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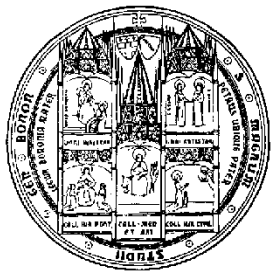

Intelligent Information Integration: The MOMIS Project

Integrazione Intelligente Di Informazioni: Il Progetto MOMIS

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Foreword

This document describes the work done during my Ph.D studies in Computer Engineering. It is organized in two parts.

The *first and main part* describes the reseach project **MOMIS** for the *Intelligent Integration* of heterogeneous information. It outlines the theory for Intelligent Integration and the design and implementation of the prototype that implements the theoretical techniques.

During my Ph.D. studies I stayed at the Northeastern University in Boston, Mass. (USA). Subject of the *second part* of this document is the work I did with Professor Ken Baclawski in *information retrieval* on *annotation* of documents using ontologies, and *retrieval* of the annotated documents.

Contents

Chapter 1

Part I - Intelligent Integration

Developing intelligent tools for the integration of information extracted from multiple heterogeneous sources is a challenging issue to effectively exploit the numerous sources available on-line, for example, in global, Internet-based information systems.

The problem we consider is the identification of semantically related information, that is, information describing the same real-world concepts in different sources having semantic heterogeneity. In fact, information sources to be integrated are usually pre-existing and have been developed independently. Consequently, semantic heterogeneity can arise for the aspects related to terminology, structure, and context of the information, and has to be properly dealt with during integration in order to effectively and correctly exploit the information available at the sources. Integration and reconciliation of data coming from heterogeneous sources is a research topic in databases [Hul97]. Several contributions have appeared in literature, including methods, techniques and tools for integrating and querying heterogeneous databases [CHS+94, GKD97, LRO96, PGMW95].

This document describes solutions to the integration issue developed in the *MOMIS* (Mediator envirOnment for Multiple Information Sources) [BCV99, BCVB00, BBC+00] project[1][2].

The goal of information extraction and integration techniques developed in **MOMIS** is to construct synthesized, integrated descriptions (i.e., *a global virtual view*) of the information coming from multiple heterogeneous sources, to provide the user with a uniform query interface against the sources independent from their location and the level of heterogeneity of their data. Moreover, to meet the requirements of global, Internet-based information systems with a possibly high number of sources to be integrated, it is important to develop tool-assisted techniques in oreder to automate as much as possible information extraction and integration activities. This goal has been achieved with the **MOMIS** project by developing the SI-Designer [BBC+00].

Like other integration projects [AKH96, CHS+94, LRO96], **MOMIS** follows a "semantic approach" to information integration based on the conceptual schemas of the information sources, and on a mediator component. **MOMIS** implements a I^3 [Age]

[1] **MOMIS** is a joint project among the Università di Modena e Reggio Emilia, the Università di Milano, and the Università di Brescia started within the Italian research project INTERDATA, theme n.3 "Integration of Information over the Web", coordinated by V. De Antonellis, Università di Brescia.

[2] **MOMIS** will also financed by the MURST in 2000/2001 within the *D2I: Integration, Warehousing, and Mining of Heterogeneous Data Sources* project

architecture for integration and query optimization, the mediator component relies on several tools, namely ARTEMIS [CA99b], developed by University of Milano and University of Brescia, and ODB-Tools [BBSV97a], developed by University of Modena e Reggio Emilia and WordNet [GGV96] developed by the Cognitive Science Laboratory at Princeton University.

Most of the information for integration is provided by the *wrappers*, using ODL_{I^3} from the source description and stored in ODL_{I^3} data structure. By exploiting the WordNet lexical system [Mil95] and the OLCD Description Logic inference capabilities a Common Thesaurus is built. The Common Thesaurus is composed of relationships between schema elements extracted from the schemata descriptions, derived from the lexical relationships between the concepts in WordNet, and explicitly stated by the integration designer. Based on the relationships in the Common Thesaurus, affinity coefficients are computed. These coefficients give a measure of the level of matching between the elements of the different sources. **MOMIS** computes a set of candidates *Global Classes* by applying affinity-based clustering on the affinity coefficients. For each *Global Class Mapping rules* are defined that describe which *local classes* belong to the global class and how local attributes are mapped into the global attributes. Moreover, *extensional relationships* and *join maps* are defined to provide a solution to the *object fusion* problem. Such information are used by the Query Manager during the merge process of the local queries result.

The *MOMIS project* also faces the problems and challenges related to the integration of semistructured data sources. In this case, there is no strong distinction between meta information and data, but meta-information is stored directly in the data. The significant growth of semi-structured data sources (e.g., Web documents) calls for the development of methods, techniques, and languages for this type of data [Bun97, BDHS96, CGL98]. Thus, the typical problems of integration should be addressed in the light of these new requirements.

Part of the project is the development of a prototype which is the software application based on the **MOMIS** theory. The prototype is written in Java, is based on the CORBA architecture and supports most of the **MOMIS** features like the Description Logics capabilities, the ARTEMIS affinity computation and clustering and the interaction with WordNet.

Base terminology

In this document we argue about concepts like sources, classes, interface, which are briefly introduced, here.

A *Local Source* is a source of data, such as a *database* or a text file. Each local source is interfaced to **MOMIS** through a *wrapper*. A *Local Class* is an *interface* (or *class*) present in a *local source*. A *Local Attribute* is an attribute of a *local class*. The *Integration Designer* is a person that faces the integration problem using the **MOMIS** system. The *Global View* is a source schema presented by the *mediator* after the integration process that allows to access in a uniform way to the data in the local sources. A *Global Class* is an interface (or *class*) that is part of *the*[3] *Global View*. A *Global Attribute* is an attribute of a *global class*.

[3] Since we integrate one schema at time during an integration session we will reference a single global views. Obviously it is possible to have several global view on the same or different local classes generated by several integration sessions built with different targets.

How this part is organized

This part of the document is organized as follows.

Chapter 2 describes the theory on which the ***MOMIS*** *project* is based. The integration approach is discussed from a theoretical point of view.

Chapter 3 discusses the software architecture of *the* ***MOMIS*** *prototype*. All its modules (except the SI-Designer) are outlined.

Chapter 4 gives a discussion of the main Graphical User Interface of *the* ***MOMIS*** *prototype* called SI-Designer. Such interface leads the integration designer through the integration phases from local sources to the integrated schema.

Chapter 5, we give our concluding remarks and an overview of future work about the **MOMIS** project.

Note

This document should also be a reference for the software I wrote. The description of some (I assume important) annoying technical details is targeted to people that will manage the software written during my studies.

Chapter 2

MOMIS: The Theory

This chapter discusses theoretical aspects of the **MOMIS** project. **MOMIS** is an *Heterogeneous Source Integration* project. The goal of the project is to study the problems related to integration and build a prototype that acts as a I^3 Semantic Integration and Transformation Service (see [Age, HK95] for a description of the I^3 architecture).

In **MOMIS**, theoretical solutions for several problems of integration are proposed. Most of the solutions discussed in this chapter have been implemented in the *MOMIS prototype*; others, like the semistructured meta-information extraction, have not.

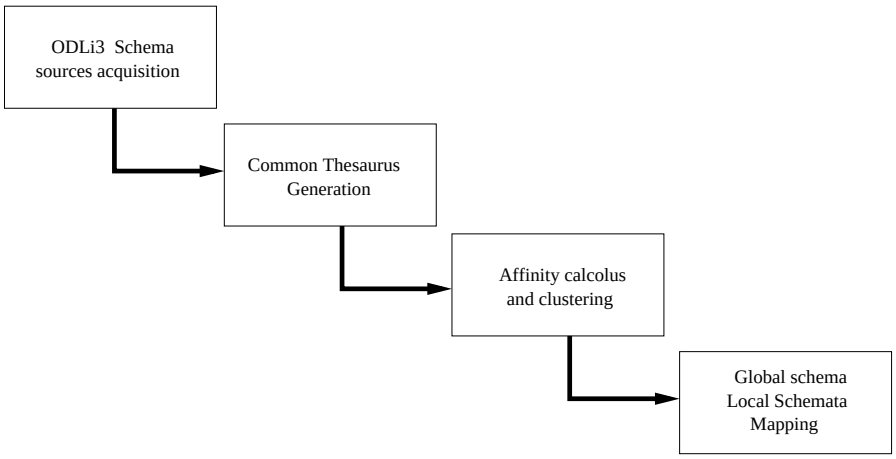

Figure 2.1: Integration phases in **MOMIS**

In **MOMIS** we divide the integration in the phases (showed in Figure 2.1): (1) description of a generic data source in ODL$_{I^3}$, (2) generation of the common thesarus, repository of integration knowledge, (3) computation of affinity between schema elements (local classes and local attributes) and generation of global classes as clusters of local classes, and (4) description of the local classes in terms of mapping of the global attributes on the corresponding local attributes.

This chapter is organized as follows:

In section 2.1, we describe the tools we use to automatically retrieve as much *semantics* as possible during the integration process. In particular we introduce the ODL$_{I^3}$

language, the OLCD Description Logic, and WordNet. In section 2.2, we describe how such tools are used to feed the integration knowledge base called *Common Thesaurus*. In section 2.3, we describe the integration techniques for building the mediator virtual global schema of considered sources using the knowledge in the *Common Thesaurus*. Sections 2.4 and 2.5 respectively present, techniques for optimizing query execution based on *Base Extension* and *Extensional Hierarchy*, and the way we faced the *Object Fusion* problem. Section 2.6, we make comparisons with related works. Finally, in section 2.7, the Interpretation and semantic of the OLCD language is briefly described.

2.1 Information extraction with ODL$_{I^3}$

An important goal of information extraction is the construction of a semantically rich representation of the information sources to be integrated by means of a common data model. In semantic approaches to integration, this task is performed by defining a model, ODL$_{I^3}$ in **MOMIS** and by wrapper tools developed for each kind of data source type, which translate the conceptual schema of the given sources into the common model. For conventional structured information sources (e.g., relational databases, object-oriented databases), schema descriptions are always available and can be directly translated into the selected common data model.

For example, for relational databases *transformation rule-sets*, as described in [FV95] for relational to ODMG schema conversion can be used. To show wrappers functionalities, let us introduce a running example, including a relational source and a semistructured source.

2.1.1 The running example

```
Restaurant(r_code, name, street, zip_code, pers_id,
           special_dish, category, tourist_menu_price)
Bistro(r_code, type, pers_id)
Person(pers_id, first_name, last_name, qualification)
Brasserie(b_code, name, address)
```

Figure 2.2: Food Guide Database (FD)

We consider two sources in the Restaurant Guide domain, storing information about restaurants. The `Eating Source` guidebook (ED) is semistructured and contains information about fast foods of the West coast, their menus, quality, and so on. A portion of this source is shown in Figure 2.3. The `Food Guide` Database (FD) is a relational database containing information about USA restaurants from a wide variety of publications (e.g., newspaper reviews, regional guidebooks). The schema of this source is composed of four relations (see figure 2.2), namely, `Restaurant`, `Bistro`, `Person`, and `Brasserie`. Information related to restaurants is maintained in the `Restaurant` relation. `Bistro` instances are a subset of `Restaurant` instances and give information about the small informal restaurants that serve wine. Each `Restaurant` and `Bistro` is managed by a `Person`. Information about places where drinks and snacks are served are stored in the `Brasserie` relation.

2.1.2 Managing semistructured data

In this subsection we discuss how semi-structured data (e.g., Web data sources) can be handled in the MOMIS system where schema descriptions generally are not directly available. In fact, a basic characteristic of semistructured data is that they are "self-describing". This means that the information generally associated with the schema is specified directly within data [Bun97].

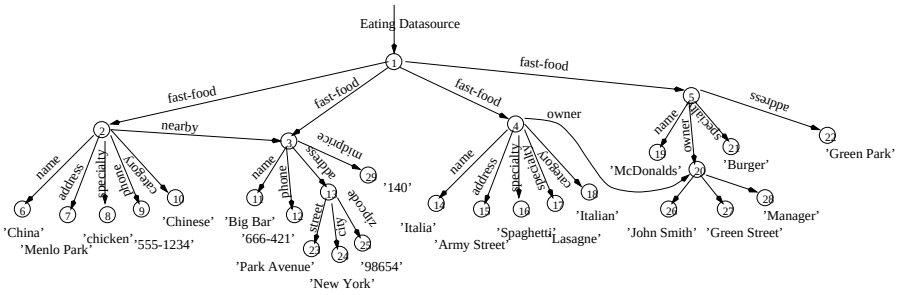

Figure 2.3: Semistructured source *Eating* (ED)

One of the goals of information extraction for integration when semistructured information sources are involved is to derive and explicitly represent the schema of the source as well. For this purpose, we proceed as follows. According to the models proposed in literature for semistructured information sources [Bun97, PGMW95], a semistructured source is represented as a rooted, labeled graph where nodes contain data (e.g., an image or free-form text) and labeled edges describe the concept represented by data in the corresponding node.

Figure 2.3 shows an example of a graph-based representation of a semistructured source, called `Eating Source`, containing information related to local fast food. In the graph model, a semistructured object (object, for short) can be viewed as a triple of the form $\langle$`id`, `label`, `value`$\rangle$, where `id` is the object identifier, `label` is a string describing what the object represents, and `value` is the value, which can be atomic or complex. The atomic value can be integer, real, string, image, while the complex value is a set of pairs (*id*,*label*), where *id* is an object identifier.

A complex object can be thought as the parent of all the objects that form its value (children objects). A given object can have one or more parents. We denote the fact that an object so' is a child object of another object so by $so \rightarrow so'$ and use notation $label(so)$ to denote the label of so. With reference to the source in Figure 2.3, there is one complex root object with four complex children objects that represent fast-foods.

Each `Fast_Food` object has an atomic object `name`, `category` and `specialty`. Furthermore, some `Fast_Food` objects have an atomic `address` while some others a complex object `address`, an atomic `phone`, a complex object `nearby` (that specifies the nearest fast-food), and a complex object `owner`, specifying the `name`, the `address` and the `job` of the fast-food's owner.

To extract *schema* information from a semistructured source S, we introduce the notion of *object pattern*. In semistructured data models, labels are descriptive as much as possible. Furthermore, the same label is generally assigned to all objects describing the same concept in S. All objects so of S are partitioned into disjoint sets, denoted set_l, such that all objects belonging to the same set have the same label l. An object

pattern is then extracted from each set to represent all the objects in the set. Formally, an object pattern is defined as follows:

Definition 2.1.1 (Object pattern) *Let set_l be a set of objects in a semistructured source S having the same label l. The* object pattern *of set_l is a pair of the form $\langle l,A \rangle$, where l is the label of the objects belonging to set_l, and $A = \bigcup label(so')$ such that there exists at least one object $so \in set_l$ with $so \rightarrow so'$.*

From this definition, an object pattern is representative of all different objects that describe the same concept in S. In particular, label l of an object pattern denotes the concept and set A of an object pattern denotes the properties (or attributes) characterising the concept in the source. Since semistructured objects can be heterogeneous, labels in A correspond to child object that can be defined only for some of the objects in set_l, but not for all. We call such kind of labels "optional" and denote them with symbol "?".

```
Fast_Food-pattern = (Fast_Food, {name,address, midprice?
                     phone?, specialty, category,
                     nearby?, owner?})
Owner-pattern     = (Owner, {name, address, job})
Address-pattern   = (Address, { street, city, zipcode})
```

Figure 2.4: Object patterns for the ED source

With respect to the ED source of Figure 2.3, three object patterns are extracted (see Figure 2.4): Fast_Food, representing objects describing eating places; Owner representing objects describing people involved; Address, representing objects describing addresses. The extraction process produces also the Address pattern to take into account the different structure of the Address objects in the ED source (i.e., in semistructured objects 2, 4, and 5 address is atomic while in object 3 it is complex).

An object pattern description follows an *open world semantics* typical of the Description Logic approach [WS89]. Objects conforming to a pattern share a common minimal structure represented by non optional properties, but can have additional (i.e., optional) properties. In this way, objects in a semistructured data source can evolve and add new properties, but they will be retrieved as valid instances of the corresponding object pattern when processing a query.

2.1.3 The ODL$_{I^3}$ language

For a semantically rich representation of source schemas and object patterns associated with information sources to be integrated, we introduce an object-oriented description language, called ODL$_{I^3}$. According to recommendations of ODMG and to the diffusion of I^3POB [Age, ed.97], the object data model ODL$_{I^3}$ is very close to the ODL language. ODL$_{I^3}$ is a source independent language used for information extraction to describe heterogeneous schemas of structured and semistructured data sources in a common way. Refer to appendix A for the complete syntax of the ODL$_{I^3}$.

ODL$_{I^3}$ introduces the following main extensions with respect to ODL:

Union constructor. The union constructor, denoted by `union`, is introduced to express alternative data structures in the definition of an ODL$_{I^3}$ class, thus capturing requirements of semistructured data. An example of its use will be shown in the following.

Optional constructor. The optional constructor, denoted by the question mark "?", is introduced for class attributes to specify that an attribute is optional for an instance (i.e., it could be not specified in the instance). This constructor too has been introduced to capture requirements of semistructured data. An example of its use will be shown in the following.

Integrity constraint rules. This kind of rule is introduced in ODL$_{I^3}$ in order to express, in a declarative way, *if then* integrity constraint rules at both intra and inter-source level.

Intensional relationships. These are *terminological relationships* expressing inter/intra-schema knowledge for the source schemas. Intensional relationships are defined between classes and attributes, and are specified by considering class/attribute names, called terms. The following relationships can be specified in ODL$_{I^3}$:

- SYN (Synonym-of), defined between two terms t_i and t_j, with $t_i \neq t_j$, that are considered synonyms in every considered source (i.e., t_i and t_j can be indifferently used in every source to denote a certain concept).
- BT (Broader Terms), or hypernymy, defined between two terms t_i and t_j such as t_i has a broader, more general meaning than t_j. BT relationship is not symmetric. The opposite of BT is NT (Narrower Terms), or hyponymy.
- RT (Related Terms), or positive association, defined between two terms t_i and t_j that are generally used together in the same context in the considered sources.

An intensional relationships is only a terminological relationship, with no implications on the extension/compatibility of the structure (domain) of the two involved classes (attributes).

Extensional relationships. To express knowledge about the source extensions the ODL$_{I^3}$ provides the concept of *extensional* relationships:

- C_1 SYN$_{ext}$ C_2: this means that the instances of C_1 are the same of C_2. A SYN$_{ext}$ relationship implies an intensional SYN relationship.
- C_1 BT$_{ext}$ C_2: this means that the instances of C_1 are a superset of the instances of C_2. A BT$_{ext}$ relationship implies an intensional BT relationship.
- C_1 NT$_{ext}$ C_2: this means that the instances of C_1 are a subset of the instances of C_2. A NT$_{ext}$ relationship implies an intensional NT relationship.
- C_1 DISJ$_{ext}$ C_2: this means that C_1 and C_2 will never share instances - the instances are disjoint.

Note: defining extensional axioms *syn*$_{ext}$, *nt*$_{ext}$ and *bt*$_{ext}$ requires a structural compatibility between the involved classes in **MOMIS**.

Foreign keys. To preserve information between *classes* (tables) proper of the relational schema we support also Foreign keys descriptions. We use *foreign keys* information to feed the common thesaurus and enrich semantic knowledge of the sources.

Mapping Rules. This kind of rule is introduced in ODL$_{I^3}$ in order to express relationships existing between the integrated ODL$_{I^3}$ schema description of the information sources and the ODL$_{I^3}$ schema description of the original sources. These rules will be illustrated in detail in Section 2.3, together with examples of use.

The extraction process has the goal of translating object patterns and source schemas into ODL$_{I^3}$ descriptions. Translation is performed by a wrapper. Moreover, a wrapper can be asked for the source name and type (e.g., relational, semistructured).

The translation into ODL$_{I^3}$, on the basis of the ODL$_{I^3}$ syntax and of the schema definition, is performed by the wrapper as follows:

Given a *relation of a relational source* or a class or a pattern $\langle l, A \rangle$, translation involves the following steps: i) an ODL$_{I^3}$ class name corresponds to the relation name or to l, respectively, and ii) for each relation attribute or label $l' \in A$, an attribute is defined in the corresponding ODL$_{I^3}$ class. Furthermore, attribute domains are extracted. Structure extraction can be performed as proposed in [aSBDFS97, NAM98].

