`
	Side effects: None
`kill`	Kills the server
	Syntax: `Kill`
	Return values: `inference server killing…`
	Side effects: None
`query`	Sends a F-Logic query to the server and receives the answers
	Syntax: `query [<temporary facts>] <flogic query>` e.g.: `query “FORALL X,Y <- X:Y.”`
	Return values:
	Side effects: None
`shutdown`	Shutdown without argument causes the OntoBroker to process all outstanding queries and commands, but no new queries and commands are accepted anymore. The variant “shutdown NOW” causes the OntoBroker to drop all waiting queries and commands and to stop all running queries and commands immediately in a controlled way. See also the kill command.
	Syntax: `shutdown [NOW]`
	Return values: `inference server shutting down ...`
	Side effects: None

3.3.1.4 Client-Side Access

For accessing the inference server from a client application two script files are available. A query is sent to the server using the command line client:

```
query [-h <hostname>] [-p <port>] [-l <user>:<pwd>] <query>
```

For sending commands to the inference server the command line client can be executed using the following script:

```
command [-h <hostname>] [-p <port>] [-l <user>:<pwd>] <command>
```

The optional arguments `<hostname>` and `<port>` specify the location of the server on the remote machine. If no `<hostname>` is given the `localhost` will be used. If no port number is given the standard port 2267 will be used. When login credentials are required they ca be provided in the optional arguments `<user>` and `<pwd>`.

3.3.1.5 Client-Side Java API

From within Java, the access to an existing Inference Server is very similar to the console-based access described in the section above. The relevant classes are

```
com.ontoprise.app.AbstractClient
com.ontoprise.app.EmbeddedCommandClient
com.ontoprise.app.EmbeddedQueryClient
```

The `AbstractClient` provides generic functionality inherited by its subclasses, the `EmbeddedCommandClient` and the `EmbeddedQueryClient`. The constructors of the Clients take the IP-address and the port-number of the Inference Server as arguments. Once the connection is established, commands can be sent via `EmbeddedCommandClient.sendCommand()` and queries can be sent via `EmbeddedQueryClient.sendQuery()` or `queryAllInOne()`.

`sendCommand` takes the same arguments as the console command (cf. Section 3.3.1.3 "Inference Server Commands") and synchronously returns the Inference Server's response.

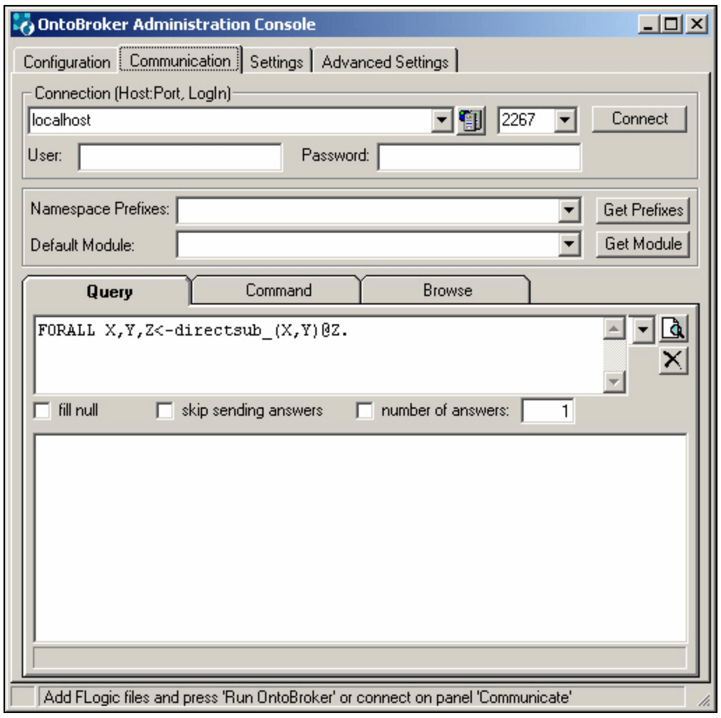
`queryAllInOne` takes an Flogic query and synchronously returns a two dimensional String array with bound variables as result of the query.