In figures 2.5 and 2.6 we report the ODL$_{I^3}$ representation of the `ED.Fast_Food` object pattern and of the `FD.Restaurant` relation. The complete ODL$_{I^3}$ schemas representation of the `ED` and `FD` sources are shown in figures 2.17 and 2.18.

```
interface Fast_Food
  ( source semistructured ED ) {
    attribute string      name;
    attribute Address     address;
    attribute integer     phone?;
    attribute set<string> specialty;
    attribute string      category;
    attribute Fast_Food   nearby?;
    attribute integer     midprice?;
    attribute Owner       owner?;     };
```

Figure 2.5: ODL$_{I^3}$ representation of a Semistructured Class from object patterns from the `ED` source

```
interface Restaurant ( source relational FD
  key r_code
  foreign_key(pers_id) references Person ) {
    attribute string         r_code;
    attribute string         name;
    attribute string         street;
    attribute string         zip_code;
    attribute integer        pers_id;
    attribute string         special_dish;
    attribute integer        category;
    attribute integer        tourist_menu_price; };
```

Figure 2.6: ODL$_{I^3}$ representation of a Relational table from the `FD` source

To represent object patterns in ODL$_{I^3}$, union and optional constructors are used. In particular, the `union` constructor is used to represent object patterns describing het-

erogeneous objects in the source. An example of use of the `union` constructor in the ODL$_{I^3}$ class representing the `Address` pattern of the `ED` source (see Figure 2.4) is shown in Figure 2.7. The semantics of the `union` constructor and of optional attributes in ODL$_{I^3}$ will be discussed in the section 2.1.4, using the OLCD Description Logics.

```
interface Address
  ( source semistructured Eating_Source ) {
    attribute string city;
    attribute string street;
    attribute string zipcode; };
  union
{  string; };
```

Figure 2.7: An example of `union` constructor in ODL$_{I^3}$

2.1.4 The OLCD Description Logic

ODL$_{I^3}$ descriptions are translated into OLCD (*Object Language with Complements allowing Descriptive cycles*) descriptions in order to perform Description Logics inferences that will be useful for semantic integration.

In this section, we give the syntax of OLCD (the semantics is given in section 2.7); Readers interested in a formal account can refer to [BBLS98].

Types and Schemas We assume a countable set of symbols $\mathbf{A}$ of *attribute names* (denoted by $a, a_1, a_2, \ldots$) and we assume a countable set $\mathbf{N}$ of *type names* (denoted by N, N_1,N_2, ...), which includes the set $\mathbf{B} = \{\texttt{Integer}, \texttt{String}, \texttt{Bool}, \texttt{Real}\}$ of base-type designators (which will be denoted by B) and the symbols $\top$, $\bot$. A *path* p is either the symbol ϵ, or a dot-separated sequence of elements $e_1 . e_2 . \cdots . e_n$, where $e_i \in \mathbf{A} \cup \{\triangle, \exists\}$ $(i = 1, \ldots, n)$. ϵ denotes the unique path of length 0. Let $\mathbf{W}$ denote the set of all paths. $\mathbf{S}(\mathbf{A}, \mathbf{N})$ denotes the set of all *finite type descriptions* (denoted by S, S_1, S_2, ...), also briefly called *types*, over given $\mathbf{A}, \mathbf{N}$, obtained according to the following abstract syntax rule, where $a_i \neq a_j$ for $i \neq j$ (in the sequel p, p_1, p_2, ..., denote a path, d denotes a base value, θ denotes a relational operator): $S \rightarrow N \mid S_1 \sqcup S_2 \mid S_1 \sqcap S_2 \mid \neg S \mid \{S\}_\forall \mid \{S\}_\exists \mid [a_1 : S_1, \ldots, a_k : S_k] \mid \triangle S \mid p\theta d \mid p\uparrow$

$\top$ denotes the *top type*, $\bot$ denotes the *empty type*, $\{\}_\forall$ and $[\ ]$ denote the usual type constructors of set and record (tuple), respectively. The $\{S\}_\exists$ construct is an existential set specification, where at least one element of the set must be of type S. The construct $\sqcap$ stands for *intersection*, the construct $\sqcup$ stands for *union*, the construct $\neg$ stands for *complement*, whereas $\triangle$ constructs class descriptions, i.e., is an object set forming constructor. $p\theta d$, $p\uparrow$ represent *atomic predicates*: $p\theta d$ is a *range restriction* and $p\uparrow$ expresses *path undefinedness*.

Given a set of type descriptions $\mathbf{S}(\mathbf{A}, \mathbf{N})$, a *schema* σ over $\mathbf{S}(\mathbf{A}, \mathbf{N})$ is a total function $\sigma : \mathbf{N} \setminus (\mathbf{B} \cup \{\top, \bot\}) \rightarrow \mathbf{S}(\mathbf{A}, \mathbf{N})$, which associates type names to descriptions. σ is partitioned into two functions: σ_P, which introduces the description of primitive type names whose extensions must be explicitly provided by the user; and σ_V, which introduces the description of virtual type names whose extensions can be recursively obtained from the extension of the types occurring in their description.

In OLCD cyclic type names are allowed: in fact, since a type name may appear in type descriptions, we can have *circular references*, that is, type names which make direct or indirect references to themselves.

Giving a *type as set* semantics to type descriptions, Description Logics, and thus OLCD, allows one to provide relevant reasoning techniques: computing *subsumption* relations between types (i.e., "is-a" relationships implied by type descriptions), deciding *equivalence* between types, and detecting *inconsistent* (i.e., always empty) types.

ODL$_{I^3}$ to OLCD translation

In this section, we describe how ODL$_{I^3}$ source schema descriptions are translated into OLCD descriptions.

ODL$_{I^3}$ classes. In general, a ODL$_{I^3}$ class is translated into a OLCD primitive class in a simple way: each attribute of the ODL$_{I^3}$ class becomes an attribute of the corresponding OLCD class. For example, the `Restaurant` ODL$_{I^3}$ class is translated as follows:

σ_P(`ES.Restaurant`)=$\triangle$[`r_code`: `String`, `name`: `String`, `street`: `String`, `zip_code` : `String`, `pers_id` : `Integer`, `special_dish` : `String`, `category` : `Integer`, `tourist_menu_price` : `Integer`]

Some aspects of an ODL$_{I^3}$ class declaration, such as `key r_code` in the `Restaurant` ODL$_{I^3}$ class, are not translated into OLCD, but will be used in the semantic information integration.

Union constructor. The `union` constructor of ODL$_{I^3}$ is translated using the construct $\sqcup$ of OLCD; for example, the `Address` pattern of figure 2.7 is translated in OLCD as follows:

$$\sigma_P(\texttt{ES.Address}) = \triangle\Big(\texttt{String} \sqcup [\texttt{city}: \texttt{String}, \texttt{street}: \texttt{String}, \texttt{zipcode}: \texttt{String}]\Big)$$

Optional constructor. The construct $\sqcup$ is also used to translate *optional* attributes into OLCD. In fact, an optional attribute `att` specifies that a value may exist or not for a given instance. This fact is expressed in OLCD as the union between the attribute specification (with its domain) and *attribute undefinedness*, denoted by$\uparrow$ operator: ([`att1`: `domain1`]$\sqcup$`att1`$\uparrow$). For example, in the `Fast_Food` interface, the optional attributes are translated as follows:

$$\begin{aligned}\sigma_P(\texttt{ES.Fast\_Food}) = \triangle\Big([\ &\texttt{name} : \texttt{String}, \texttt{address} : \texttt{ES.Address},\\ &\texttt{specialty} : \{\texttt{String}\}, \texttt{category} : \texttt{String}\ ] \sqcap\\ &([\ \texttt{phone} : \texttt{Integer}\ ] \sqcup \texttt{phone}\uparrow) \sqcap\\ &([\ \texttt{nearby} : \texttt{ES.Fast\_Food}\ ] \sqcup \texttt{nearby}\uparrow) \sqcap\\ &([\ \texttt{midprice} : \texttt{Integer}\ ] \sqcup \texttt{midprice}\uparrow) \sqcap\\ &([\ \texttt{owner} : \texttt{ES.Owner}\ ] \sqcup \texttt{owner}\uparrow)\Big)\end{aligned}$$

Integrity constraint rules. An *if then* integrity constraint rule is integrated into an OLCD class description, by using the $\sqcap$, $\sqcup$ and $\neg$ constructs. For example, the rule:

```
rule Rule1 forall X in Restaurant :
   (X.category > 5) then X.tourist_menu_price > 100;
```

is added to the `ES.Restaurant` description as follows:

$$\sigma_P(\texttt{ES.Restaurant}) = \triangle \Big([\ \texttt{r\_code} : \texttt{String}, \texttt{name} : \texttt{String}, \texttt{street} : \texttt{String}, \texttt{zip\_code} : \texttt{String}, \texttt{pers\_id} : \texttt{Integer}, \texttt{special\_dish} : \texttt{String}, \texttt{category} : \texttt{Integer}, \texttt{tourist\_menu\_price} : \texttt{Integer}\ ] \sqcap (\neg(\texttt{category} > 5) \sqcup (\texttt{tourist\_menu\_price} > 100))\Big)$$

Then, in our framework, integrity constraints are statements about the world and not about the contents of the database as in Reiter's approach [Rei88].

Intensional relationships. Are not translated.

Extensional relationships. An "isa" relationships C_1 ISA C_2 related to an Extensional relationships and expressed in ODL$_{I^3}$ by the rule:

```
rule Rule2 forall X in C1 then X in C2
```

is integrated in the C_1 class description, by using the $\sqcap$ construct: $\sigma_P(C_1) = C_2 \sqcap \ldots$

Foreign keys. A Foreign key where the class c_1 contains a field that references the class c_2, is translated introducing one *dummy* attribute in both classes to keep track of the relationship.

For such foreign key we introduce in the definition of c_1 the attribute `dummy1` of type c_2, and we introduce in c_2 the attribute `dummy2` of type c_1.

Mapping Rules. Are not translated.

Join Map. Are not translated.

2.1.5 The WordNet lexical database

WordNet [GGV96, Mil95] is an on-line lexical reference system whose design is inspired by current psycholinguistic theories of human lexical memory. It is the most important resource for researcher in computational linguistic, text analysis, and other related fields.

In WordNet English nouns, verbs, and adjectives are organized into synonym sets, each representing one underlying lexical concept. Different relations link the synonym sets. WordNet presently contains approximately 95,600 different word forms organised into some 70,100 word meanings, or sets of synonyms (*synset*).

Lexical semantics begins with a recognition that a word is a conventional association between a lexicalized concept (the meaning) and an utterance (the written or pronounced word) that plays a syntactic role. This is a many-to-many association; associations can be distinguished in the following properties:

Synonymy: property of a meaning that has two or more words that express it. A group of synonyms is called (in WordNet) *synset*. Note that for each meaning/concept exists one and only one *synset*. We will denote a *synset* as s, and $\mathcal{S}$ will denote the set of all *synset*.

Polysemy: property of a word to have two or more meanings.

Since the word *word* is commonly used to refer both to the utterance and to its associated concept, discussions of this lexical association are vulnerable to terminological confusion. In order to reduce ambiguity, therefore, *word form* will be used here to refer to the physical utterance or inscription and *word meaning* to refer to the lexicalized concept that a form can be used to express.

The correspondence between the *word form* and the *word meaning* is given by the *Lexical Matrix* $\mathcal{M}$, where by columns there are the word form and by rows the word meaning (one row represent a *synset*). If there is more than one entry in the same column, the word form is polysemous; if there are two entries in the same row, the two word forms are synonyms (relative to a context).

Every element of the matrix is an *entry* definition $e = (f, m)$, where f is the *word form* and m (*meaning*) is the meaning counter. For example, (`address`, `2`) refers to the place where a person or organisation can be found or communicated with, and (`address`, `1`) refers to a computer address.

In the following we will denote a *word form* and the meaning of a definition $e = (f, m)$ respectively with $e.f$ and $e.m$. An element of the lexical matrix $\mathcal{M}$ can be *null* or *undefined*.

Since a *synset* is associated with a single line of the $\mathcal{M}$, in the following we will denote $s \in \mathcal{S}$ as row index for $\mathcal{M}$. In other words, the not null elements of the row $\mathcal{M}[s]$, represent all and only the elements of s. In the same way, since a *word form* is associated to a single column or $\mathcal{M}$ in the following we will use the *word form* as column index of $\mathcal{M}$.

Semantic relationships between schema terms

In this subsection we formally define what we mean by *extracting Thesaurus relation from the WordNet database*.

Formalization of the WordNet database Let $\mathbb{T}_w$ the list of terms in WordNet and let $\mathbb{S}_w$ the list of *synset* in WordNet.

The lexical Matrix $\mathcal{M}$ can be expressed as a set:

$$\mathcal{M} \subseteq \mathbb{T}_w \times \mathbb{S}_w$$

We express the set of possible WordNet relationships between *synsets* as:

$$\mathbb{P}_w = \{\mathbf{S}_{ynonymy}, \mathbf{H}_{ypernymy}, \mathbf{O}_{lonymy}, \mathbf{C}_{orrelation}\}$$

The lexical database can then be expressed as a set of relationships:

$$\mathbb{R}_w \subseteq \mathbb{S}_w \times \mathbb{P}_w \times \mathbb{S}_w$$

The tuple $(\mathbb{T}_w, \mathbb{S}_w, \mathcal{M}, \mathbb{R}_w)$ represents the information we use from WordNet.

Formalization of the thesaurus relationships Let $\mathbb{E}_s$ the set of element in a schema to be integrated. An element $e \in \mathbb{E}_s$ represents a local class or a local class attribute.

We define the set of thesaurus relations

$$\mathbb{P}_t = \{SYN, BT, RT\}$$

Our goal is to extract as much as possible *correct* relationships between elements in $\mathbb{E}_s$, that is, we need to express a definition formulae for the set:

$$\mathbb{R}_t \subseteq \mathbb{E}_s \times \mathbb{P}_t \times \mathbb{E}_s$$

Extracting thesaurus relationships from the WordNet database Our process for extracting $\mathbb{R}_t$ is the following:

1. Definition of a mapping function between the relationships of WordNet and the thesaurus relationships:

   $$\phi_t : \mathbb{P}_w \rightarrow \mathbb{P}_t$$

   The definition of the function ϕ_t is given by the following table:

   - **Synonymy:** corresponds to a SYN relation.
   - **Hypernymy:** corresponds to a BT relation.
   - **Olonymy:** corresponds to a RT relation.
   - **Correlation:** corresponds to a RT relation.

   The ϕ_t function is independent from the schema to be integrated.
2. Definition of a partial Annotation function $\alpha : \mathbb{E}_s \rightarrow 2^{\mathbb{S}_w}$.
   The ϕ_t function **is strictly dependent** from the schema to be integrated. This function must be defined by the designer during the integration process.
3. The set of interesting thesaurus relationships $\mathbb{R}_t$ derived from WordNet is given by:

   $$\mathbb{R}_t = \{(e_1, r_t, e_2) \in \mathbb{E}_s \times \mathbb{P}_t \times \mathbb{E}_s : \\ \exists (a_1, \phi_t(r_t), a_2) \in \mathbb{R}_w, a_1 \in \alpha(e_1), a_2 \in \alpha(e_2)\}$$

Use case

To be used, the algorithm of thesaurus relationship extraction requires the designer to *annotate* the source schema. This means that for *almost*[1] each element of the various sources the designer must associate to it a WordNet synset.
The method we propose to annotate a schema element is in two phases and consists of:

1. choosing the *word form* of the element. By default the given utterance is selected, but, such name is not always correct. For example, consider the attribute `FD.Fast_Food.midprice` the designer will have to map it into the *word form* `price` in order to get a proper meaning from WordNet.
2. when the *word form* has been selected, the designer must resolve the word Polysemy. This is done by choosing the *right* synset between the ones related to the selected *word form*.

The human contribution is necessary since the designer, relying on his experience and source knowledge, will choose which is the *right* word form and the *right* meaning for each entity.
The annotation is the most sensible phase of the integration in the **MOMIS** environment, since a *good* annotation will cause the extraction of *good* relationships and this will generate good clusters of similar concepts in different sources.

[1] The attributes to be annotated are usually the ones the designer considers significant.

With annotation we state the association between elements and WordNet *synsets*; this allows us to transpose relationships between *synsets* on the *implied* relationships between schema elements.

2.2 Building the Common Thesaurus

To develop intelligent techniques for semantic integration, inter-schema knowledge between information sources in the considered domain has to be identified and properly represented. For this purpose, we construct a *Common Thesaurus* of intensional and extensional relationships, describing inter-schema knowledge about ODL_{I^3} classes and attributes of source schemas. The Common Thesaurus provides a reference on which to base the identification of ODL_{I^3} classes candidate to integration and subsequent derivation of their global representation. In the Common Thesaurus, we express inter-schema knowledge in form of relationships (SYN, BT, NT, and RT) and extensional relationships (SYN_{ext}, BT_{ext}, and NT_{ext}) between classes and/or attribute names. The Common Thesaurus is constructed through an incremental process during which the following type of relationships are added:

1. *schema-derived relationships*
2. *lexicon-derived relationships*
3. *designer-supplied relationships*
4. *inferred relationships*

Relationships present in the Common Thesaurus are used by the subsequent phase of semantic information integration (see section 2.3).

There are basically two types of relationships differing by strength: (1) intensional relationships, which are the weakest type of relationships, and (2) extensional relationships, which are the stronger type of relationships since they also have an extensional impact.

The designer may at any time "*strengthen*" an intensional relationship and promote it to an extensional relationship. The specification of an extensional relationship implies compatibility between the related elements and enables subsumption computation (i.e., inferred relationships) and consistency check between the elements involved in the relationship.

2.2.1 Schema-derived relationships

In this step terminological and extensional relationships at intra-schema level are extracted by analysing each source schema description separately.

Here are various cases for the different types of sources.

- From *object* sources
  ODB-Tools [BBSV97a] examines the given inheritance and aggregation hierarchies between classes and generates respectively NT_{EXT} and RT relationships. NT_{EXT} and RT may be explicit (direct inheritance, complex attributes) or computed by the *subsumption* algorithm.
- From *relational* sources
  an RT relationship is extracted for each foreign key.

a $\mathtt{NT}_{EXT}$ relationship is extracted each time the foreign key is also a key (primary or candidate) of the class.
a $\mathtt{SYN}_{EXT}$ relationship is extracted each time between two classes there exists a *reciprocal* relationship of $\mathtt{BT}_{EXT}$ (or $\mathtt{NT}_{EXT}$).

- From *semistructured* sources
  relationships are extracted applying techniques cited for the *object* and *relational* sources.

Example 1 Consider the ED and FD sources. A subset of intra-schema relationships automatically extracted are the following:

- `ED.Fast_Food rt ED.Owner`
  since the type of the attribute *owner* of *ED.Fast_Food* is *Owner*.
- `ED.Fast_Food rt ED.Address`
  since the type of the attribute *address* of *ED.Fast_Food* is *Address*.
- `FD.Restaurant rt FD.Person`
  since exists a *foreign key* from *Restaurant* to *Person*.
- `FD.Restaurant bt FD.Bistro`
  since there is a *foreign key* from *Bistro* to *Restaurant* and such foreign key is also a key for *Bistro*.
- `FD.Bistro rt FD.Person`
  since there is a *foreign key* from *Bistro* to *Person*.
- `ED.Address rt ED.Owner`
  since the type of the attribute *address* of *ED.Owner* is *Address*.

2.2.2 Lexicon-derived relationships

In this step, terminological and extensional relationships existing at inter-schema level are extracted by analyzing ODL_{I^3} schemas together. The extraction of these relationships is based upon the lexical relationships existing between classes and attributes names, deriving from the meaning associated to the schema element's name (see section 2.1.5 on page 15). It is the designer's task to assign descriptive/meaningful names or, at least, correctly interpretable names.

Knowledge carried by schema names is one of the most important information we can rely in the integration process. To better exploit such knowledge for extracting terminological relationship, WordNet [Mil95] lexical system has been used. This enables our system to extract a very high number of thesaurus relationships. It is very hard to carry out manually these relationships when the number and dimensions of schema grows. Relationships extracted by WordNet are then proposed to the the designer for validation (the designer can drop unwanted relationships).