The `sendQuery` method asynchronously sends a query to the server and immediately returns. Via the methods `getRowCount` and `getRow` the tuples can be incrementally received from the Inference Server.

If necessary, both client classes can pass credentials to the Inference Server via the `login()` method.

3.3.1.6 Client Functionality of the Administration Console

In addition to the configuration and execution of OntoBroker via the Administration Console it can also be used to access a remote server acting as a client. In the *Communication tab* you can specify the remote machine which hosts the inference server by providing server (host) and the port. When authorization is required the user and password can be given in the corresponding fields. When clicking the "Connect" button the connection will be established. If the Administration Tool was able to connect to the inference server an appropriate message appears in the status bar.



localhost 2267

```
FORALL X,Y,Z<-directsub_(X,Y)@Z.
```

number of answers: 1

Add FLogic files and press 'Run OntoBroker' or connect on panel 'Communicate'

Figure 11: The client-side aspects of the administration console

In the *Query* section of the administration console you can enter arbitrary F-Logic-queries (cf. [Ontoprise 2007b]) to be sent to the Inference Server. The magnifier icon sends the query and initiates the reasoning process. The results for queries will be displayed in the bottom part of the window. In order to provide additional facts that should be used during reasoning, they can be entered together with the query in the query field. Each fact must be terminated with a new-line character (see escaping below). These facts will be added temporarily to the KB for the time of the reasoning about the given query.

Choosing the »Default Namespace« and the »Default Module« - entry and changing the query will affect the result view. By activating the options »fill null«, »skip sending answer« and »number of answer« the processing behaviour of the query can be influenced.

In a similar manner as for sending queries to the Inference Server, commands can be issued. In the »*Command*« tab you can send commands and receive the server's responses. The set of available commands is briefly discussed in one of the following sections.

Sometimes it is necessary to send special characters to the server. In order to send them appropriately they must be quoted according to the following table.

`\n`	`Line break after temporary facts.`
`\“`	`Marks quotes to be quoted inside of queries or commands.`
`\\`	`Marks a backslash inside of queries and commands.`

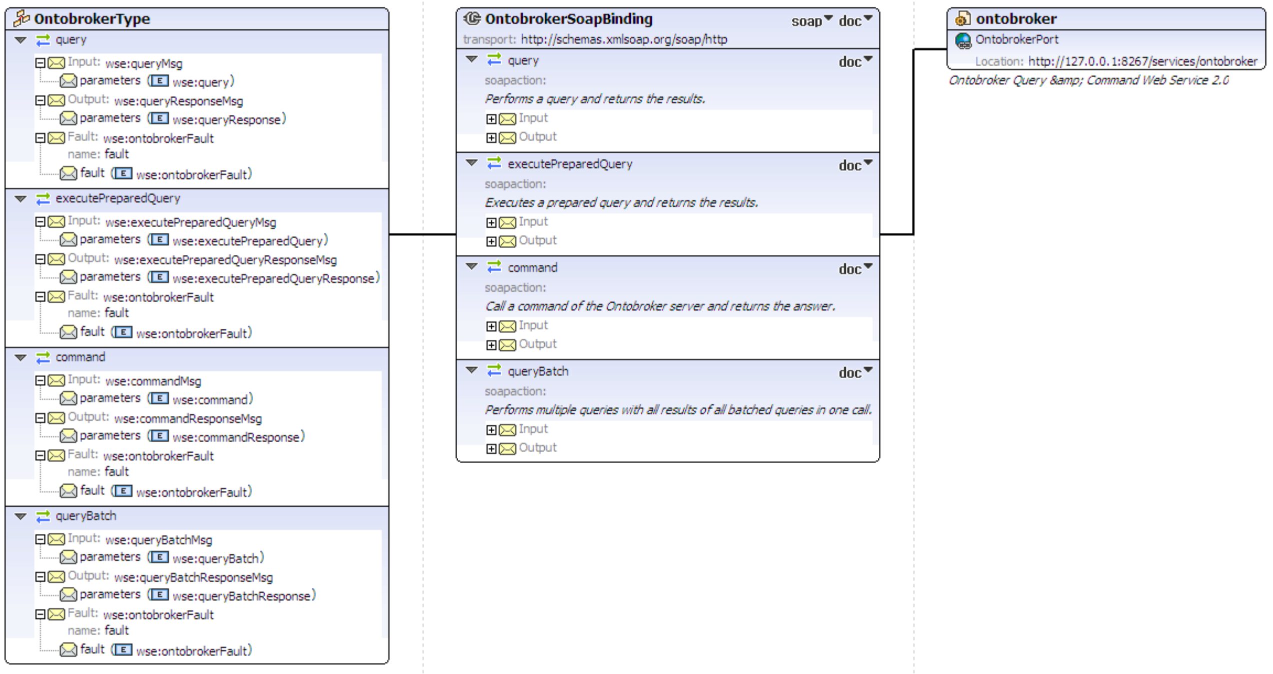
In the *Browse* tab you can visualize the ontology hosted in the Inference Server. After clicking “Load Ontology” the taxonomy of the server's KB is loaded and can be navigated in a convenient way.