Example 2 Consider the ED and FD sources. The relationships derived using WordNet are the following:

```
ED.Address syn ED.Fast_Food.address
ED.Address syn ED.Owner.address
ED.Address syn FD.Brasserie.address
ED.Address.street syn FD.Restaurant.street
ED.Fast_Food.address syn FD.Brasserie.address
ED.Fast_Food.category syn FD.Restaurant.category
ED.Fast_Food.midprice syn FD.Restaurant.tourist_menu_price
ED.Fast_Food.specialty syn FD.Restaurant.special_dish
```

```
ED.Owner nt FD.Person
ED.Owner syn ED.Fast_Food.owner
ED.Owner.address syn ED.Fast_Food.address
ED.Owner.address syn FD.Brasserie.address
ED.Owner.name syn FD.Brasserie.name
ED.Owner.name syn FD.Restaurant.name
FD.Brasserie nt FD.Restaurant
FD.Brasserie rt FD.Bistro
FD.Brasserie.name syn FD.Restaurant.name
FD.Person bt ED.Fast_Food.owner
FD.Person.first_name nt ED.Owner.name
FD.Person.first_name nt FD.Brasserie.name
FD.Person.first_name nt FD.Restaurant.name
FD.Person.first_name rt FD.Person.last_name
FD.Person.last_name nt ED.Owner.name
FD.Person.last_name nt FD.Brasserie.name
FD.Person.last_name nt FD.Restaurant.name
```

2.2.3 Designer-supplied inter-schema relationships

In this step, new relationships can be added directly by the designer to capture specific domain knowledge about the source schemas (e.g. new synonyms).

This is a crucial operation, because the new relationships are forced to belong to the Common Thesaurus and are thus used to generate the global integrated schema. This means that, if a nonsense or wrong relationship is inserted, the subsequent integration process can produce a wrong global schema. The following Relationship validation section shows how our system helps the designer in detecting wrong relationships.

Example 3 In our example, the designer supplies the following relationships for classes and attributes:

```
ED.Fast_Food           syn    FD.Restaurant
ED.Fast_Food.category  bt     FD.Bistro.type
ED.Fast_Food.specialty bt     FD.Bistro.special_dish
```

2.2.4 Relationships validation

In this step, ODB-Tools is employed to validate intensional relationships between attributes and extensional relationships between classes.

Intensional relationships between attributes

The validation of intensional relationships between attributes is based on the compatibility of the domains of the attributes. This way, *valid* and *invalid* intensional relationships are distinguished. In particular, let $a_t = \langle n_t, d_t \rangle$ and $a_q = \langle n_q, d_q \rangle$ be two attributes characterized by name and domain. The following checks are executed on intensional relationships defined on attributes in the Common Thesaurus:

- $\langle a_t \text{ SYN } a_q \rangle$: the relationship is marked as valid if d_t and d_q are equivalent, or if one is a specialization of the other;
- $\langle a_t \text{ BT } a_q \rangle$: the relationship is marked as valid if d_t contains or is equivalent to d_q;

- $\langle a_t$ NT $a_q\rangle$: the relationship is marked as valid if d_t is contained in or is equivalent to d_q.

When an attribute domain d_t (d_q) is defined using the `union` constructor, as in the `Address` example (see Figure 2.7 on page 13), a *valid relationship* is recognised if at least one domain d_t (d_q) is compatible with d_q (d_t).

Extensional relationships between two classes

As an extensional relationship between two classes C_1 and C_2, the validation is performed checking the consistency of a *virtual schema* described in OLCD exploiting ODB-Tools capabilities. The *virtual schema* is generated by applying common thesaurus relationships to the ODL$_{I^3}$ schema. Extensional relationships affects the inheritance hierarchies of the schema.

For example, the extensional relationship:

`FD.Restaurant btExt FD.Bistro`

stated by the designer is expressed in the `FD.Bistro` class description as follows:

σ_P(`FD.Bistro`) = `FD.Restaurant` $\sqcap$
$\triangle$ [`r_code` : `String`, `type` : `String`, `pers_id` : `Integer`]

Since the `FD.Bistro` class description is consistent, the relationship between `FD.Bistro` and `FD.Restaurant` is validated. On the other hand, the extensional relationship

`FD.Restaurant btExt ED.Fast_Food`

is rejected since the class description: σ_P(`ED.Fast_Food`) = `FD.Restaurant` $\sqcap \ldots$ is inconsistent (the attribute `category` is defined in both the classes but on disjoint domains). In the presence of integrity rules less intuitive incoherencies may arise. In this case the designer may choose to maintain only the terminological relationship

`ED.Restaurant bt FD.Fast_Food`

in the Common Thesaurus.

2.2.5 Checking consistency and inferring new relationships

In this step, inference capabilities of ODB-Tools are exploited to validate the common thesaurus relationships and to infer new relationships, in order to set up a rich common thesaurus to support the identification of semantically similar ODL$_{I^3}$ classes in different sources, as will be shown in next section. *In the running example there are no inferred relations.* To perform this task it is necessary to build a *virtual schema* taking in account all the common thesaurus relationships, then to run ODB-Tools on such virtual schema. ODB-Tools will compute incoherent relationships and will also infer all relationships involved by the *virtual schema*, then, such new relationships will be added to the common thesaurus.

2.2.6 Virtual schema creation

The virtual schema passed to ODB-Tools description logic engine is described in OLCD (see section 2.1.4 on page 13) and is derived from the schema of the sources applying some modifications implied by the common thesaurus relationships.

Generating the virtual schema we exploit the ODB-Tools validation and inference capabilities to discover incoherences due to the common thesaurus relationships, validate relationships between attributes with respect to domain matching, and infer all possible relationship involved by the existent ones.

Since ODB-Tools is able to discover schema *incoherences*, during the virtual schema generation we transform the *extensional* relationships (the strongest relationship type) into structural declarations. if ODB-Tools does not signals any incoherence this means that *extensional* relationships are not conflicting.

Validation of the existing relationships is possible by defining, in the virtual schema, a virtual classes for each schema element involved in a relation. ODB-Tools will compute all relationships between such virtual classes based on relationships and schemata information and will produce a list of *schema compliant relationships*. If an *old* relationship appears in the list then this is marked as valid. Relationships that are in the list but do not exist in the common thesaurus are added as *inferred relationships*.

The various relationships types will produce the following modifications:

- *Extensional* SYN
  such relationship cause the creation of a double inheritance, that is

  $$c_1 SYN_{ext} c_2$$

  is converted into the following two OLCD declarations

  $$\sigma_P(c_1) = c_2 \sqcap ...$$
  $$\sigma_P(c_2) = c_1 \sqcap ...$$

- *Extensional* NT *and* BT

  $$c_1 NT_{ext} c_2$$

  is converted into the following OLCD declaration:

  $$\sigma_P(c_1) = c_2 \sqcap ...$$

- *Intensional* SYN
  the idea is to find sets of *synonym classes* and make them *homogeneous*.
  A set of *synonym classes* is given by all the local classes directly related by a *SYN* relationship.
  To make a set of *synonym classes* "homogeneous" all class description are redefined in order to share a common definition obtained by the union of the definitions of all the synonym classes. To do that we need to define *inheritance*, *attributes* and *related classes* (which are the classes in RT relation).
  Using the notation introduced in section 2.1.5 on page 16,
  Let $\mathbb{C}_s$ the set of local classes in the schema.
  Let $\mathbb{A}_s$ the set of attributes of all local classes in the schema.
  Let $\gamma_s : \mathbb{A}_s \rightarrow \mathbb{C}_s$ the function that relates attributes and classes of the schema; $\gamma_s(a)$ returns the class where a is defined as attribute.
  Let $\mathbb{R}_t$ the set of common thesaurus relations.
  Let $S_{syn} \subseteq \mathbb{C}_s$ a set of *synonym classes*.
  The set of inheritance shared by all the classes in the set, s_i, can be calculated by the following iterative algorithm:

1. let $s_i = S_{syn}$
2. let $s_i = s_i \cup \{c \in \mathbb{C}_s : \exists(c, r, c_1) \in \mathbb{R}_t,$
   $c_1 \neq c, r = NT, c_1 \in s_i, c \in \mathbb{C}_s\}$
3. let $s_i = s_i \cup \{c \in \mathbb{C}_s : \exists(c_1, r, c) \in \mathbb{R}_t,$
   $c_1 \neq c, r = BT, c_1 \in s_i, c \in \mathbb{C}_s\}$
4. if s_i grew then goto point 2
5. done.

Let $s_a \subseteq \mathbb{A}_s$ the set of attributes shared by all the classes in the set

$$s_a(S_{syn}) = \{a \in \mathbb{A}_s : \exists c = \gamma_s(a), c \in S_{syn}\}$$

Let $s_r \subseteq \mathbb{C}_s$ the set of classes related to the classes in the set
$s_r(S_{syn}) =$
$\{c \in \mathbb{C}_s : \exists(c, r, c_1) \in \mathbb{R}_t, r = RT, c_1 \in S_{syn}, c \in \mathbb{C}_s, c_1 \neq c\} \cup$
$\{c \in \mathbb{C}_s : \exists(c_1, r, c) \in \mathbb{R}_t, r = RT, c_1 \in S_{syn}, c \in \mathbb{C}_s, c_1 \neq c\}$
Once calculated, the sets s_i, s_a and s_r in the definition of each class c of the *set of synonym classes* S_{syn} will be something like:
$\sigma_P(c) = c_{i1} \sqcap ... \sqcap c_{in} \sqcap \triangle[$
$a_{n1} : a_{t1}, a_{n2} : a_{t2}, ..., a_{nm} : a_{tm}, a_{r1} : c_{r1}, a_{r2} : c_{r2}, ..., a_{ro} : c_{ro}]$
where
$c_{i1}, ..., c_{i1} \in s_i$
$a_{n1}, ..., a_{nm}$ are attribute name for attributes in s_a
$a_{t1}, ..., a_{tm}$ are attribute type for attributes in s_a
$a_{r1}, ..., a_{ro}$ are dummy attributes name, and
$c_{r1}, ..., c_{ro} \in s_r$.

- *Intensional NT and BT*
  This is a case similar to the intensional SYN relationship. In this case we have to *homogenize* a class c_b with the classes c_b from which intensionally it inherits. We need to compute:
  - The set S_{bt} of intensional superclasses.
  - The set s_a of attributes that represent the union of attribute of c_b and attributes of the classes in S_{bt}.
  - The set s_r of classes *related to* c_b or related to any of the classes in S_{bt}.

  The set S_{bt} can be computed by applying the following iterative algorithm:
  1. $S_{bt} = \{c_b\}$
  2. let $S_{bt} = S_{bt} \cup \{c \in \mathbb{C}_s : \exists(c, r, c_1) \in \mathbb{R}_t,$
     $c_1 \neq c, r = NT, c_1 \in S_{bt}, c \in \mathbb{C}_s\}$
  3. let $S_{bt} = S_{bt} \cup \{c \in \mathbb{C}_s : \exists(c_1, r, c) \in \mathbb{R}_t,$
     $c_1 \neq c, r = BT, c_1 \in S_{bt}, c \in \mathbb{C}_s\}$
  4. if S_{bt} grew then go to point 2
  5. done.

  Both sets s_a and s_r can be computed using the algorithm described above for the case of *SYN relationship* considering $S_{syn} = S_{bt}$
- *terminological RT*
  For each RT relationship involving a given class c and one other class c_1, a *virtual* complex attribute a_r of type c_1 is added to the definition of c in the *virtual schema*.

See section 3.4.1 on page 53 for how this feature has been implemented in the **MOMIS** prototype.

2.3 Semantic information integration

In this section, we describe the information integration process to construct the global integrated view of ODL$_{I^3}$ source schemas. The proposed process allows semi-automatic identification of ODL$_{I^3}$ classes candidate to integration by means of clustering procedures based on the concept of affinity and on the relationship knowledge in the Common Thesaurus. Moreover, the process supports a semi-automated synthesis of each selected cluster into an integrated global ODL$_{I^3}$ class, by handling semantic heterogeneity through the definition of suitable mapping rules for each global class.

2.3.1 Affinity of ODL$_{I^3}$ classes

To integrate the ODL$_{I^3}$ classes of the different sources into global ODL$_{I^3}$ classes, we employ hierarchical clustering techniques based on the concept of *affinity*. This way, we identify ODL$_{I^3}$ classes that describe the same or semantically related information in different source schemas and give a measure of the level of matching of their structure.

This activity is performed with the ARTEMIS tool environment. ARTEMIS has been conceived for a semi-automatic integration of heterogeneous structured databases [CAV00]. In the context of MOMIS, the ARTEMIS affinity framework has been extended and applied to the analyzis of ODL$_{I^3}$ schema descriptions. In the following, we describe the extensions to the affinity-based clustering to cope with object patterns and semistructured data integration. ODL$_{I^3}$ classes are analyzed and compared by means of *affinity coefficients* which allow us to determine the level of similarity between classes in different source schemas.

In particular, ARTEMIS evaluates a *Global Affinity* coefficient as the linear combination of a *Name Affinity* coefficient and a *Structural Affinity* coefficient, respectively. Affinity coefficients for ODL$_{I^3}$ classes are evaluated by exploiting terminological relationships of the Common Thesaurus. To this end, a strength $\sigma_{\Re}$ is assigned to each type of terminological relationship $\Re$ in the Common Thesaurus, with $\sigma_{\text{SYN}} \geq \sigma_{\text{BT/NT}} \geq \sigma_{\text{RT}}$. In the following, when necessary, we use notation $\sigma_{ij_{\Re}}$ to denote the strength of the terminological relationship $\Re$ for terms t_i and t_j in the Thesaurus; furthermore, we use $\sigma_{\text{SYN}} = 1$, $\sigma_{\text{BT}} = \sigma_{\text{NT}} = 0.8$ and $\sigma_{\text{RT}} = 0.5$.

An affinity function $A()$ is defined on top of the Common Thesaurus to evaluate the affinity of two terms. The affinity $A(t, t')$ of two terms t and t' is equal to the highest-strength path of terminological relationships between them, if at least one path exists, and is otherwise zero. Given two terms t and t' and a path of terminological relationships between them, the strength of this path is computed by multiplying the strengths of all terminological relationships involved in it. $A(t, t')$ coincides with the strength of the highest-strength path between t and t', denoted by $\rightarrow^m$, that is, $A(t, t') = \sigma_{12_{\Re}} \cdot \sigma_{23_{\Re}} \cdot \ldots \cdot \sigma_{(m-1)m}$. In the following, we use the symbol $\sim$ to denote the fact that two terms have affinity in the Common Thesaurus. Let c and c' be two ODL$_{I^3}$ classes belonging to sources S and S' respectively. Let us now define how the affinity coefficients are computed.

Name Affinity coefficient

The Name Affinity coefficient of two ODL$_{I^3}$ classes c and c', denoted $NA(c, c')$, is the measure of the affinity between their names n_c and $n_{c'}$, if this measure exceeds a specified threshold (see Table 2.1).

Table 2.1: Name Affinity coefficient

Coefficient	Value	Condition
$NA(c, c')$	$A(n_c, n_{c'})$	if $A(n_c, n_{c'}) \geq \alpha$
	0	if $A(n_c, n_{c'}) < \alpha$

Legend:

$n_c, n_{c'}$ denote the name of c and c', respectively.

α is a threshold used to select high values of $NA(c, c')$.

$A(t, t')$ coincides with the strength of the highest-strength path between t and t'.

For any pairs of classes, $NA(c, c') \in [0, 1]$. $NA(c, c')$ is equal to the strength of the path $\rightarrow^m$ of terminological relationships in the Common Thesaurus originating the highest strength value, if this value exceeds a specified threshold α (e.g., $\alpha \in [0.4, 0.6]$). In this case, the Name Affinity value is proportional to the length of the path and to the type of relationships involved in this path. In particular, $NA(c, c')$ is 1 if only SYN relationships are involved in a path. Otherwise, $NA(c', c')$ is zero.

Structural Affinity coefficient

The Structural Affinity coefficient of two ODL$_{I^3}$ classes c and c', denoted $SA(c, c')$, is the measure of the level of matching of c and c' based on attribute relationships in the Common Thesaurus (see Table 2.2).

Table 2.2: Structural Affinity coefficient

Coefficient	Value	Condition
$SA(c, c')$	$\frac{\lvert\{a_t \mid a_t \in A(c), a_q \in A(c'), n_t \sim n_q\}\rvert + \lvert\{a_q \mid a_t \in A(c), a_q \in A(c'), n_t \sim n_q\}\rvert}{\lvert A(c)\rvert + \lvert A(c')\rvert} \cdot F_c$	if $\lvert C\rvert \neq 0$
	0	if $\lvert C\rvert = 0$

Legend:

$C = \{(a_t, a_q) \mid a_t \in A(c), a_q \in A(c'), n_t \sim n_q\}$, where $A(c)$ and $A(c')$ are the sets of attributes in c c', respectively

$F_c = \frac{\lvert\{x \in C \mid flag(x) = 1\}\rvert}{\lvert C\rvert}$, control factor where $flag(x) = 1$ stands for a valid terminological relationship in the Common Thesaurus

The Structural Affinity coefficient returns a value in the range $[0, 1]$ proportional to the number of attributes of the two classes whose names have affinity in the Common Thesaurus, refined by a control factor F_c. In particular, F_c evaluates the percentage of attributes having affinity that have a valid relationship in the Common Thesaurus (see step Validation of relationships illustrated in Section 2.2.4).

The value 0 indicates the absence of attributes with affinity in the considered classes, while the value 1 indicates that all attributes defined in the two classes have affinity and are considered valid. The greater the number of attributes with affinity in the considered classes, and the greater the number of positive validity control results, the higher the value of $SA(c, c')$.

In general, given two classes, an attribute of one class may have affinity with more than one attribute of the other class. In the evaluation of the $SA(c, c')$ coefficient, we consider these multiple affinities as a single affinity correspondence between one attribute and a set of attributes. For the evaluation of Structural Affinity, *optional* attributes of

ODL_{I^3} classes representing object patterns must be considered properly. Depending on which attributes are taken into account, the following options are possible for the computation of the $SA()$ coefficient:

1. *All attribute-based.* With this option, *optional* attributes are treated as the other ones and are always taken into account when evaluating the affinity of ODL_{I^3} classes describing object patterns.
2. *Common attribute-based.* With this option, *optional* attributes are not taken into account when evaluating the affinity.
3. *Threshold-based.* With this option, *optional* attributes are taken into account for affinity evaluation only if they are common to at least a certain number of objects (i.e., a threshold) of the considered object pattern.

The third option is difficult to apply, since it requires setting the value of a threshold, which can be dependent on the specific object pattern or on the source. As for the other two options, they have different implications on the affinity values produced. Given a pattern to be compared, the second option gives affinity values higher than the first one, in presence of the same number of attribute pairs with affinity. In fact, fewer attributes are considered at the denominator of the $SA()$ formula choosing option 2). On the other hand, if most attributes of an object pattern are optional, then option 1) is better for Structural Affinity evaluation. The choice between the first two options depends on the specific application under analysis. In our example, we applied both options and we discuss obtained values in the following, when presenting results of clustering.

Example 4 Consider classes `ED.Owner` and `FD.Person`. By applying the all attribute-based option, we have that SA(`ED.Owner,FD.Person`) = $\frac{2+1}{3+4} \cdot 1 = 0.43$ due to the following affinities:
`ED.Owner.name`$\sim\{$`FD.Person.first_name`,`FD.Person.last_name`$\}$.

Global Affinity coefficient

The Global Affinity coefficient of two ODL_{I^3} classes c and c', denoted $GA(c, c')$, is the measure of their affinity computed as the weighted sum of the Name and Structural Affinity coefficients (see Table 2.3).

Table 2.3: Global Affinity coefficient

Coefficient	Value	Condition
$GA(c, c')$	$w_{NA} \cdot NA(c, c') + w_{SA} \cdot SA(c, c')$	in all cases

Legend:
w_{NA} and w_{SA}, with $w_{NA}, w_{SA} \in [0, 1]$ and $w_{NA} + w_{SA} = 1$, are introduced to assess the relevance of each coefficient computing the global affinity value.

Weights in $GA(c, c')$ allow the analyst to differently stress the impact of each coefficient in the evaluation of the global affinity value.

Example 5 The Global Affinity coefficient of `ED.Owner` and `FD.Person` is computed as follows: GA(`ED.Owner`,`FD.Person`) = $0.5 \cdot 0.8 + 0.5 \cdot 0.43 = 0.61$ using $w_{NA} = w_{SA} = 0.5$, since we consider both affinity coefficients equally relevant.