3.3.1.7 Web Service Interface for the Reasoner

The Inference Server web service provides four operations:

1. “command” – use this operation to send commands to the Inference Server

2. "transaction" – use this operation to add(s and remove multiple facts in a single message
3. "query" – use this operation to send Flogic queries
4. "queryBatch" – special operation to send multiple queries in a single message



```
OntobrokerType
  query
    Input: wse:queryMsg
      parameters (E wse:query)
    Output: wse:queryResponseMsg
      parameters (E wse:queryResponse)
    Fault: wse:ontobrokerFault
      name: fault
      fault (E wse:ontobrokerFault)
  executePreparedQuery
    Input: wse:executePreparedQueryMsg
      parameters (E wse:executePreparedQuery)
    Output: wse:executePreparedQueryResponseMsg
      parameters (E wse:executePreparedQueryResponse)
    Fault: wse:ontobrokerFault
      name: fault
      fault (E wse:ontobrokerFault)
  command
    Input: wse:commandMsg
      parameters (E wse:command)
    Output: wse:commandResponseMsg
      parameters (E wse:commandResponse)
    Fault: wse:ontobrokerFault
      name: fault
      fault (E wse:ontobrokerFault)
  queryBatch
    Input: wse:queryBatchMsg
      parameters (E wse:queryBatch)
    Output: wse:queryBatchResponseMsg
      parameters (E wse:queryBatchResponse)
    Fault: wse:ontobrokerFault
      name: fault
      fault (E wse:ontobrokerFault)

OntobrokerSoapBinding                                  soap doc
transport: http://schemas.xmlsoap.org/soap/http
  query                                                     doc
    soapaction:
    Performs a query and returns the results.
    Input
    Output
  executePreparedQuery                                      doc
    soapaction:
    Executes a prepared query and returns the results.
    Input
    Output
  command                                                   doc
    soapaction:
    Call a command of the Ontobroker server and returns the answer.
    Input
    Output
  queryBatch                                                doc
    soapaction:
    Performs multiple queries with all results of all batched queries in one call.
    Input
    Output

ontobroker
  OntobrokerPort
    Location: http://127.0.0.1:8267/services/ontobroker
Ontobroker Query &amp; Command Web Service 2.0
```

Figure 12: Visualization of WSDL for operations and SOAP bindings of the Inference Server

Please see Figure 8 for an overview of the structure of the Inference Server web server description (the WSDL document), esp. for the specifications of the operations. For retrieving the actual WSDL description of the Inference Server open a web browser using this URL with appropriate IP and port numbers:

```
http://<host>:<port>/services/ontobroker?wsdl
```

For the query operations the web service returns a result set following a dynamic XML schema within the `queryResponse` element. For bound variables in each result tuple its value is returned in an XML tag with the same name as the variable. For example the Flogic query

```
FORALL X,Y <- (X is 1.0 or X is 2.0) and Y is "Hi".
```