Clustering of ODL$_{I^3}$ classes

To identify all the ODL$_{I^3}$ classes having affinity in the considered source schemas, we employ a hierarchical clustering technique, which classifies classes into groups at different levels of affinity, forming a tree [Eve74]. The hierarchical clustering procedure uses a matrix M of rank K where K is the total number of ODL$_{I^3}$ classes to be analysed. An entry $M[h,k]$ of the matrix represents the affinity coefficient $GA(c_h, c_k)$ between classes c_h and c_k. Clustering is iterative and starts by placing each class in a cluster by itself. Then, at each iteration, the two clusters having the greatest affinity value in M are merged. M is updated at each merging operation by deleting the rows and the columns corresponding to the merged clusters, and by inserting a new row and a new column for the newly defined cluster c_{hk}. The affinity value between c_{hk} and each remaining cluster $\bar{c}$ in M is computed. The new value between c_{hk} and a remaining cluster $\bar{c}$ is set to the maximum affinity value between the affinity values that c_h and c_k had with $\bar{c}$ in M. The procedure terminates when only one cluster is left and produces as the output a tree, where leaves correspond to ODL$_{I^3}$ classes and intermediate nodes have an associated affinity value characterizing the underlying leaves.

```
Initial Distance matrix:
  Elements: 18
    e0 Interface [ED.Address]
    e1 Interface [ED.Fast_Food]
    e2 Interface [ED.Owner]
    e3 Interface [FD.Bistro]
    e4 Interface [FD.Brasserie]
    e5 Interface [FD.Person]
    e6 Interface [FD.Restaurant]
    e7 [odli3.SimpleAttribute: ED.Address.street type: string]
    e8 [odli3.SimpleAttribute: ED.Fast_Food.address type: odli3.TypeToSolve@275a92]
    e9 [odli3.SimpleAttribute: ED.Fast_Food.midprice type: signed long]
   e10 [odli3.SimpleAttribute: ED.Owner.address type: odli3.TypeToSolve@2b5267]
   e11 [odli3.SimpleAttribute: ED.Owner.name type: string]
   e12 [odli3.SimpleAttribute: FD.Brasserie.name type: string]
   e13 [odli3.SimpleAttribute: FD.Person.first_name type: string]
   e14 [odli3.SimpleAttribute: FD.Person.last_name type: string]
   e15 [odli3.SimpleAttribute: FD.Restaurant.name type: string]
   e16 [odli3.SimpleAttribute: FD.Restaurant.street type: string]
   e17 [odli3.SimpleAttribute: FD.Restaurant.tourist_menu_price type: signed long]
  src-| e0 | e1 | e2 | e3 | e4 | e5 | e6 | e7 | e8 | e9 |e10 |e11 |e12 |e13 |e14 |e15 |e16 |e17 |
   e0 |    |0.5 |0.5 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
   e1 |0.5 |    |0.5 |    |    |    |0.8 |    |    |    |    |    |    |    |    |    |    |    |
   e2 |0.5 |0.5 |    |    |    |0.8 |    |    |    |    |    |    |    |    |    |    |    |    |
   e3 |    |    |    |    |0.5 |0.5 |0.8 |    |    |    |    |    |    |    |    |    |    |    |
   e4 |    |    |    |0.5 |    |    |0.8 |    |    |    |    |    |    |    |    |    |    |    |
   e5 |    |    |0.8 |0.5 |    |    |0.5 |    |    |    |    |    |    |    |    |    |    |    |
   e6 |    |0.8 |    |0.8 |0.8 |0.5 |    |    |    |    |    |    |    |    |    |    |    |    |
   e7 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |1.0 |    |
   e8 |    |    |    |    |    |    |    |    |    |    |1.0 |    |    |    |    |    |    |    |
   e9 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |1.0 |
  e10 |    |    |    |    |    |    |    |    |1.0 |    |    |    |    |    |    |    |    |    |
  e11 |    |    |    |    |    |    |    |    |    |    |    |    |1.0 |0.8 |0.8 |1.0 |    |    |
  e12 |    |    |    |    |    |    |    |    |    |    |    |1.0 |    |0.8 |0.8 |1.0 |    |    |
  e13 |    |    |    |    |    |    |    |    |    |    |    |0.8 |0.8 |    |0.5 |0.8 |    |    |
  e14 |    |    |    |    |    |    |    |    |    |    |    |0.8 |0.8 |0.5 |    |0.8 |    |    |
  e15 |    |    |    |    |    |    |    |    |    |    |    |1.0 |1.0 |0.8 |0.8 |    |    |    |
  e16 |    |    |    |    |    |    |    |1.0 |    |    |    |    |    |    |    |    |    |    |
  e17 |    |    |    |    |    |    |    |    |    |1.0 |    |    |    |    |    |    |    |    |
```

Figure 2.8: Initial affinity matrix for clustering

We can see a complete process of clustering starting from initial thesaurus relationships applying the relationships weights (for SYN, NT, RT respectively 1, 0.8, 0.5) is computed the Initial affinity matrix (Figure 2.8). In Figure 2.9 showns the corresponding Naming Affinity Matrix, Figure 2.10 shows the Structural Affinity Matrix, and last Figure 2.11 shows the Global Affinity Matrix

Figure 2.12 shows the affinity tree resulting from clustering (using 0.4 as threshold value) our set of ODL$_{I^3}$ classes by using the *all attribute-based* method. Once the affinity tree has been constructed, an important issue is related to the selection of clus-

```
Naming Affinty matrix:
  Elements: 18
    e0 Interface [ED.Address]
    e1 Interface [ED.Fast_Food]
    e2 Interface [ED.Owner]
    e3 Interface [FD.Bistro]
    e4 Interface [FD.Brasserie]
    e5 Interface [FD.Person]
    e6 Interface [FD.Restaurant]
    e7 [odli3.SimpleAttribute: ED.Address.street type: string]
    e8 [odli3.SimpleAttribute: ED.Fast_Food.address type: odli3.TypeToSolve@275a92]
    e9 [odli3.SimpleAttribute: ED.Fast_Food.midprice type: signed long]
   e10 [odli3.SimpleAttribute: ED.Owner.address type: odli3.TypeToSolve@2b5267]
   e11 [odli3.SimpleAttribute: ED.Owner.name type: string]
   e12 [odli3.SimpleAttribute: FD.Brasserie.name type: string]
   e13 [odli3.SimpleAttribute: FD.Person.first_name type: string]
   e14 [odli3.SimpleAttribute: FD.Person.last_name type: string]
   e15 [odli3.SimpleAttribute: FD.Restaurant.name type: string]
   e16 [odli3.SimpleAttribute: FD.Restaurant.street type: string]
   e17 [odli3.SimpleAttribute: FD.Restaurant.tourist_menu_price type: signed long]
  src-| e0 | e1 | e2 | e3 | e4 | e5 | e6 | e7 | e8 | e9 |e10 |e11 |e12 |e13 |e14 |e15 |e16 |e17 |
   e0 |    |0.5 |0.5 |0.32|0.32|0.4 |0.4 |    |    |    |    |    |    |    |    |    |    |    |
   e1 |0.5 |    |0.5 |0.64|0.64|0.4 |0.8 |    |    |    |    |    |    |    |    |    |    |    |
   e2 |0.5 |0.5 |    |0.4 |0.32|0.8 |0.4 |    |    |    |    |    |    |    |    |    |    |    |
   e3 |0.32|0.64|0.4 |    |0.64|0.5 |0.8 |    |    |    |    |    |    |    |    |    |    |    |
   e4 |0.32|0.64|0.32|0.64|    |0.4 |0.8 |    |    |    |    |    |    |    |    |    |    |    |
   e5 |0.4 |0.4 |0.8 |0.5 |0.4 |    |0.5 |    |    |    |    |    |    |    |    |    |    |    |
   e6 |0.4 |0.8 |0.4 |0.8 |0.8 |0.5 |    |    |    |    |    |    |    |    |    |    |    |    |
   e7 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |1.0 |    |
   e8 |    |    |    |    |    |    |    |    |    |    |1.0 |    |    |    |    |    |    |    |
   e9 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |1.0 |
  e10 |    |    |    |    |    |    |    |    |    |1.0 |    |    |    |    |    |    |    |    |
  e11 |    |    |    |    |    |    |    |    |    |    |    |    |1.0 |0.8 |0.8 |1.0 |    |    |
  e12 |    |    |    |    |    |    |    |    |    |    |    |1.0 |    |0.8 |0.8 |1.0 |    |    |
  e13 |    |    |    |    |    |    |    |    |    |    |    |0.8 |0.8 |    |0.64|0.8 |    |    |
  e14 |    |    |    |    |    |    |    |    |    |    |    |0.8 |0.8 |0.64|    |0.8 |    |    |
  e15 |    |    |    |    |    |    |    |    |    |    |    |1.0 |1.0 |0.8 |0.8 |    |    |    |
  e16 |    |    |    |    |    |    |    |    |1.0 |    |    |    |    |    |    |    |    |    |
  e17 |    |    |    |    |    |    |    |    |    |1.0 |    |    |    |    |    |    |    |    |
```

Figure 2.9: Naming Affinity Matrix for clustering

ters to be integrated for the definition of the global ODL$_{I^3}$ classes of the integrated schema. Cluster computation is interactive, based on the numerical affinity values in the affinity tree. In particular, ARTEMIS provides a threshold-based mechanism for cluster selection. The designer specifies a value for a threshold T and clusters characterised by an affinity value greater than or equal to T are selected and proposed to the designer. High values of threshold will generate small, highly homogeneous clusters. By decreasing T's value, clusters containing more ODL$_{I^3}$ classes can be selected (see cluster generated with $T = 0.4$ in figure 2.14). In the tool, the default value of T is set to 0.5. This default value can be refined dynamically, on the basis of the characteristics of retrieved clusters and of the specific application under analysis. Once clusters have been selected, ODL$_{I^3}$ classes that have an extensional terminological relationship with at least one class in the cluster and not yet included in it (if any), are forced to belong to the cluster anyway, to define an integrated global ODL$_{I^3}$ class that is representative of all possible semantically related source classes.

The designer can confirm this threshold-based cluster selection made by the tool for the subsequent synthesis activity.

2.3.2 Synthesis into an integrated schema description

The generation of ODL$_{I^3}$ *global classes* out of selected clusters is a synthesis activity performed interactively by the designer. Synthesis of clusters of ODL$_{I^3}$ classes requires taking into account semantic heterogeneity, which has to be treated properly to come up with an integrated and uniform representation at the global level. Let Cl_i be a selected cluster in the affinity tree and gc_i the global ODL$_{I^3}$ class to be defined for Cl_i.

```
Structural Affinty matrix:
  Elements: 6
    e0 Interface [ED.Address]
    e1 Interface [ED.Fast_Food]
    e2 Interface [ED.Owner]
    e3 Interface [FD.Brasserie]
    e4 Interface [FD.Person]
    e5 Interface [FD.Restaurant]
  src-| e0 | e1 | e2 | e3 | e4 | e5 |
   e0 |    |    |    |    |    |0.08|
   e1 |    |    |0.09|    |    |0.06|
   e2 |    |0.09|    |0.16|0.28|0.09|
   e3 |    |    |0.16|    |0.28|0.09|
   e4 |    |    |0.28|0.28|    |0.16|
   e5 |0.08|0.06|0.09|0.09|0.16|    |
```

Figure 2.10: Structural Affinity Matrix for clustering

First, we associate with gc_i a set of *global attributes*, corresponding to the *union* of the attributes of the classes belonging to Cl_i. The attributes having a valid terminological relationship are unified into a unique global attribute in gc_i. The attribute unification process is performed automatically for what concerns names according to the following rules:

- for attributes that have a SYN relationship, only one term is selected as the name for the corresponding global attribute in gc_i;
- for attributes that have a BT/NT relationship, a name which is a broader term for all of them is selected and assigned to the corresponding global attribute in gc_i.

For example, the attribute unification process for cluster Cl_2 of figure 2.13 on page 32 (that will be named in Food_Place) automatically produces the following set of global attributes:

```
name, address, phone?, specialty, category, nearby?,
midprice?, owner?, special_dish, street, zip_code, type,
r_code, b_code, pers_id, tourist_menu_price
```

The designer can add mapping rules to properly set the global class. A global class also includes mapping rules for global attributes. A mapping rule is defined for each global attribute a of gc_i and specifies:

- *Attribute correspondences in the cluster*: values of a depend on the attributes that have been unified into a during the construction of gc_i. Mapping rules are defined to state for a which attributes of the ODL$_{I^3}$ classes in the cluster under analysis correspond to a. In specifying mapping rules for global attributes, the following correspondences can be specified:

  1. *And correspondence*: this specifies that a global attribute corresponds to the concatenation of two or more attributes of a class $c_h \in \mathtt{Cl_i}$.
     For example, by defining a mapping rule for the global attribute `name` of

```
Global Affinty matrix:
  Elements: 7
    e0 Interface [ED.Address]
    e1 Interface [ED.Fast_Food]
    e2 Interface [ED.Owner]
    e3 Interface [FD.Bistro]
    e4 Interface [FD.Brasserie]
    e5 Interface [FD.Person]
    e6 Interface [FD.Restaurant]
  src-| e0 | e1 | e2 | e3 | e4 | e5 | e6 |
   e0 |    |0.25|0.25|0.16|0.16|0.2 |0.24|
   e1 |0.25|    |0.29|0.32|0.32|0.2 |0.43|
   e2 |0.25|0.29|    |0.2 |0.24|0.54|0.24|
   e3 |0.16|0.32|0.2 |    |0.32|0.25|0.4 |
   e4 |0.16|0.32|0.24|0.32|    |0.34|0.44|
   e5 |0.2 |0.2 |0.54|0.25|0.34|    |0.33|
   e6 |0.24|0.43|0.24|0.4 |0.44|0.33|    |
```

Figure 2.11: Global Affinity Matrix for clustering

Cl_2, the designer specifies that a global attribute `name` corresponds to both `first_name` and `last_name` attributes of `FD.Person` class. By specifying the *and* correspondence between `first_name` and `last_name` for the global attribute `name`, the designer states that the values of both `first_name` and `last_name` attributes have to be considered as values of `name` when class `FD.Person` is considered.

2. *Or correspondence*: this specifies that a global attribute corresponds at most to one of the attributes of a class $c_h \in Cl_i$. An *or* correspondence is useful when a global attribute is suitable for two or more local attributes of a source, depending on the value of another local attribute, called "tag attribute". For example, let us suppose we have a cluster describing an `automobile` global class and that classes in the cluster have price values for cars in Italian Liras and US Dollars. Here, `country` is the tag attribute. In this example, it is possible to define an *or* correspondence between the attributes `Italian_price` and `US_price` by declaring the following mapping rule:

```
attribute integer price
  mapping rule(S.car.Italian_price union
               S.car.US_price on Rule1),
               ...
rule Rule1 { case of S.car.country:
       ''Italy'' : S.car.Italian_price;
       ''US''    : S.car.US_price; }
```

- *Default/null values*: these are possibly defined for local attributes corresponding to a, based on the knowledge of the single local source, if a is not applicable in the considered source. For example, with reference to Cl_1, the mapping rule defined for the global attribute `zone` specifies that the objects of the class `ED.Fast_Food` regard the "Pacific Area" while objects of `FD.Restaurant`

```
ClusterTree:
tools.Distance: 0.25
+src:
|  Interface [ED.Address]
+dst:
|  tools.Distance: 0.34285714285714286
|  +src:
|  |  tools.Distance: 0.5428571428571429
|  |  +src:
|  |  |  Interface [ED.Owner]
|  |  +dst:
|  |  |  Interface [FD.Person]
|  |
|  +dst:
|  |  tools.Distance: 0.4
|  |  +src:
|  |  |  Interface [FD.Bistro]
|  |  +dst:
|  |  |  tools.Distance: 0.43125
|  |  |  +src:
|  |  |  |  Interface [ED.Fast_Food]
|  |  |  +dst:
|  |  |  |  tools.Distance: 0.4454545454545455
|  |  |  |  +src:
|  |  |  |  |  Interface [FD.Brasserie]
|  |  |  |  +dst:
|  |  |  |  |  Interface [FD.Restaurant]
|  |  |  |  |
|  |  |  |
|  |  |
|  |
|
```

Figure 2.12: Cluster Tree in clustering

and `FD.Bistro` wherever in the USA.

For each global ODL$_{I^3}$ class gc_i, a persistent mapping table storing all the mapping information is generated.

As an example, the mapping table for the `Food_Place` class, set by the mapping rules of figure 2.15, is shown in figure 2.16.

The mapping table in figure 2.15 describes the *Food_Place* global class. In the first row there is the list of local classes composing the global class. In the first column there is the list of the *global attributes* of the global class. Given a row (the global attribute a_g) and a column (the local class c_l) the corresponding mapping table cell m_c describes how combine the local attribute of c_l to compute the value for a_g. The content of the cell m_c means as follows:

- a single name: means simple mapping, the local attribute is mapped as global attribute for the instance of the local class.
- *NULL*: the local class does not *export* any values for the given global attribute. It simply returns a *null* value.

```
Clusters:
  cluster [0]
    [Interface [ED.Address]]
  cluster [1]
    [Interface [ED.Owner]]
    [Interface [FD.Person]]
  cluster [2]
    [Interface [FD.Bistro]]
    [Interface [ED.Fast_Food]]
    [Interface [FD.Brasserie]]
    [Interface [FD.Restaurant]]
```

Figure 2.13: Proposed clusters

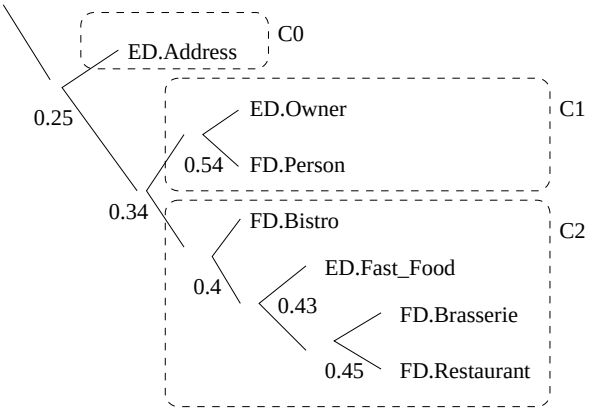

Figure 2.14: Example of affinity tree

- an *and* between names: there is an *and corrispondence* between attributes.
- an *or* between names: there is an *or corrispondence* between attributes.
- a string between quotation marks: a constant (default) value is associated to this global attributes for each instance of the local class.

Integrity constraint rules can also be specified for global ODL$_{I^3}$ classes to express semantic relationships existing among the different sources. Suppose that in our domain, a relationship exists between the category and the price of a food place. For example, the fact that all the food places with a 'High' category have a price higher then $ 100 can be expressed by the following integrity constraint rule in the global schema:

```
rule Rule2 forall X in Food_Place :
   (X.category ='High') then X.price > 100;
```

```
interface Food_Place
{ attribute name
   mapping_rule ED.Fast_Food.name,
                FD.Brasserie.name,
                FD.Restaurant.name;
    ...
  attribute   category
   mapping_rule   ED.Fast_Food.category,
                  FD.Bistro.type,
                  FD.Restaurant.category;
  attribute   specialty
   mapping_rule   ED.Fast_Food.specialty,
                  FD.Restaurant.special_dish;
  attribute   address
   mapping_rule   ED.Fast_Food.address,
                  FD.Brasserie.address,
                  (FD.Restaurant.street and
                   FD.Restaurant.zip_code);
  attribute   price
   mapping_rule   ED.Fast_Food.midprice,
                  FD.Restaurant.tourist_menu_price;
  attribute  zone
   mapping_rule    ED.Fast_Food  = 'Pacific Coast',
                   FD.Bistro     = 'Atlantic Coast',
                   FD.Brasserie  = 'Atlantic Coast',
                   FD.Restaurant = 'Atlantic Coast';
}
```

Figure 2.15: Example of global class specification in ODL$_{I^3}$

2.4 Base Extension and Extensional Hierarchy

Base Extension and *Extensional Hierarchy* are used by MOMIS to optimize the execution cost of a query.

A base extension data structure describes how data (extensions) stored in different local classes overlap. For each global class, a set of base extensions is build which describes how local classes data overlaps.

The information required for building base extensions is both supplied by the *integration designer* in the form of extensional axioms, and is extracted also from the local schemata.

In this section we will use the following terms with these meanings:

- *Instance* represents one of the data structure instance of any local classes.
- *Object* represents one object in the reality. For example, a restaurant r, which is an example of a real world object. The object r is described in various data sources like the yellow pages database or the tax office database. In both such data sources there is at least one *instance* that refers to the same r *object*.