The web service returns the following XML:

```
<queryResponse>
  <queryKey>238</queryKey>
  <result><X>1.0</X><Y>"Hi"</Y></result>
  <result><X>2.0</X><Y>"Hi"</Y></result>
</queryResponse>
```

3.3.2 Extensibility of the Reasoner

The Flogic reasoner OntoBroker can be extended by everybody to support features that are not easy to implement using pure logic, or which are too costly during query answering time. This includes e.g. mathematical operations to do calculations with the atomic datatype number, operations on character strings, conversions between different datatypes, handling of calendar dates, or connecting to external data sources such as databases, full-text indexes, or search-engines (or even other Inference Server instances).

OntoBroker provides a built-in mechanism to introduce procedural attachments into the logic reasoning process. Since Flogic implements a subset of First-Order Logic and its complete knowledge representation is based on predicates and (Horn) formulas, procedural attachments also come in the form of predicates. Each built-in has a name and takes a fixed number of arguments.

In order to implement your own built-in you simply create a Java class that extends the abstract class `com.ontoprise.operators.SimpleBuiltin`. As an example we specify the `concat/3` built-in that can concatenate two character strings to create a new one. In the built-in's constructor we simply define the name and the arity of the built-in/predicate:

```
this.predicate = “concat”;

this.arity = 3;
```

Since this built-in should only be available for concatenating strings, and not, e.g. numbers we can restrict its signature, i.e. the admissible types of values for its arguments:

```
possibleSignatures = new int[][] {

      {STRING, STRING, VARIABLE},

      {STRING, VARIABLE, STRING},

      {VARIABLE, STRING, STRING},

      {STRING, STRING, STRING}};
```

This statement says that all argument patterns are admissible that have at least two strings and the third argument is either a string or a variable. Even built-ins should follow the declarative tradition of logic programs by allowing all possible flows of information, i.e. they should, if possible, not assume certain input or output arguments. In our example this means, that a variable at the first argument position is ok, as long as the second and third arguments are ground strings. The implementation has to make sure that all specified signatures are correctly handled.

The OntoBroker built-in mechanism provides a number of available types that can be used to specify the signatures:

• `ANY`	e.g. `X,f(X),bar,”foo”,-3.1`
• `GROUND`	e.g. `bar,”foo”,-3.1, f(2)`
• `NUMBER`	e.g. `0, -3.1`
• `STRING`	e.g. `“foo”`
• `CONSTANT`	e.g. `bar, “foo”, -3.1`
• `FUNCTION`	e.g. `f(X,Y)`
• `VARIABLE`	e.g. `X, Y`
• `GROUNDFUNCTION`	e.g. `f(1,3),”http://x”#bar`
• `LIST`	e.g. `[bar, “foo”, 3]`

Optionally, each built-in can specify some documentation about its implemented functionality and about the semantics of its arguments:

```
this.description = “concatenate two strings”;

this.parameters = “first string, second string, concatenation result”;
```

The actual implementation of the built-in's functionality must be provided by overwriting the `receive()` method. This method gets an `Ituple` as argument that represent the (three) arguments of the built-in. Within the `receive()` method this `Ituple` object must be interpreted and the missing value (the variable position in the tuple) must be computed. Once all values are known the built-in must call the `send()` method passing a new `Ituple` object containing all values. It is important that this tuple object must be ground, i.e. must not contain variables and it must match with the input tuple, i.e. the two tuples must formally be unifyable. Often it is possible to reuse the input tuple and only replace some of its members with the computed values. Also one input tuple can result in multiple output tuples, e.g. a square root built-in `sqrt/2` could return the positive and the negative square root. This is achieved by calling the `send()` method multiple times, with different tuple objects.

Besides the simple built-ins presented above there are two other kinds of built-ins:

- *Connector* built-ins enable to access external data sources such as databases. They subclass the abstract Java class `com.ontoprise.operators.Connector` and instead of implementing `receive()` they implement the `eval()` method and send a list of `Ituple` objects rather than individual tuples.
- *Aggregator* built-ins are special because they do not process single tuples but are called once for a set of input tuples and can aggregate all these tuples, e.g. by computing a maximum or average value or can create the sum of all input values. Aggregators must subclass the abstract Java class `com.ontoprise.operators.Aggregation`. It is not intended that third-party developers implement aggregation built-ins. Thus we will not give more details about the API, here.