The main property of a **Base Extension** is that an *object* always belongs to a single base extension, which further groups all local classes containing the instances that

Food_Place	ED.Fast_Food	FD.Bistrot	FD.Brasserie	FD.Restaurant
name	name	*NULL*	name	name
code	*NULL*	r_code	b_code	r_code
owner	owner	pers_id	pers_id	*NULL*
phone	phone	*NULL*	*NULL*	*NULL*
nearby	nearby	*NULL*	*NULL*	*NULL*
category	category	type	*NULL*	category
specialty	specialty	*NULL*	*NULL*	special_dish
address	address	*NULL*	address	street and zip_code
price	midprice	*NULL*	*NULL*	tourist_menu_price
zone	'Pacific Coast'	'Atlantic Coast'	'Atlantic Coast'	'Atlantic Coast'

Figure 2.16: Food_Place mapping table

references the object.

The set of Base Extensions specific to each global class is then organized in such a way to optimize retrieving during global class querying. An **Extensional Hierarchy** is *intuitively* a specialisation hierarchy of basic extensions, based on the *attributes* common to the various basic extensions. The Extensional Hierarchy allows, given the attribute set of a query, to quickly retrieve the (minimal) set of basic extensions to query for obtaining the correct query answer with the minimal cost.

The algorithm for Base Extensions and Extensional Hierarchy computation is described in [SS98] starting from *Extensional relationships* (see section 2.1.3 on page 11) that we call also *extensional axioms*.

Base Extension and *Extensional Hierarchy* are *Global class* specific. Each global class has its own *Base Extension* and *Extensional Hierarchy*.

In the Masters thesis [Ven00] the theory related to the Base Extension and Extensional Hierarchy is described in detail, moreover it describes how such techniques are implemented in the **MOMIS** prototype.

Using Base Extension and Extensional Hierarchy

Here is a brief description of how Base Extension and Extensional Hierarchy technique are used in query execution optimization.

The execution plan is the following:

- generic queries containing joins are split in a set of *basic queries*. A *basic query* is a query on a single global class.
- each basic query is split into *local queries* to send to the source wrappers. This phase relies on Extensional Hierarchy and Base Extension in order to quickly choose local class involved by the basic query and generate the local queries.
- local queries are executed and the results are fused (using *join maps*, see section 2.5 on page 35) to obtain the basic query result set.
- last the join between the *basic queries* is computed in order to obtain the global query result set.

2.5 The Object Fusion problem: the Join Maps

The Object Fusion problem faces the problem of *how to identify entries in different local classes (from different data sources) that refer to the same* real world *object*.

This is a problem that the *query manager* should resolve at each query execution during the phase of *recomposition* of data coming from the local classes, according to the information given by the designer during integration phase.

Fusion ensures the correctness, completeness and minimality of the response but is not easy to implement. The following points basically exists:

- the mediator is not *owner* of the objects stored in local classes but only provides a global view. This mean that the mediator cannot impose a way to identify objects in the different sources. Each source may have its own techniques to retrieve objects, such as *keys* for relational sources and OID for object sources. Usually instance referring the same real word object are identified with different keys or OID, depending on the source such object is stored.
- it is necessary to study and use techniques to uniquely identify a given object across global schema and local sources.
- it is it is necessary to supply information to make such techniques work.

The **MOMIS** approach to *object fusion* is based on data structures called *Join Maps*. *Join Maps* are *extensional* relationships between *local classes* of the same global class; this fusion is performed on global classes object from local classes objects.

Join Maps are based on the implicit assumption of the existence of keys for the local Interfaces. A single Join Map relationship between (local) classes c_1 and c_2 expresses how uniquely *map* instances of c_1 and instances of c_2 specifying something like a join predicate. This is possible expressing the correspondence between the keys attributes of the two interfaces.

In **MOMIS** we faced the problem of automatically extracting as much *implied* Join Maps as possible, and how to manage fusion based on semantically homogeneous and heterogeneous keys.

By exploiting information, such as: extensional thesaurus relationships, terminological thesaurus relationships, extensional axioms, mapping table, and keys (primary and candidate) of the local classes, it is possible to compute automatically a number of possible Join Maps[2]. For example, we automatically extract a Join Map between two attributes a_1 and a_2 semantically homogeneous, when (1) the are respectively *key* for two local classes c_1 and c_2 mapped in the same global class, (2) exists a terminological *SYN* relationship between a_1 and a_2 and (3) are both mapped in the same global attribute.

Joins between local classes having heterogeneous keys is possible using an appropriate *conversion table*. Such table is imported in momis as any other local classes from a source connected by a wrapper.

Refer to the thesis [Fer00] for more details on *fusion* solution adopted in the **MOMIS** project.

[2] All Join Maps automatically computed must be validated by the designer

2.6 Related works

Works related to the issues discussed in this paper are in the area of semistructured data and heterogeneous information integration.

Heterogeneous information integration

In this area, many projects based on a mediator architecture have been developed. For example, the mediator-based TSIMMIS project [CMH+94] follows a 'structural' approach and uses a self-describing model (OEM) to represent heterogeneous data sources and pattern matching techniques to perform a predefined set of queries based on a query template.

The semantic knowledge is effectively encoded in the MSL (Mediator Specification Language) rules enforcing source integration at the mediator level. Although the generality and conciseness of OEM and MSL make this approach a good candidate for the integration of widely heterogeneous and semistructured information sources, a major drawback in such an approach is that dynamically adding sources is an expensive task. In fact, new TSIMMIS sources must first be wrapped and the mediator rules have to be redefined to take into account new knowledge and their MSL definitions recompiled. The administrator of the system must figure out whether and how the new sources have to be assimilated in the mediator. In our case, this information is automatically discovered by means of clustering.

MOMIS is based on a mediator architecture and follows the 'semantic approach'. Following the classification of integration systems proposed by Hull [Hul97], MOMIS is in the line of the "virtual approach" and is in the category of "read-only views"; that is, it is a system whose task is to support an integrated, read-only, view of data stored in multiple sources. The most similar projects are GARLIC, SIMS [AKH96], Information Manifold [LRO96] and Infomaster [GKD97].

The GARLIC project [CHS+94] builds up on a complex wrapper architecture to describe the local sources with an OO language (GDL), and on the definition of Garlic Complex Objects to manually unify the local sources to define a global schema.

The SIMS project [AKH96] proposes to create a global schema definition by exploiting the use of Description Logics (i.e., the LOOM language) for describing information sources. The use of a global schema allows both GARLIC and SIMS projects to support every possible user queries on the schema instead of a predefined subset of them.

Information Manifold system [LRO96], as the MOMIS project, provides a source independent and query independent mediator. The input schema of Information Manifold is a set of descriptions of the sources. Given a query, the system will create a plan for answering the query using the underlying source descriptions. Algorithms to decide the useful information sources and to generate the query plan have been implemented. The integrated schema is defined mainly manually by the designer, while in our approach it is tool-supported.

Infomaster [GKD97] provides integrated access to multiple distributed heterogeneous information sources giving the illusion of a centralized, homogeneous information system. It is based on a global schema, completely modeled by the user, and a core system that dynamically determines an efficient plan to answer the user's queries by using translation rules to harmonise possible heterogeneities across the sources.

An approach based on Description Logics and ontologies is taken in the OBSERVER

system to support semantic interoperation and formulation of rich queries over distributed information repositories where different vocabularies are used [MKSI96]. Here the idea is that each repository has its own ontology. Inter-ontology relationships are specified in a declarative way (using Description Logics) in an inter-ontology manager module to handle vocabulary heterogeneities between ontologies of different information repositories for query processing. In this respect, our Common Thesaurus plays a similar role in that we specify inter-source terminological relationships. The focus here is more on representation of inter-ontology relationships to solve vocabulary problems at the intensional and extensional level for query processing rather than on using these relationships for deriving an integrated virtual view of the underlying information sources. Moreover, in our approach, we try to extract as much information as possible from source descriptions and from WordNet and we show how this information can be used for affinity evaluation and integration purposes.

The analysis, discovery, and representation of inter-schema properties is another critical aspect of the integration process and research proposals have appeared on this topic. In [PSU98a], semi-automatic techniques for discovering synonyms, homonyms and object inclusion relationships from database schemas are described and a semi-automatic algorithm for integrating and abstracting database schemes is presented in [PSU98b]. It is worth noticing that the design of systems for information gathering from multiple sources is also addressed in Artificial Intelligence through multi-agent systems [LHK+98], concentrating mainly on high level tasks (e.g., o-operation, planning, belief revision) related to the extraction process [Dra97].

Object fusion

In this section, we will briefly discuss related works on Object fusion problem.

An interesting work on Object Fusion problem present in literature is [HST99] where a classification of heterogeneity in schema integration is presented. An architecture for schema mapping is also included. Object Fusion is solved by powerful rules stated by the BRIITY mapping language able to express conversion function and SQL *where* clauses.

One other interesting approach to the Object Fusion is the one implemented in the TSIMMIS mediator system [PAGM96, ea95]. In TSIMMIS it is assumed minimal knowledge of the structure and contents of the sources and have been developed optimisation techniques for data access to the fused objects. To represent such data, they use a *schema-less* object-oriented model, called Object Exchange Model (OEM). The approach to object fusion is based on semantic object identifiers specified by a set of declarative, logic rules. Each rule maps objects at a source that pertain to some identifiable real world entity, into a *virtual* object at the mediator. The virtual object is assigned a semantically meaningful object identifier. Mediator objects that have the same object-id are then fused together.

Semistructured data

The issue of modelling semistructured data has been investigated in the recent literature. In particular, a survey of problems concerning semistructured data modelling and querying is presented in [Bun97]. Two similar models for semistructured data have been proposed [BDHS96, PGMW95], based on rooted, labelled graph with the objects

as nodes and labels on edges. According to the model presented in [BDHS96], information resides at labels only, while according to the "Object Exchange Model" (OEM) proposed by Papakonstantinou et. al. in [PGMW95], information also resides at nodes.

Very similar proposals for modeling semi-structured data come from the Artificial Intelligence area [CGL98], where in analogy with our approach, a Description Logic is adopted. The issue of adding structure to semistructured data, which is more directly concerned with our concept of object pattern, has also been investigated. In particular, in [GW97], the notion of *dataguide* has been proposed as a "loose description of the structure of the data" actually stored in an information source. A proposal to infer structure in semistructured data has been presented in [NAM98], where the authors use a graph-based data model derived from [BDHS96, PGMW95].

In [Bun97], a new notion of a graph schema appropriate for rooted, labelled graph databases has been proposed. The main usages of the structure extracted from a semistructured source have been presented for query optimization. In fact, the existence of a path in the structure simplifies query evaluation by limiting the query only to data that are relevant. In this paper, we are more concerned with usage of the structure in form of object patterns to support the integration of semistructured sources with structured databases. More recently, XML [Bos97] has emerged in the framework of information representation over the Web allowing the designer to explicitly point out the semantic role of data within a source. Here, the notion of Document Type Definition (DTD) is introduced to model the structure of a set of documents. DTDs play a role similar to our object patterns and can be directly used to derive the ODL_{I^3} description of the information associated with them.

Original contributions of MOMIS w.r.t. previous works

The original contribution of the work presented in this chapter is related to the availability of a set of techniques for the designer to face common problems that arise when integrating pre-existing information source, containing both semistructured and structured data.

The idea of combining reasoning capabilities of Description Logics with affinity-based clustering techniques is new and allows both the validation of the inter-source knowledge used for the integration and the identification of candidates to integration in a way automated as much as possible.

The interactive exploitation of WordNet from within our tools combined with subsequent affinity analysis is also a novel capability for an integration tool. In this way, we can take into account and interactively revise semantic knowledge related to the meaning of names in the considered source description, as well as the structure of classes in source schema descriptions and their level of matching to come up with as much information as possible for the extraction of global integrated classes.

Furthermore, we provide the capability of explicitly introducing many kinds of knowledge such as: integrity constraints, extensional relationships and to check the global consistency of implicit and designer provided knowledge.

2.7 OLCD : Interpretations and database instances

We assume the union of the integers, the strings, the booleans, and the reals as the set $\mathcal{D}$ of *base values*. To build *complex values*, we further assume a countable, set disjoint

```
interface Fast_Food
( source semistructured  ED )
{ attribute string      name;
  attribute Address     address;
  attribute integer     phone?;
  attribute set<string> specialty;
  attribute string      category;
  attribute Fast_Food   nearby?;
  attribute integer     midprice?;
  attribute Owner       owner?;};

interface Address
( source semistructured ED ) {
   attribute string city;
   attribute string street;
   attribute string zipcode;
}; union  {
   string;
};

interface Owner ( source semistructured  ED )
{ attribute string   name;
  attribute Address  address;
  attribute string   job;};
```

Figure 2.17: Example source Eating_Source (ED)

from $\mathcal{D}$, of *object identifiers* (denoted by $o, o_1, o_2, \ldots$). The set $\mathcal{V}$ of all *values over* O is defined as the smallest set containing $\mathcal{D}$ and O, such that, if $v_1, \ldots, v_p$ are values, then the set $\{v_1, \ldots, v_p\}$ is a value, and a partial function $t\colon \mathbf{A} \rightarrow \{v_1, \ldots, v_p\}$ is a value. The function t is the usual tuple value; the standard notation $[a_1\colon v_1, \ldots, a_p\colon v_p]$ will be henceforth used. Let $=, \neq, >, <, \geq, \leq$ be the equality, inequality and total order relations, denoted by θ, defined as usual on $\mathcal{D}$. Equality and inequality can be extended from $\mathcal{D}$ to all $\mathcal{V}$: the equality operator ($=$) has the meaning of *identity*, i.e., two objects are equal if they have the same identifier, two sets are equal iff they have equal elements, two tuples, say $v_a = [a_1\colon v_1, \ldots, a_p\colon v_p]$ $v_b = [a'_1\colon v'_1, \ldots, a'_q\colon v'_q]$, are equal if they have the same attributes and equal attribute labels are mapped to equal values. Object identifiers are assigned values by a *total value function* δ from O to $\mathcal{V}$. Let $\mathbf{W}$ denote the set of all paths. Given a set of object identifiers O and a value function δ, let $\mathcal{J}\colon \mathbf{W} \longrightarrow 2^{\mathcal{V}\times\mathcal{V}}$ a function defined as follows:

- empty path: $\mathcal{J}[\epsilon] = \Big\{(v, v) \in \mathcal{V} \times \mathcal{V}\Big\}$
- single element path:
  $\mathcal{J}[a] = \Big\{(v_1, v_2) \in \mathcal{V} \times \mathcal{V} \mid v_1 = [\ldots, a : v_2, \ldots]\Big\}$
  $\mathcal{J}[\triangle] = \Big\{(o, v) \in O \times \mathcal{V} \mid \delta(o) = v\Big\}$
- multiple element path: $\mathcal{J}[e_1 \,.\, e_2 \,.\, \cdots \,.\, e_n] = \mathcal{J}[e_1] \circ \mathcal{J}[e_2] \circ \cdots \circ \mathcal{J}[e_n]$
  where $\circ$ is the symbol of function composition.

Notice that, for all p, $\mathcal{J}[p]$ is undefined on set values. Let v be a value and p be a path. By $\mathcal{J}[p](v)$ we mean the unique value (when it exists) reachable from v following p, that is the value of the partial function $\mathcal{J}[p]$ in v. Let $\mathcal{I}_{\mathbf{B}}$ be the (fixed) standard interpretation function from $\mathbf{B}$ to $2^{\mathcal{D}}$. For a given object assignment δ, each type expression S is mapped to a set of values (its interpretation). An *interpretation function* is a function $\mathcal{I}$ from $\mathbf{S}$ to $2^{\mathcal{V}}$ satisfying the following equations:

$$
\begin{aligned}
\mathcal{I}[\top] &= \mathcal{V} \\
\mathcal{I}[\bot] &= \emptyset \\
\mathcal{I}[B] &= \mathcal{I}_{\mathbf{B}}[B] \\
\mathcal{I}[\{S\}_\forall] &= \{M \mid M \subseteq \mathcal{I}[S]\} \\
\mathcal{I}[\{S\}_\exists] &= \{M \mid M \cap \mathcal{I}[S] \neq \emptyset\} \\
\mathcal{I}\Big[[a_1 : S_1, \ldots, a_p : S_p]\Big] &= \{t\colon \mathbf{A} \to \mathcal{V} \mid t(a_i) \in \mathcal{I}[S_i], 1 \leq i \leq p\} \\
\mathcal{I}[S_1 \sqcap S_2] &= \mathcal{I}[S_1] \cap \mathcal{I}[S_2] \\
\mathcal{I}[S_1 \sqcup S_2] &= \mathcal{I}[S_1] \cup \mathcal{I}[S_2] \\
\mathcal{I}[\neg S] &= \mathcal{V} \setminus \mathcal{I}[S] \\
\mathcal{I}[\triangle S] &= \left\{ o \in O \,\middle|\, \delta(o) \in \mathcal{I}[S] \right\} \\
\mathcal{I}[(p \theta d)] &= \left\{ v \in \mathcal{V} \mid \mathcal{J}[p](v) \theta d \right\} \\
\mathcal{I}[(p\uparrow)] &= \{v \in \mathcal{V} \mid v \notin \text{ dom } \mathcal{J}[p]\}
\end{aligned}
$$

Note that the interpretation of tuples implies an open world semantics for tuple types similar to the one adopted by Cardelli [Car84], and that $(p\uparrow)$ selects objects which do not have the path p.

It should be noted than an interpretation does not necessarily imply that the extension of a named type is identical to the type description associated with the type name via the schema σ. For this purpose, we have to further constrain the interpretation function: An interpretation function $\mathcal{I}$ is a *legal instance* of a schema σ iff the set O is finite, and for all $N \in \mathbf{N}$: $\begin{array}{ll} \mathcal{I}[N] \subseteq \mathcal{I}[\sigma_P(N)] & \text{if } N \in \text{dom } \sigma_P \\ \mathcal{I}[N] = \mathcal{I}[\sigma_V(N)] & \text{if } N \in \text{dom } \sigma_V \end{array}$ From the above definition, we see that the interpretation of a primitive type name *is included* in the interpretation of its description, while the interpretation of a virtual type *is* the interpretation of its description. In other words, the interpretation of a primitive type name has to be provided by the user, according to the given description, while the interpretation of a virtual type name is drawn from its definition and from the interpretation of primitive type names, thus corresponding to a view in database context. Given a type S of a schema σ, we say that S is *consistent* if and only if there is a legal instance $\mathcal{I}$ of σ such that $\mathcal{I}[S] \neq \emptyset$. Given two types S_1, S_2 of a schema σ, we say that S_1 *subsumes* S_2 iff $\mathcal{I}[S_1] \supseteq \mathcal{I}[S_2]$ for all legal instances $\mathcal{I}$ of σ.

```
interface Restaurant
  ( source relational FD
    key (r_code)
    foreign_key(pers_id) references Person
  ) {
    attribute string         r_code;
    attribute string         name;
    attribute string         street;
    attribute string         zip_code;
    attribute integer        pers_id;
    attribute string         special_dish;
    attribute integer        category;
    attribute integer        tourist_menu_price;
};

interface Person
  ( source relational FD
    key (pers_id)
  ) {
    attribute integer pers_id;
    attribute string  first_name;
    attribute string  last_name;
    attribute integer qualification;
};

interface Bistro
  ( source relational FD
    key (r_code)
    foreign_key (r_code)  references Restaurant
    foreign_key (pers_id) references Person
  ){
    attribute string      r_code;
    attribute set<string> type;
    attribute integer     pers_id;
};

interface Brasserie
  ( source relational FD
    key (b_code)
  ){
    attribute string  b_code;
    attribute string  name;
    attribute string  address;
};
```

Figure 2.18: Example source Food_Guide_Source (FD)

Chapter 3

The MOMIS Prototype: Architecture and Implementation

The **MOMIS** prototype is a software of about 100 thousands lines of Java code and was (and will be) developed by several people. To develop a coherent system, reusing code as much as possible, we needed a effective and clean architecture and a set of small tools (like makefiles or start script) to manage the system.
In this chapter, the **MOMIS** architecture the software organization are described[1].
During my Ph.D. studies I set up most of the architecture described in this chapter, both software (organization of software development directories and tools) and organizational (a web site for the development coordination).