3.3.3 General Reasoner Service Interface

3.3.3.1 Accessing OWL Reasoners via DIG

The DIG-Interface, developed by the DL Implementation Group, is a de facto standard for access to Description Logic Reasoners. It utilizes a simple protocol based on HTTP and XML. A number of reasoners including FaCT++, Pellet, Racer, KAON2 and Jena2 provide support for the DIG-Interface. In the NeOn architecture, we therefore foresee DIG as a standard interface for a loose integration with external reasoners.

DIG 1.1: The current version of the interface is DIG 1.1[18] (which is also the one implemented by most reasoners).

In the current version 1.1 there are still problems such as the datatype support for OWL-DL and compatibility with OWL 1.1.

DIG 2.0: The DIG Working Group is addressing these (and other issues) in the DIG 2.0 proposal. This new version is intended to provide the following features and extensions:

- *Concept language:* The core functionality of DIG 2.0 permits a client to tell the reasoner axioms that make up an OWL 1.1 knowledge and pose semantic queries against that knowledge base.
- *Extensibility*: Different Description Logic reasoners support different Description Logics and different reasoning facilities. To partly support these differences, DIG 2.0 provides an extensibility mechanism.

[18] For the complete specification we refer to http://dig.sourceforge.net/

- *Accessing Told Information*: In many applications (for example debugging a knowledge base created by several clients) it is useful to be able to access the unprocessed information sent to a Description Logic reasoner. To this end, one of the standard DIG 2.0 extensions provides the ability to retrieve the information that has been explicitly given to the reasoner ("told") as axioms. The simplest form of this extension returns axioms that explicitly mention at top level a named class, property, or individual.
- *Retracting Information*: The core DIG 2.0 functionality builds up a knowledge base monotonically. The only facility for removing information involves starting over from an empty knowledge base. A DIG 2.0 extension provides a simple method for retracting information from a knowledge base. In this retraction extension, only top-level axioms that had been previously added to the knowledge base can be retracted. The axioms are identified either via identification tags associated with axioms when they were added to the knowledge base or by tags associated with retrieved told information.
- *Non Standard Inferences*: Non-standard Inferences are increasingly recognised as a useful means to realise applications. For example, Least Common Subsumer (LCS) provides a concept description that subsumes all input concepts and is the least specific (w.r.t. subsumption) to do so. A DIG 2.0 extension provides a proposal for an extension supporting NSIs.
- *Abox query language*: In many practical application systems based on DLs, a powerful Abox query language is one of the main requirements, which will be addressed by DIG 2.0

For all of the above features, the DIG Working Group has developed a set of proposals[19].

3.3.3.2 Current Support for DIG in the NeOn platform

In the current version of the NeOn Toolkit 1.1, we provide an implementation of DIG 1.1 within the KAON2 reasoner. This implementation allows using KAON2 as a DIG server.

In the following, we describe how to interact with KAON2 in the DIG server mode.

The first thing one needs to do is to start the server. The main class of the server is org.semanticweb.kaon2.server.ServerMain. The class can take the following parameters relevant for the DIG mode:

-h	prints the help message
-dig	starts the DIG connector of KAON2
-digport <n>	specifies the port of the DIG connector
-ontologies <directory>	the directory containing the ontologies

Initially the server does not contain any ontologies. Clients use ontology URIs to request ontologies to be open. When such a request arrives to the server, the registry must somehow translate the ontology URI into a physical URI to be able to open the actual ontology file. The server does this through a special ontology resolver. It is possible programmatically to register a custom ontology resolver.

Then, it is possible to specify the directory (using the –ontologies parameter) which contains registered ontologies. Similarly, new ontologies are placed into this directory. To register or unregister ontologies, simply drop them into the directory.

It is possible to start the server through the command line, e.g. as follows:

[19] available at http://dig.cs.manchester.ac.uk/overview.html

```
java org.semanticweb.kaon2.server.ServerMain –ontologies server_root –dig
–digport 8088
```

3.3.3.3 Implementation plan for future DIG support

As next steps, we will provide implementations for:

GUI-side plugin: As the current implementation only supports DIG on the server side, as a next step we will provide a GUI-side plugin to to interact with DIG reasoners and to visualize results (in particular the classification hierarchy) obtained from the reasoner

Support for DIG 2.0: We will extend the existing implementation to cover the new features provided by DIG 2.0.

A web service interface for DIG 2.0: While the DIG working group has outlined the usefulness of providing web service interfaces for DIG, the current plans for DIG 2.0 only foresee a transport of DIG requests directly via HTTP. To better align DIG with the service-oriented architecture of NeOn, we will provide an interface and implementation compatible with Web Service standards.

3.3.4 Registry Service

The NeOn Ontology registry service is based on the OMV ontology meta model. This is used to specialize the general purpose ebXML registry service to an ontology registry web service. This service has been realized with the research oriented Oyster registry server as well as with the general purpose commercial SOA registry repository CentraSite [WaterfeldPalma2007].

3.3.5 Repository Service

The NeOn repository service is an extension of the registry service. All life cycle operations of the service (create, update, delete, deprecate, undeprecate) contain in addition to the optional ontology registry objects the corresponding NeOn ontologies. Thus NeOn ontologies can be stored and queried from the repository. With the same operation it is possible to maintain the registry information [WaterfeldPalma2007].

4 Conclusion

This second version of the NeOn architecture and API explored two quite different directions.

On one hand it details in many aspects the direction of the first version by describing the ontology engineering-oriented infrastructure of the NeOn toolkit. In this respect it continues to utilize the rich functionality of the Eclipse platform and applies it to ontology engineering. A major driving force for this has been the first experiences from the different case studies and other users of the NeOn toolkit.

On the other hand it drastically widens the scope of the NeOn architecture by introducing the technology for the usage of ontology in semantic applications at runtime. The strong separation between engineering and runtime of traditional applications is blurred to some extent for semantic applications, because ontologies can be directly evaluated by a reasoner. Nevertheless there is still a distinction needed for most semantic applications due to completely different application and load characteristics. We explore several approaches focussing on the usage of web services as the runtime infrastructure and on utilizing Eclipse-based technology to develop GUI components for web applications.

The increased usage of the NeOn toolkit also required to have more open interfaces to include other semantic technology. A prominent example is reasoners. Based on the dual language approach the NeOn toolkit will be able incorporate both type of reasoners via defined web service interfaces as an evolution of the DIG interface.

Based on further experiences with the NeOn toolkit in the case studies and from other users we expect the need for additional open interfaces for important components. Together with further planned enhancements of the runtime components these will be described in a final deliverable of the NeOn architecture and API. Opposite to this description this will be a complete and self contained description.

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6 Acronyms

FSDAS	Fisheries Stock Depletion Assessment System Ontology based system of FAO in the fishing domain
DIG	Description Logic Implementation Group Known for the Description Logic Reasoner Server Interface
EMF	Eclipse Modeling Framework Utilizing the OMG MOF modelling framework to develop Eclipse applications
GEF	Graphical Editing Framework Eclipse infrastructure to develop editors together with EMF based modelling
GMF	Graphical Modeling Framework Integration of GMF and EMF
J2EE	Java 2 Enterprise Edition. One of 3 Java platforms. J2EE contains the most advanced features needed for commercial applications
OSGI	Open Service Gateway Initiative Definition of a light-weight component model, used in Eclipse
POJO	Plain old Java objects Java objects realized as conventional Java classes
RAP	Rich Ajax Platform Eclipse platform to develop Ajax based applications with compatibility to RCP
RCP	Rich Client Platform Utilizing the Eclipse development platform to offer Java runtime applications
WSDL	Web Service Description Language. Major W3C web service standard for describing a web service
WTP	Web Tools Platform Very broad platform of Eclipse for the development of web applications