3.1 Introduction

The **MOMIS** system is designed for schema integration. Figure 3.1 shows the architecture of the system in terms of functional modules. The system is composed by several object that communicates using the CORBA [Groa] standard.
The object are:

Wrappers Each data source (relational, object, XML, ...) must be presented to **MOMIS** in a standard way, and this is what the wrappers do. Each object represents a data structure (see section 3.5 for a detailed description).

SI-Designer SI-Designer is the GUI (Graphic User Interface) for the **MOMIS** Global Schema Builder. Its goal is to lead designer from the schemata acquisition of sources to the tuning of the mapping table through the various steps of the integration. This is the client object that uses other server objects (see chapter 4 for a detailed description).

[1] We describe many details; this is written to be a quick reference for people who will be part of the **MOMIS** development team

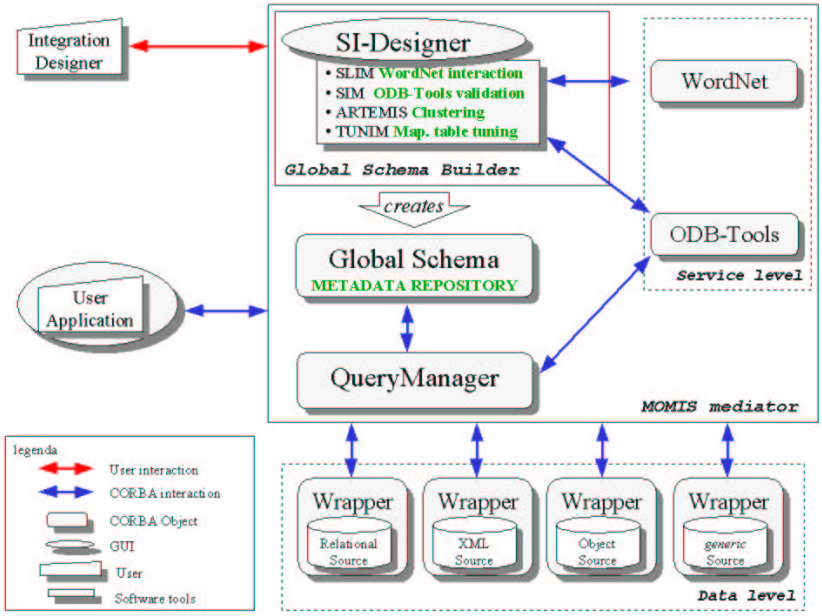

Figure 3.1: **MOMIS** prototype architecture

WordNet This is the server whose object provides the access to the WordNet, and that is able to extract lexicon derived intensional relationships between attributes and classes, exploiting the lexical relationships contained in the WordNet lexical system (see section 3.6 for a detailed description).

ODB-Tools This object provides access to the ODB-Tools prototype. ODB-Tool is a framework for object-oriented database (OODB) schema validation, preserving taxonomy coherence and performing taxonomic inference, and semantic query optimization (see section 3.7 for a detailed description).

Global Schema A Global Schema object contains all information for querying the resulting global schema by a queryies manager object. Such object is produced by the SI-Designer GUI and contains the sources schemata, the thesaurus, and the mapping table (see section 3.8 for a detailed description).

Query Manager A Global Schema object uses information produced during the integration steps to query a global schema. It is able to divide a query on the global schema in a set of query for the local sources and to merge results (for further information see the Silvia Zanni's thesis [Zan00] in Italian).

This chapter describes module implementation and all the organizational infrastructures to support the software development.

3.2 Overview of organizational infrastructures

In developing the **MOMIS** protype we had to spread development work between several developers, assigning to each person the responsibility of a part of the prototype.

To coordinate the development team we periodically have group meetings and set up a development private (password protected) web site and one mailing list.

The development site is the official media for group communication. All meetings, news and choices are reported through the site.

Each group member can modify both the source code directory and the development site directory, has the responsibility to develop part of the **MOMIS** software and maintain updated the corresponding documentation. Such documentation is related both to theoretical aspects and implementation architecture choices.

It is mandatory for each group member to present his work at meetings using documents written in HTML stored on the development web site. This guarantees that the development site content is constantly updated.

Other information present on the coordination site includes:

- *The group agenda*, document that contains a synthesis of all group meetings.
- *The to-do document*, containing constantly updated future work divided by *Theoretical aspects*, *Product re-engineering* and *Implementation aspects*.
- *The conventions document*, describing guidelines and standards shared by the group members.
- *The how-to document*, a few practical how-to to solve most common problems.
- *The know bugs document*.

Nowadays we have a 10 Mega bytes of on-line hand made documentation on modules.

Moreover, other services provided through the development site are the access to all manuals (such as CORBA specification, and Java API and tutorial) and **MOMIS** prototype source code documentation generated by *javadoc* (roughly 7 Mega bytes).

We found meetings, mailing list and development web site very useful tools for knowledge sharing and coordination.

3.3 Overview of software organization

Software development directories are divided in different packages; this allows several people to work together on the prototype development. The development documentation is a collection of HTML pages where the documentation structure is cloned by the software structure.

Each development member is responsible for its assigned project module and should maintain aligned both software and documentation.

Following a *macro* distinction between the **MOMIS** prototype, components can be divided into the following directories:

- *shared components* Contains code (libraries) that is shared by all **MOMIS** modules like the package `odli3`, the parser for ODL$_{I^3}$ and several *tools* classes.
- *server* Contains the implementation of CORBA server objects, main momis servant and factory objects. These are the main interface for accessing the **MOMIS** distributed integration services. Basically it contains the implementation for the *Momis Factory*, the *Global Schema* and the *Query Manager* servers.
- *modules* Every code that is not a server or a shared library, every application that is related or developed for the **MOMIS** project is stored in this directory.

Before examining the content of each one of the cited directories, let me say a few words on the other *service* directories and files present in the root directory of the **MOMIS** prototype.

Prototype directories structure

- *applications* contains all *demonstration* application developed for or using the **MOMIS** prototype.
- *declarationsIDL* Contains the IDL CORBA declaration for all the **MOMIS** CORBA interfaces.
- *doc* contains source code documentation produced by JavaDoc for the whole **MOMIS** prototype code.
- *lib* contains Java libraries used by several modules. It contains, for example, the libraries for XML parsing and management.
- *utilities* contains miscellaneous Java tools.
- *var* contains log and Pid (Process identifier) files for the running **MOMIS** server objects (such as wrappers or WordNet interface).
- *bat* contains all script to start the **MOMIS** prototype on MS Windows systems.

Important files

- *0setVars* Script (for both `csh` and `bash`) for setting environment variable for the **MOMIS** prototype.
- *momis.conf* is the *configuration file* for all the **MOMIS** server objects. Each server, starting, reads configuration from this file.
- *startMomis* is a *bash* script to start and stop

General conventions for directories In the *important* directory there are *special proposal* files or directories with the following functions:

- `0note.txt`: file used to add development notes and documentation for the current dir. Usually contains a brief description of *what* the directory contains, instructions for using the software implemented in the directory, and a (optional) *file by file* description of the directory content.

  I wrote a small *perl* program called `ldir`, to help to manage the 0note.tex file.

- `Makefile`: this file describes *how to do* the following actions: *compile* the code contained in the current directory from source code, *clean* the directory from compiled classes and all useless files generated during development, and generate the documentation for the code contained in the current directory in the directory *doc*.

- `doc`: this dir contains the documentation generated from the source code.

The rest of this section will be devoted to the most important directories and files.

The starting script `startMomis`

As shown in Figure 3.2, the script `startMomis` in the momis prototype development main directory is able to start or stop all **MOMIS** services or to start or stop the single service, including the most commonly used wrappers.

```
Start or stop MOMIS components
sintax:   ./startMomis (start|stop) [option]

where "option" are:
 n  name server
 m  MOMIS factory server
 o  ODB-Tools
 w  CORBA_WordNet
 wd1  Wrapper dummy Univers
 wd2  Wrapper dummy University

 Example:
  to start ODB-Tools use:
     ./startMomis start o

 TO START THE WHOLE MOMIS:
     ./startMomis start

 TO STOP THE WHOLE MOMIS:
     ./startMomis stop
```

Figure 3.2: The hints from the `startMomis` script

This script maintains the process number and the log file for each managed server object generating files with extensions respectively `.pid` and `.log` in the directory `var`, the file name without extension identifies the *server*.

The *pid* file is created each time a server is started and is removed when the server is stopped and contains the *Pid* to kill to stop the server.

Starting MOMIS under Windows

We brought the **MOMIS** prototype on the MS Windows platform. We did not have to recompile a single file, but we had to write a set of scripts to start servers in Windows. Such scripts are the following:

- `setVars.bat` called from the other scripts, sets the common environment variables
- `0startMomis_naming.bat` Starts naming server
- `1startMomis_services.bat` Starts basic Momis services, MomisFactory and WordNetServer
- `SIDesigner.bat` Start a new session of SI-Designer

The configuration file `momis.conf`

In figure 3.3 the `momis.conf` file currently used is shown. With this file we can specify several configuration parameters such as the CORBA naming server address, the server time out period, where to write temporary files and where are located ODB-Tools commands in the system.

The `modules` component directory

This directory contains the *modules* used by the MOMIS prototype such as:

```
#
#
# Configuration file for the MOMIS prototype
#
#
orbPort=1050
orbServer=sparc20.dsi.unimo.it
#
# Time out in seconds
timeOutGracePeriod=28800
timeOutCheckPeriod=3600

#
# OdbTools parameters
#
#
# name for the registration in the naming server
odbt_namingName=odbt
#
# dir where write the tmp files
odbt_dirTmp=/tmp/
#
# command used to limit the system resources at each run
odbt_limitaCommand=/export/home/progetti.comuni/Momis/prototype/\
            modules/ODBTools/_sorgentiC/odbtools/limita 10
odbt_odlTrasl=/export/home/progetti.comuni/Momis/prototype/modules\
            /ODBTools/_sorgentiC/odbtools/odl_trasl
#
odbt_olcdDesigner=/export/home/progetti.comuni/Momis/prototype\
            /modules/ODBTools/_sorgentiC/odbtools/ocdl-designer
odbt_odbqo=/export/home/progetti.comuni/Momis/prototype/modules\
            /ODBTools/_sorgentiC/odbtools/odbqo

#
# Global Schema parameters
#

#
# mext: Momis Extensional knowledge management
mext_namingName=mextServer
```

Figure 3.3: **MOMIS** main configuration file `momis.conf`

- `ODBTools` This module implements a CORBA interface of the Description logics based Object Schema optimization tool.
- `SIDesigner` Main **MOMIS** Graphical User Interface. This module leads the Designer in integration from local schema acquisition to the definition of the mapping tables.
- `WordNet` Implementation of the CORBA interface for the WordNet ontology. The server directly accesses the database files of WordNet and implements *Thesaurus relations* extraction capabilities.
- `wrapperAccess` This is a MOMIS Wrapper for MS Access.
- `wrapperClient` MOMIS simple MOMIS Wrapper client. Allows access to all wrappers functionalities through a command line text interface.
- `wrapperDummy` MOMIS Wrapper for files, the only action is to return as description the content of a given file
- `wrapperJDBC` MOMIS Wrapper for JDBC data sources
- `wrapperXMLg` MOMIS Wrapper for XML documents.

3.4 The shared component directory

This directory contains all java code shared by all servers and **MOMIS** modules. This directory must be included in the CLASSPATH to run almost all **MOMIS** tools.

This directory contains the following files:

- Parser.java generated from odli3.y by byacc/j [Jam], is the parser for the ODL$_{I^3}$ language. From an ODL$_{I^3}$ stream it generates *in memory* object representation using the classes of the odli3 package.
- GSStatus.java nowadays is a *serializable* object that stores all java objects produced during the **MOMIS** integration phase using SI-Designer.
- GlobalSchemaProxy.java this class supplies facilities to access, serialize, save and load a GSStatus object including the communication with GlobalSchema CORBA objects.

This directory contains packages that implement Java *Stubs* and *Skeleton* for the CORBA interfaces generated using idlj command starting from the IDL definition in the declarationsIDL directory.

In addiction, the following fundamental packages are implemented:

- *odli3* Contains classes to manage the ODL$_{I^3}$ language
- *globalschema* Contains classes to manage integration steps like mapping table or join maps.
- *tools* Contains several classes that implements useful features like the management of *time out* or read a configuration file.

For further information about classes and implementation see the documentation generated by javadoc, it can be request from the webmaster of the **MOMIS** web site [Grob].

3.4.1 The ODL$_{I^3}$ classes and the Parser

During my thesis I modified the parser and some data structure in the ODL$_{I^3}$ package created by Alberto Zanoli (see [Zan99]).

This package contains all data structures used for the local classes description.

Figure 3.4 showns the list of the classes in the odli3 package preserving ordered to show the inheritance hierarchy. For example, it contains Java classes that describe types where odli3.Type is the ancestor class and odli3.StructType is a leaf class that inherits from odli3.ConstrType and then from odli3.Type.

Major changes I made to the package are described in the following subsections.

Introduction of MomisObject

All the objects of the package odli3 inherit from the MomisObject. This was done to eventually add features shared by all *odli3* object.

This feature is used by the SI-Designer to save the status of its component modules. Each component module of SI-Designer saves a single object in the *additional info* of the current schema using as key a name what is unique for the module.

```
class java.lang.Object
  class odli3.Error (implements java.io.Serializable)
  class odli3.MomisObject (implements java.io.Serializable)
    class odli3.Attribute (implements java.io.Serializable)
      class odli3.GlobalAttribute (implements java.io.Serializable)
      class odli3.Relationship (implements java.io.Serializable)
      class odli3.SimpleAttribute (implements java.io.Serializable)
    class odli3.CandidateKey (implements java.io.Serializable)
    class odli3.Case (implements java.io.Serializable)
    class odli3.Constant (implements java.io.Serializable)
    class odli3.ForeignKey (implements java.io.Serializable)
    class odli3.KeyList (implements java.io.Serializable)
    class odli3.MappingRule (implements java.io.Serializable)
      class odli3.AndList (implements java.io.Serializable)
      class odli3.AttributeOnly (implements java.io.Serializable)
      class odli3.DefaultValue (implements java.io.Serializable)
      class odli3.UnionList (implements java.io.Serializable)
    class odli3.Operation (implements java.io.Serializable)
    class odli3.OpVar (implements java.io.Serializable)
    class odli3.Rule (implements java.io.Serializable)
      class odli3.CaseRule (implements java.io.Serializable)
      class odli3.ExtRule
      class odli3.ForallRule (implements java.io.Serializable)
    class odli3.RuleBody (implements java.io.Serializable)
      class odli3.Compare (implements java.io.Serializable)
      class odli3.ForallExist (implements java.io.Serializable)
        class odli3.Exist (implements java.io.Serializable)
        class odli3.Forall (implements java.io.Serializable)
      class odli3.In (implements java.io.Serializable)
      class odli3.RuleOperation (implements java.io.Serializable)
    class odli3.RuleOpArg (implements java.io.Serializable)
      class odli3.DotNameArg (implements java.io.Serializable)
      class odli3.ValueArg (implements java.io.Serializable)
    class odli3.StructVar (implements java.io.Serializable)
    class odli3.ThesRelation (implements java.io.Serializable)
      class odli3.AttributeRel (implements java.io.Serializable)
      class odli3.AttrIntRel (implements java.io.Serializable)
      class odli3.InterfaceRel (implements java.io.Serializable)
    class odli3.Type (implements java.io.Serializable)
      class odli3.TypeToSolve (implements java.io.Serializable)
      class odli3.ValueType (implements java.io.Serializable)
        class odli3.ConstrType (implements java.io.Serializable)
          class odli3.EnumType (implements java.io.Serializable)
          class odli3.StructType (implements java.io.Serializable)
          class odli3.UnionType (implements java.io.Serializable)
        class odli3.SimpleType (implements java.io.Serializable)
          class odli3.BaseType (implements java.io.Serializable)
            class odli3.AnyType (implements java.io.Serializable)
            class odli3.BooleanType (implements java.io.Serializable)
            class odli3.CharType (implements java.io.Serializable)
            class odli3.FloatingType (implements java.io.Serializable)
            class odli3.IntegerType (implements java.io.Serializable)
            class odli3.OctetType (implements java.io.Serializable)
            class odli3.RangeType (implements java.io.Serializable)
            class odli3.StringType (implements java.io.Serializable)
          class odli3.DefinedType (implements java.io.Serializable)
          class odli3.TemplateType (implements java.io.Serializable)
            class odli3.ArraySequence (implements java.io.Serializable)
            class odli3.BagType (implements java.io.Serializable)
            class odli3.ListType (implements java.io.Serializable)
            class odli3.SetType (implements java.io.Serializable)
    class odli3.TypeContainer (implements java.io.Serializable)
      class odli3.IntBody (implements java.io.Serializable)
      class odli3.Interface (implements java.io.Serializable)
      class odli3.Module (implements java.io.Serializable)
      class odli3.Schema (implements java.io.Serializable)
      class odli3.Source (implements java.io.Serializable)
  class java.lang.Throwable (implements java.io.Serializable)
    class java.lang.Exception
      class odli3.OdlException
```

Figure 3.4: Hierarchy tree of the classes of the `odli3` package

When the *schema* that contains the whole integration status object is serialized and saved, the status objects of the component modules are saved too.

Introduction of TypeContainer

To allow a nested definition, we needed a uniform way to store types. Now the data type containers (IntBody, Interface, Module, Schema, Source) inherited types management facilities from this object. In addiction, this enables a way to resolve types identified by identifier in a post-processing phase.

Types managed by this object are: constants, types defined through typedef, enums, interfaces, modules, rules, structs, thesaurus relations, types to be solved in a post processing phase and unions.

Each container also knows his parent, and this allows the inherited data types to be found.

Methods defined for each data type by this Object, for example, for the struct type are:

```
public StructType getStruct(java.lang.String name)
public void addStruct(StructType c) throws OdlException
public void addStructs(java.lang.Object[] c)
                throws OdlException
public java.lang.Object[] getStructs()
```

The search method `getStruct` performs the recursive search back from parent to parent up to the top element of the schema tree. Similar methods are defined for the other kinds of data managed by the `TypeContainer` objects.

Types name post parsing resolution

The `Parser` has been modified to accept recursive definitions and ODL *modules*.

During parsing all types referenced by identifier (not basic types) or foreign keys are used without any control of existence because the definition could be after that point of elaboration. These types are accepted as `TypeToSolve` and for each `TypeContainer` there is trace of all such `TypeToSolve`.

In post parsing processing, all references leaved *to be resolved* must be checked and resolved. This process is performed by two methods defined in the class `TypeContainer`:

- `solveUnsolvedForeignKeys`: This method tries to solve unsolved references for: Foreign Keys, Keylist and Thesaurus relations. It also verifies that there are no duplicated Thesaurus relations. If any reference is not correct, an exception `OdlException` is thrown.

- `solveUnsolved`: Tries to solve types defined by typedef, for each interfaces an attribute list is built since (because of the *union* clause) the same name of attribute could be associated with different attributes (differing in type).

  Since types can be defined in schema, interfaces and modules, these procedures are recursive through the object tree that describes the ODL$_{I^3}$ schema.

  Type solved are: Interfaces, types defined by TypeDef and ExtRule.

  These are recursively solved in the following sub-type-container: Interfaces, Modules, IntBody.

`toOdl` implementation

This feature exports the content of the `odli3` classes into a ODL$_{I^3}$ format.

This feature has been implemented defining the `toOdl` method for each `odli3` class. Calling such method on the (top level) `Schema` object will produce the ODL$_{I^3}$ description of the schema and of all its sub-components like `typedef`s interfaces, attributes, const, etc. recursively calling the `toOdl` method for each sub-components.

The produced ODL$_{I^3}$ code will reflect the in memory data structure where are allowed nested module definitions.

`toOlcd` implementation

This features exports the content of the `odli3` classes into a *olcd* format ready to be used by ODB-Tool for schema validation.

Olcd is the input data format recognized by ODB-Tools. Since ODL$_{I^3}$ is richer than *Olcd*, information is lost during the conversion and the process is not reversible.

This feature has been implemented defining the `toOlcd` method for (almost) each class in the package `odli3`. The method invocation on high level objects, causes the recursive call of the method on every sub-component.

Tables 3.1, 3.2 and 3.3 shows how this *function* maps the types. Figure 3.5 shows an example of mapping, since in *olcd* yet the concept of union or `or` does not exist. All attributes of all `InterfaceBodies` of an interface are mapped as attributes in *olcd*. Attributes with the same name are *duplicated* using unique names.

```
interface Course
 ( source object Univers
   extent Courses
   key (course_name) )
{  attribute string course_name;
   attribute Professor taught_by;  }
union Course_1
{  attribute string course_name;
   attribute string course_description;
   attribute Professor taught_by;  };
```

is mapped as:

```
prim Course = ^ [
      course_name : string ,
      taught_by : Professor ,
      course_desc : string ,
      course_name0 : string ,
      taught_by0 : Professor ] ;
```

Figure 3.5: Example of /odli3/ to *olcd* mapping

`toOlcdSimB` implementation

toOlcdSimB is a feature very similar to *toOlcd* (see section 3.4.1 on page 52) but is used to implement Thesaurus Relationships validation and inference (by the module SIMb).

This method will create a virtual schema (see section 2.2.6 on page 21 for more information) described in OLCD to be passed to ODB-Tools for Thesaurus Relationships

ODL	OLCD
any	*top*
boolean	bool
char	string
double	real
float	real
int	integer
long	integer
short	integer
string	string
unsigned short	integer
unsigned long	integer

Table 3.1: Mapping between ODL$_{I^3}$ and *olcd* simple data types

ODL	OLCD
type [] (arrays)	< type > *(list of)*
list	< > *(list of)*
bag	{ } *(set of)*
set	{ } *(set of)*

Table 3.2: Mapping between ODL$_{I^3}$ and *olcd* of collections

validation and inference.

A main characteristic of this feature is that *Thesaurus Relationships* contribute in Interface definition.

NT lexical relationships cause the Interface to inherit from the Broader Interface.

RT interface cause the definition of dummy attributes that links to the *related¿* interface.

SYN relationships cause the Interface to be grouped in a set of Synonym Interface. These interfaces share the same definition in terms of Parent Interfaces and attributes. The parent Interfaces of each of the synonym Interfaces is given by the union of the Interface each Interface inherits from or takes part in a NT or BT relationship. The set of attribute is given by the union of the attributes each interface inherits from. RT relationship that give rise to the RT dummy attributes is given by the union of the RT relationship that involves at least one Interface in the SYN group.

Introduction of `ThesaurusByObject`

This class speeds up relationships retrieving from a Schema object. All the ThesRelation objects are organized in `Map` objects where keys are the element as ODL$_{I^3}$ Objects of the `ThesRelation` objects.

This object is constructed over a schema and indexes all thesaurus relations contained by such schema giving a set of method for fast access to set of relations.

To index relations a *HashMap* is used, which allows information (objects) to be related to a given *key* object, thus providing a fast way to retrieve such information given the *key* object.

ODL	OLCD
interface	prim
view	virt
const	btype
struct	type
typedef	type

Table 3.3: Mapping between ODL$_{I^3}$ and *olcd* of *elements*

This object provides methods like:

- *Set getRelations(java.lang.Object element)* that returns a set of ThesRelations related to a given element.
- *Set getRelations(java.lang.Object element1, java.lang.Object element2)* that returns a set of ThesRelations between the given elements.
- *Set getSynRelations(java.lang.Object element)* Returns all the *synonymy* relation for a given Element
- *Set getInterfaceParentRelations(Interface element)* Given an interface, returns all `InterfaceRel` relations where the given Interface is narrow term *NT* to another Interface. Note that MOMIS stores all InterfaceRel as NT relations (broad term - BT relations are transformed in NT by the constructors). So it is enough to look for the relations where the given interface appears as FIRST element.

And so on. All interesting and used queries at the thesaurus are coded in this object and are usable by all MOMIS components.

3.5 The MOMIS wrappers

The wrappers in **MOMIS** are the access point for the data sources. Each data source (relational, object, XML, ...) must be presented to the **MOMIS** system in a standard way, and this is what the wrapper does. A wrapper is a CORBA object that is connected to a source and is able to describe the source structure using the ODL$_{I^3}$ language and supplies a way to query to source using the OQL$_{I^3}$ language.
This section shows the interface for accessing wrapper features and an overview of the wrappers I implemented for my Ph.d. thesis.

3.5.1 The IDL interface for a wrapper

Figure 3.6 shows the CORBA interface implemented by the Wrapper Objects. The functions available are:
getType returns the type of the wrapper.
getSourceName returns the name of the data source. The returned name is only the name the designer of the wrapper assigned to the data source, it is not a universal name.

```
interface Wrapper {
 string getType() raises (momisOqlException);
 string getDescription() raises (momisOqlException);
 MomisResultSet runQuery( in string oql )
              raises (momisOqlException);
 string getSourceName() raises (momisOqlException);
};
```

Figure 3.6: The **MOMIS** Wrapper IDL interface

getDescription This function asks the source the meta-information about the schema and produces a ODL$_{I^3}$ description of the source schema and returns it to the CORBA client as a string.

runQuery This function causes the source to evaluate a OQL$_{I^3}$ query and generates a `MomisResultSet` CORBA object that (like a cursor) allow to access to the resulting data set.

```
interface MomisResultSet {
 long getColumnCount()               raises (momisOqlException);
 string getColumnName(in long column) raises (momisOqlException);
 long getColumnType(in long column)   raises (momisOqlException);
 boolean next()                       raises (momisOqlException);
 void close()                         raises (momisOqlException);
 long getColumnByName(in string column) raises (momisOqlException);
 long getLong(in long column)         raises (momisOqlException);
 char getChar(in long column)         raises (momisOqlException);
 double getDouble(in long column)     raises (momisOqlException);
 float getFloat(in long column)       raises (momisOqlException);
 string getString(in long column)     raises (momisOqlException);
 string stringSet();
 const long TYPE_Unsupported  = -1; /* Unsupported Type */
 const long TYPE_Long   = 1;
 const long TYPE_Char   = 2;
 const long TYPE_Double = 3;
 const long TYPE_Float  = 4;
 const long TYPE_String = 5;
};
```

Figure 3.7: The MomisResultSet IDL interface

Figure 3.7 shows the MomisResultSet CORBA interface. It is a very simple cursor implementation. We can also see that MOMIS data types recognized through wrappers is very poor related to the data types supported by ODL$_{I^3}$.

3.5.2 The dummy wrapper

The dummy wrapper is the simplest wrapper we can implement. It is not associated with any data source and, it reads the schema description directly from a file containing a ODL$_{I^3}$ description. Obviously it is not able to reply to query requests.

This wrapper is parametrized to select in which naming server register itself as CORBA

object. Other parameters are also the registration name and the name of the file containing the ODL_{I^3} source description.

3.5.3 The JDBC wrapper

This is quite a real wrapper which means that it has both source introspection and source querying capabilities. Both these features are provided through standard JDBC calls. This ensure that this wrapper can be used for all data management systems that support JDBC.

On starting the wrapper it reads a configuration file that contains parameters for the JDBC connection like JDBC driver to use and the connection string, as well as other CORBA parameters that specifiy where is the naming server and the name to use for registering in the naming server.

The main object is a factory object because it generates a new `MomisResultSet` object each time the method *runQuery* is called. In the configuration file parameters are also specified for managing time-out of unused MomisResultSet objects.

The introspection of the source is performed using the `ResultSetMetaData` objects. Using JDBC-1 does not make certain finformation vavailable like are not available information like foreign or primary key definitions or constraints, so the description returned by this wrapper contains only a the list of tables that are mapped into /odli3/ classes and, for each class, a list of typed attributes.

The querying feature is implemented without applying any filter to the /oqli3/ query and is sent as-is to the underlying data source management system. This implies that the wrapper works fine only in cases of extremely simple queries where /oqli3/ queries are SQL queries. This is not a strong assumption because the /momis/ Query manager is also able to formulate only basic (very simple) queries towards local data sources.

3.5.4 Other wrappers

During the project development other wrappers were developed and others are in developing phase. Among the developed ones we should cite the XML wrapper, see [Gue00], which does not have the querying capabilities yet because the XML-QL is not yet a stable standard.

Other wrappers in developing are the wrapper based on JDBC 2.0 that will make it possible to obtain richer description of the source or ad-hoc wrapper like wrappers for DBMS like MS Access, IBM DB2 and Oracle.

3.6 The MOMIS WordNet interface

WordNet is a lexical database introduced in section 2.1.5 on page 15.

The **MOMIS** WordNet module was developed by Giovanni Malvezzi [Mal00] and implements a technique to find intensional relations inter-schema. The goal is to discover affinities/similitude between classes from different data sources. The modules extract lexical relations between schema element names (classes and attributes are the elements) and works on the meaning of the names used to describe the classes and attributes content.

This module provides access to the WordNet ontology by accessing the database files directly, it has been designed for use by the SLIM module of the SI-Designer GUI.
It is possible to extract from WordNet the following types of lexical relations:

Synonymy, **Hypernomy**[2], **Hyponomy**[3], **Holonomy**[4], **Meronomy**[5], **Correlation**[6]

Where Hyponomy and Meronomy are respectively inverse relations of Hypernomy and Holonomy.
The relations from WordNet are proposed as semantic relations to be added to the *Common Thesaurus* according to the following mapping:

- **Synonymy**: corresponds to a SYN relation.
- **Hypernomy**: corresponds to a BT relation.
- **Holonomy**: corresponds to a RT relation.
- **Correlation**: corresponds to a RT relation.

The *Common Thesaurus* must contains only semantic relations, so the WordNet module only proposes relations to the designer, who must validate them manually to promote lexical relations to semantic relations.
The modules implement an algorithm that, given the schema elements annotated (manually by the designer through a GUI) with the right meaning, produces all semantic relations present in the ontology.
Starting from the schema to be integrated, the designer must declare a relation between each schema elements names (class names or attribute names) and the WordNet meaning used in the context. That is, given a name, the designer must choose one or more of the name meanings.
This is a two step process.

1. **Word form choice.** In this step, the WordNet morphologic processor should aid the designer. A *word form* is the word without any suffixes due to declination of conjugation.

   For example, in Figure 3.8, by selecting the `address` attribute the morphologic processor returns the base form `address`.

   If such *word form* is not found or there is ambiguity[7], or it is not satisfactory, the designer can set a custom *word form*.

2. **Sense choice.** The designer can choose to set the mapping of an element with zero, one or more senses. For example, in figure 3.8 WordNet has 15 meanings for the *word form* `address` from which the most appropriate ones are chosen.

Figure 3.9 shows the interface to access the **MOMIS** WordNet service. A short description of the available methods follows:

[2]Generalization relation
[3]Specialization relation
[4]Aggregation relation, *part*
[5]Aggregation relation, *all*
[6]The correlation is a relation between two terms in two synonym sets that shares the same father in hypernymy sense.
[7]E.g. `axes` has 3 word forms: `ax` (1 sense), `axis` (5 senses), `axe` (2 senses).

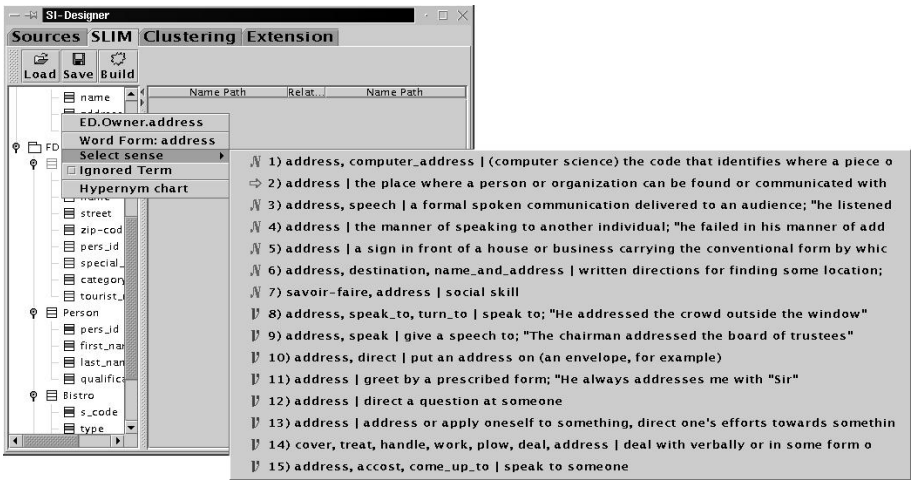

Figure 3.8: `address` meanings

```
module WordNetApp {
  interface CORBA_WordNet {
    string trovaSensi( in string word);
    string trovaParenti( in string formaBase,
            in long synset_offset, in long pos);
    string creaThes( in string namePathTaged);
    string trovaHashObject( in string word);
    long killObject();
  };
  interface WordNetFactory {
     CORBA_WordNet newCORBA_WordNet();
  };
};
```

Figure 3.9: The **MOMIS** WordNet module IDL interface

- trovaSensi means search for meanings. When given a word, it runs the morphological engine to find the *word form*. It returns a string that contains the *serialization* or a Java *Vector* of objects (`wn2slim.Meaning`) that represents WordNet meanings.
- trovaParenti means search for Parents. Given a word in a normalized form, the reference position of the synset and number that identifies the *type* of WordNet element (*noun*, *verb*, *adjective*, *adverb*), it calculates the sense's expansion to his near senses. It returns a Vector of serialized meanings.
- `creaThes` means create thesaurus. When given a string that contains the serialized form of a `wn2slim.NodeTag` vector, it returns a set of lexical relations to be added to the thesaurus. This set is given by a string that contains the serialized form of `wn2slim.ThesaurusEntry` vector.
- `trovaHashObject` searches for hypernymy tree for the *noun* syntax category. When given a *word form*, it returns all its hypernyms.

Because of the complexity of the data structure used in the WordNet interaction, the

choice (at least in this development phase where the whole prototype is evolving) was made not to pass through complex CORBA IDL interfaces and objects, but insetad to use serialized java objects.

To exchange data, the WordNet module uses the *shared* package `wn2slim`, where object that represents *Synset*, *ThesaurusEntry*, schema elements identifier, etc. are implemented.

For more information about the `wn2slim` interface, refer to the `javadoc` documentation and to [Mal00]

3.7 The MOMIS ODB-Tools interface

This section describes the module that allows access to the ODB-Tools [BBSV97b, BBSV97c] services through CORBA.

ODB-Tools is an integrated environment for object-oriented database (OODB) schemata validation and semantic query optimization, based on a description logic kernel [BN94], preserving taxonomy coherence and performing taxonomic inferences.

```
module OdbToolsApplic {
  interface OdbTools {
     string translate_Odl_Olcd ( in string odl, out string olcd );
     string translate_Odl_Olcd_vf ( in string odl,
                                    out string olcd,
                                    out string vf );

     string validate_Odl ( in string odl, out string fc );
     string validate_Odl_XML ( in string odl, out string xmlf );
     string validate_olcd_XML ( in string olcd, out string xmlf );
     string validate_OdlSS ( out string fc );
     string validate_OdlSS_vf ( out string fc, out string vf );
     string optimize_Oql ( in string odl, in string oql, out string stdOut  );
     string optimize_OqlSS ( in string oql );
     string optimize_OqlSS_vf ( in string oql, out string vf );
     long killObject();
  };
  interface OdbToolsFactory  {
     OdbTools newServant ( in string description );
  };
};
```

Figure 3.10: The ODB-Tools IDL interface

We developed a CORBA application to use ODB-TOOLS services through CORBA. Such application is made of a server side and a client side. The server part provides standard CORBA services accessible by CORBA clients.

To access the server we wrote two client applications, a *textual* client and a *graphical* client. The *Textual* client is simple and can be invoked from a command line or in batch scripts. The *Graphical* client has a user friendly interface (figure 3.11) to access ODB-Tools services. It can be executed as a Java application or applet, and contains `ScVisualTool` tool to visualize optimizations graphically.

Moreover, in order to access ODB-Tools from another CORBA application, the only things to know are (1) the *idl* interface and (2) the address of the computer on which CORBA objects resides (at present, *sparc20.dsi.unimo.it* on port 1050)).

The server side services are described by the IDL description shown in figure 3.10 and

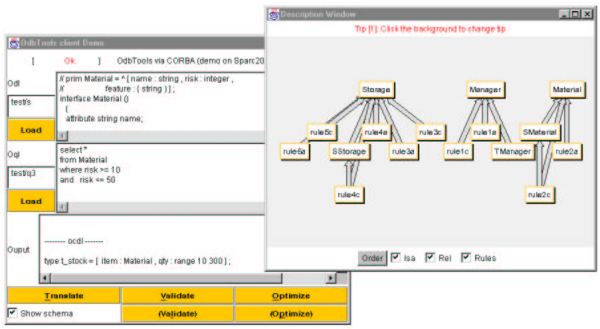

Figure 3.11: Graphical interface

correspond to the following ODB-Tools services:

OdbTool describes the *servant* object supplying ODB-Tools services invoked by the following operations:

- **translate_Odl_Olcd** translates a ODBMS schema from ODL (an ODL ODMG extension) to *OLCD* [BBLS98][8].
- **translate_Odl_Olcd_vf** Translates a schema described in ODL into a OLCD description returning also a *visual form* description used by the `ScVisual` GUI.
- **validate_Odl** Translates and validates schema described in ODL. ODB-Tools internally, translates the schema into OLCD and runs the Validator. The validator optimizes the schema and, if it exists, signals incoherences.
- **validate_Odl_XML** Works as `validate_Odl` but output is returned also in XML.
- **validate_olcd_XML** Validates (optimize) a schema described in OLCD and returns a XML file. ODB-Tools runs the Validator directly on the OLCD schema and signals any incoherences. Output is returned in XML. This is the method that used by **MOMIS**.
- **validate_OdlSS** Activates the validation and optimization of a previously translated schema. The `validate_Odl` translates and validates and optimizes a schema described in ODL[8].
- **validate_OdlSS_vf** Works as `validate_OdlSS` and a *visual form* is also returned.
- **optimize_Oql** Optimizes a OQL query on a ODL schema. The ODB-Tools query optimizer optimizes a OQL query on a given schema.
- **optimize_OqlSS** Optimizes an *OQL* (ODMG) query on a previously validated schema. `optimize_Oql` optimizes a query on a ODL schema by performing schema translation and validation and query optimization steps[8].
- **killServer** *De-allocates* the connection *servant* object. This operation should be invoked by a *client* before closing connection; if not, the *servant* object will also be de-allocated after a time-out period.

idlOT_factory Describes a *factory* object, i.e., the CORBA object to refer to in order

[8] `translate_Odl_Olcd_vf`, `validate_OdlSS_vf` and `optimize_OqlSS_vf` supply the same services of the three methods above, but generate a schema description in *visual form* (see [Cor97]).

to open a connection.

newServer Opens a new connection, i.e., creates a new *servant* object instance whose reference is posted to the *client*.

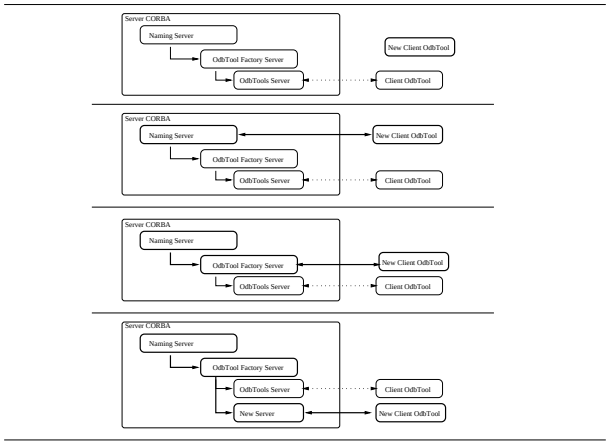

Figure 3.12: Request of a new client connection

In the implementation, the main ODB-Tools object is a *factory object* (interface `idlOT_factory`); for each client connection request a new *servant object* (interface `idlOdbTool`) is created and its reference is returned to the client (see figure 3.12).

The XML representation

The SIM module of the SI-Designer uses ODB-Tools to perform Thesaurus relation validation and inference. To provide a *standard* way to get ODB-Tools results we modified the ODB-Tools so to generate an XML output as well.

Such XML adheres to the DTD showed in figure 3.13:

The corresponding client should use a XML parser to get ODB-Tools data.

3.8 The MOMIS Global Schema

The role of a Global Schema object is to represent an integrated schema. It contains all information about integration such as the defined global classes, the mapping tables, the thesaurus and the description of the schema of the integrated sources.

This information will allow any *query manager* to perform queries on the represented integrated schema.

Nowadays, the Global Schema is an extremely simple component. Figure 3.14 shows the IDL interface to access a *GlobalSchema* object.

The method simply allows a client to access the schema name (`getName` and `setName`) or the schema status (`getStatus` and `setStatus`).

The status is exchanged as a serialized `GSStatus` Java object. This object is defined in the *shared* directory and basically contains a `odli3.Schema` object, i.e., the root

```
<!ELEMENT SCHEMA (LEVEL*)>
<!ELEMENT LEVEL (
      CLASSES_TO_DISPLAY,
      EQU,
      CLASSES_COLORS,
      ISA,
      ISA_COLORS,
      RELATIONS_TO_DISPLAY
      )>
<!ATTLIST LEVEL value CDATA #REQUIRED
                type  CDATA #IMPLIED>

<!ELEMENT CLASSES_TO_DISPLAY (CLASS*)>
<!ELEMENT EQU (RELEQU*)>
<!ELEMENT CLASSES_COLORS (color*)>
<!ELEMENT ISA (RELISA*)>
<!ELEMENT ISA_COLORS (color*)>
<!ELEMENT RELATIONS_TO_DISPLAY (RELATION*)>

<!ELEMENT CLASS (CLASS*)>
<!ATTLIST CLASS  name CDATA #REQUIRED >

<!ELEMENT ATTRIBUTE ()>
<!ATTLIST ATTRIBUTE  type CDATA #REQUIRED
                     name CDATA #REQUIRED >

<!ELEMENT RELEQU ()>
<!ATTLIST RELEQU     c1 CDATA #REQUIRED
                     c2 CDATA #REQUIRED >

<!ELEMENT color ()>
<!ATTLIST color      class CDATA #REQUIRED
                     value CDATA #REQUIRED >

<!ELEMENT RELISA ()>
<!ATTLIST RELISA     c1 CDATA #REQUIRED
                     c2 CDATA #REQUIRED >

<!ELEMENT RELATION ()>
<!ATTLIST RELATION   target CDATA #REQUIRED
                     source CDATA #REQUIRED
                     path CDATA #REQUIRED >
```

Figure 3.13: The ODB-Tools XML ouput Document Type Definition

of the tree of objects that maintains information about sources, thesaurus and global classes.

A CORBA GlobalSchema object is accessible through an instance of the class `GlobalSchemaProxy`. This manages CORBA connection and status serialization (see [Gui00]).

```
interface GlobalSchema {
   void setName(in string name);
   string getName();
   string getStatus();
   void setStatus(in string status);
   long killObject();
};
```

Figure 3.14: The Query Manager IDL Interface

Chapter 4

The MOMIS SI-Designer

This chapter presents the **MOMIS** module `SI-Designer`, architecture and user's manual. SI-Designer is the GUI (Graphic User Interface) for the **MOMIS** Global Schema Builder. SI-Designer leads the designer through the steps of the integration process, from the acquisition of schemata sources to the tuning of the mapping table.

This is the most important component of the **MOMIS** prototype; it is a modular container of tools implemented by different people.

In this chapter, we focus on the strategic choices and concepts related to the SI-Designer software. Most of the implementation choices are described in the source code documentation, so for further information refer to the documentation extracted from the source code by `javadoc`.

4.1 The SI-Designer architecture

Most of SI-Designer modules have been developed by several students during computer engineering Laurea thesis. Their goal was to analyze, design and implement one of the integrations phases described in the theory.

My role was to define and project the modular architecture to allow people to work together, establish set of guidelines for development and coordinate the students.

Figure 4.1 shows the main objects SI-Designer is composed of. For an overview of the **MOMIS** architecture, see chapter 3.

- `SI_Designer`, the main container, is a GUI object. It is responsible for CORBA connections (through a *proxy*) towards MOMIS servers and manage all other sub-modules.
  It also maintains also the *schema* object that holds all integration information and is responsible for its initialization and serialization, it also allows saving it and allows saving it on disk.
- `GlobalSchemaProxy` is the object responsible for the creation of the *Global Schema* CORBA object.
  This maintains aligned the *Global Schema* and a local working copy of the integration knowledge (i.e. all integration information like the local schemata description, the thesaurus, etc.).
- `SIDPhase` Each panel that implements a different function inherits from this

class the features to communicate with the `SI_Designer`.

- The objects `ARM`, `ARTEMIS`, `EXTM`, `SAM`, `SIM`, `joinMap`, `testPackage`, `thesRelationEditor`, `SLIM` and `TUNIM` are the modules that compose the SI-Designer interface.

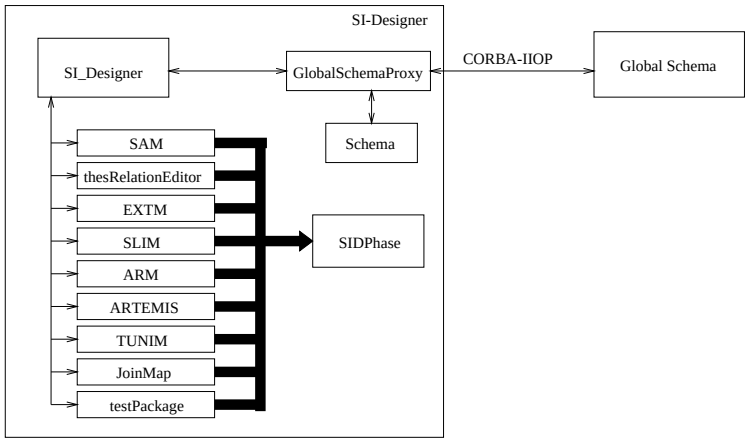

Figure 4.1: SI-Designer run-time architecture

4.2 An integration session

In this section, a whole integration session, from source wrapping to the tuning of the mapping tables, using SI-Designer is shown.

In the following *macro* steps for the integration in an ideal sequential order are described. Each step is highly interactive, the designer usually acquires better and better knowledge of the source to be integrated during integration, so, in a real integration session, the designer will move back and forth through the integration phases.

Wrapping of the sources

The first step of the integration using **MOMIS** is to prepare data sources to be accessed by **MOMIS**. Each source should be wrapped using the most appropriate Wrapper. We developed a very simple and generic JDBC wrapper (see section 3.5.3) but it may be necessary to develop an ad hoc wrapper for a specific data source.

Whoever runs the Wrapper must choose the source name and register the running Wrapper into a naming server accessible by SI-Designer.

Wrappers for a given source should be initialized and run by the responsible of the source.

Choosing a significant name for the global view

(Figure 4.2) The SI-Designer integration session starts choosing a significant name for the global schema we will build.

Source connection/acquisition

Each source, or better, the wrapper of each source to be integrated, is reached by the CORBA naming service: one need only to state the registration name and the naming service address where the wrapper is registered.

If there are two (or more) sources with the same name, SI-Designer will ask you to *internally* rename sources with the same name. This will be the name of the source in SI-Designer.

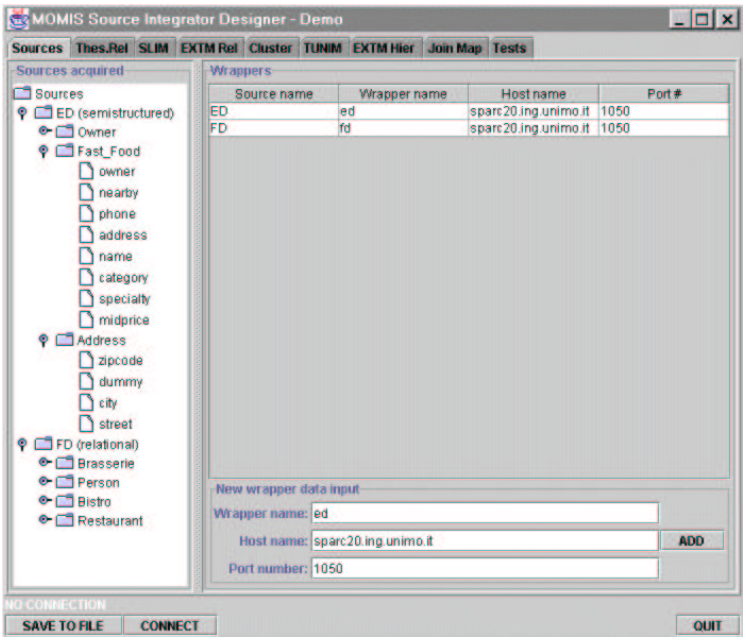

Figure 4.2: SI-Designer source acquisition module

For each source, SI-Designer reads the source description and shows the sources in terms of local classes and attributes on the left of the SI-Designer window (see Figure 4.2).

Computation of intra-schema relationships

Figure 4.3 shows the panel that enables the designer to browse and edit Thesaurus Relationships. Clicking the button *run SIM* the ODB-Tools CORBA service is called and intra schemata relations (see section 2.2.1 on page 18) extracted.

WordNet annotation and Lexical relationships extraction

Figure 4.4 shows the panel that allows the designer to annotate the schema to be integrated (see section 2.1.5 on page 16 and 3.6 on page 57). Figure 4.5 shows Common Thesaurus terminological relationships extracted from WordNet.

Validation of lexical relationships and inference of new relationships

After the terminological relationship extraction, clicking on the button *run SIMb* on the Common Thesaurus relationship editor panel, ODB-Tools service is called again to validate and infer new relationships (see section 2.2.4 on page 20 and 2.2.5 on page 21). Figure 4.6 shows again relationships in the common thesaurus, after the validation phase.

Creation of proposed Global Classes

Figure 4.7 shows a screen shot of the interface for running and tuning the ARTEMIS Clustering/affinity algorithm (see section 2.3.1 on page 24). The clustering tool can be tuned by working on clustering thresholds and relation weights. In the lower part of the window, a text area shows the trace of the intermediate results during the run of the ARTEMIS algorithm.

In addition Figures 4.8 and 4.9 show the panel for tuning the proposed global classes. Cluster of local classes computed by ARTEMIS are proposed as Global Classes, and the designer can rename or modify the composition of such Global Classes.

Creation of the global class attributes and mapping table

The last step of integration (with the current version of SI-Designer) is the Creation and tuning of the global class attribute mapping table (see section 2.3.2). After the simple mapping (Figure 4.10) an attribute aggregation is proposed, and the designer can then refine the mapping (Figure 4.11).

4.3 Methodological considerations

This section gives a few hints for the correct use of *SI-Designer* derived from our experience.

Relationships editor hints

The module shown in Figure 4.3 is designed to manage the *Common Thesaurus* relationships.

Through this module it is possible to run the extraction from schemata, validation of relationships and new relationship inferential algorithms on the schemata.

The designer can also choose to manually add or remove relationships.

We suggest running the inferential algorithm after each new thesaurus relationships is added in order to detect immediately if the new relationship generates inconsistences.

It is possible to iteratively refine the clustering adding or removing relationships. To find the relationships to add or remove to improve clustering, try to look at the cluster coefficients.

The displayed relationships are the ones used by the ARTEMIS algorithm to compute global classes by clustering.

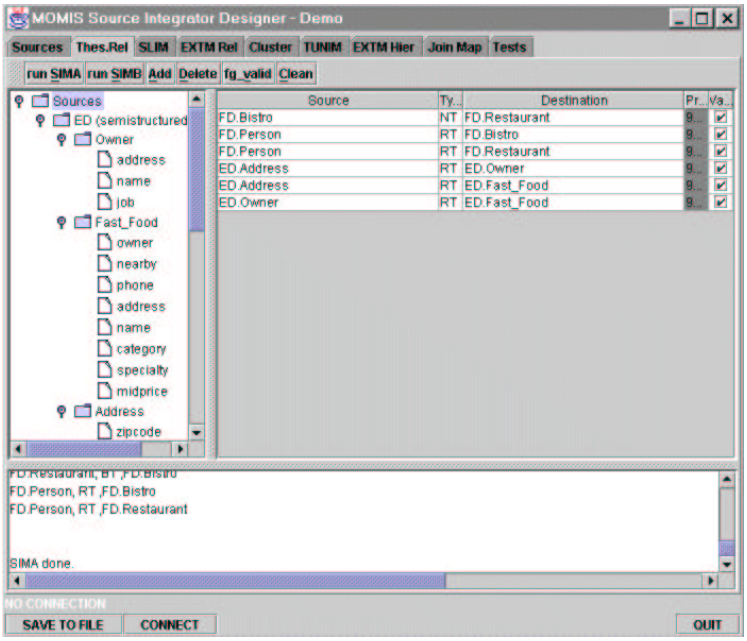

Figure 4.3: SI-Designer SIM: computation of intra-schema relationships

Lexical annotation hints

The SLIM module shown in Figure 4.4 allows interaction with WordNet. It graphically allows the designer to associate WordNet meanings to every schema element, then retrieve from WordNet lexical relationships between such meanings and convert them into (not yet validated) common thesaurus relationships.

This is the most sensible point in integration, if a schema is well when annotated the integration time and effort can dramatically be reduced.

Main rules to follow annotating are:

- Annotate every local class, taking care to choose the WordNet meaning that best corresponds with the reality the local schema describes. Context is very important.
- If the word form for the element is not significant, replace it with a meaningful word and choose the *right* meaning.
- Annotate only significant attributes.
  Attribute present in all interfaces like *name* , *code* or *identifier* could lead to the generation of wrong relationships.
  For example, *name* has the right meaning associated to the Interface name. It could mean person name, city name, or the name of anything. This mean that (*wrong*) relationships between the interface *Person* and *City*, or *Person* and anything could be generated, and so on.
- Annotate only elements you are sure about the meaning.
  If you are not sure, you should study the data source to be integrated better, and then annotate the elements.

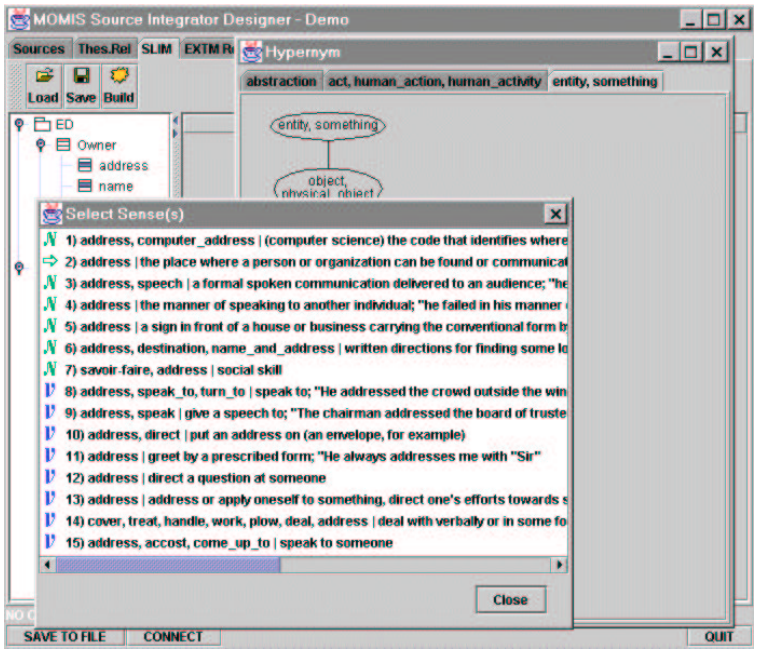

Figure 4.4: SI-Designer SLIM module, WordNet annotation

Clustering tuning hints

Remember that clustering is strictly implied by the relationships present in the thesaurus. If the relationships are wrong *it is not possible* to automatically extract a good cluster.

For a better understanding of the clustering algorithm (the ARTEMIS tool) and concepts like *naming affinity* and *structural affinity*, see section 2.3.1 on page 24;

The tuning parameters for the clustering are the following (see Figure 4.7).

- The relationship weights.
  When working on these parameters we can to give more or less importance to *this* or *that* kind of relationship.
  For example, if we have a schema with a lot of RT relationship and the number of clusters is too high, we can try to lower the weight of the RT relationship and recompute the clusters.
- The affinity threshold.
  This parameter gives an index of reliability to the *naming affinity*.
  The clustering will be affected by the naming affinity only if the naming affinity coefficient is higher than the threshold.
- The clustering threshold.
  This xparameter that influences the width of clusters. The higher the threshold, the smaller the computed clusters are because a high affinity is needed between Interfaces to be part of the same cluster.
  In case of good clustering, this parameter chooses the number of clusters vs the number of local classes in each cluster.
  To have one idea of the tree clustering quality, look at the *Clustering Tree* (like

the ones showed in Figure 4.14). From this tree you can see the *distances* in terms of affinity values between Interfaces.
If the instances the designer knows to be strictly related are represented as near tree leaves, the *tree structure* is good, and by increasing or decreasing the clustering threshold we can to obtain good clusters.
We can also try to modify other tuning parameters or study the relationships present in the thesaurus.

- The *name affinity* and the *structural affinity* coefficients.
  These parameters simply give more importance to the *name* or the *structural* affinity while weighing the affinity between Interfaces. The clustering algorithm will then use such weights to compute clusters.
  The higher the *name affinity parameter*, the higher the importance of the *name affinity*. The same goes for *structural affinity*.

Global classes tuning hints

(Figure 4.9) This is very important step.

In this phase the designer chooses the composition of the global classes. No one can guarantee that the semiautomatic model proposed by **MOMIS** is correct (usually indeed there are a few errors) and it is the responsibility of the designer to perform the right tuning.

An important step is to assign the right name to the global classes. This will help the designer gather local classes by meaning.

The designer is the judge. Right mapping relies on the designer's experience and knowledge of the sources acquired during the previous phases.

It is correct to leave some useless local classes unmapped (even if it would be better if these useless local classes where not exported by the source wrapper).

Mapping table tuning hints

In this phase the designer chooses for each *global class* how each attribute of each local class that is part of the global class is mapped into the global class global attributes.

Like for the Global classes tuning, here the experience and knowledge of the designer are the basis to obtain the *right* mapping.

4.4 Implementation

This section describes some concepts, data structures and techniques implemented in SI-Designer, and modules I implemented.

4.4.1 The *SIDPhase* interface

Each module of SI-Designer must implement this interface. Through the methods defined in this interface we can to share integration knowledge through SI-Designer modules and provide a simple way for coordination between modules.

The methods implemented by this interface include:

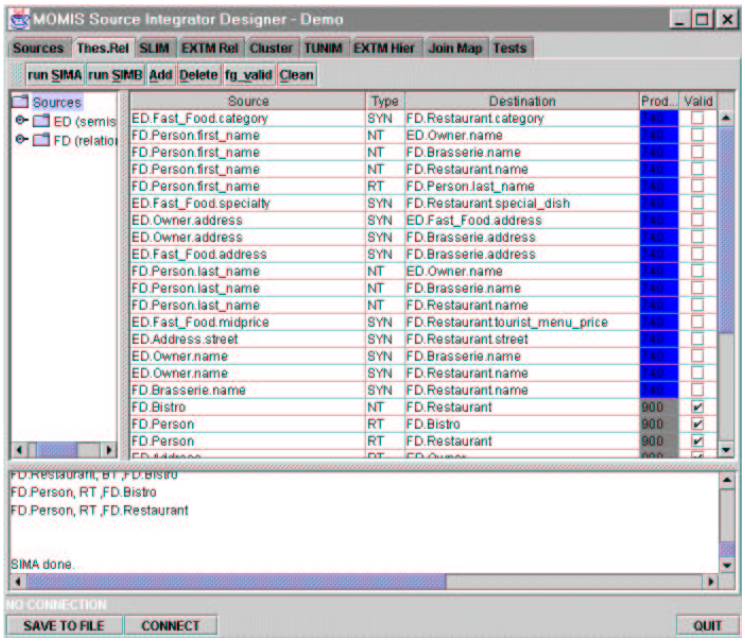

Figure 4.5: SI-Designer Part of the relationship extracted from WordNet

- *GlobalSchemaProxy getProxy()* Returns the Global schema proxy object. This is the way to retrieve and modify schema information. The `GlobalSchemaProxy` object is in fact responsible for maintainingn the GlobalSchema data repository aligned with the local copy.
- *void update() throws SIDException* This method is called by SI-Designer each time the module is displayed.
- *void saveStatus() throws SIDException* This method is called by SI-Designer each time the module loses focus.

The strategy for module coordination implemented by the SIDPhase interface is the following:

- When the user decides to get into the module, the module using the method *getProxy* is responsible for loading the module status from the main *Schema* object (that contains all information related to the integration).
- When the user decides to change module, the module is responsible for saving its status and all module information into the *Schema* object.

4.4.2 Saving and exchanging knowledge in MOMIS

Here we discuss various features adopted to save, retrieve and share Integration knowledge.
Problems related to status in **MOMIS** are:

- how to interrupt and resume an SI-Designer integration session

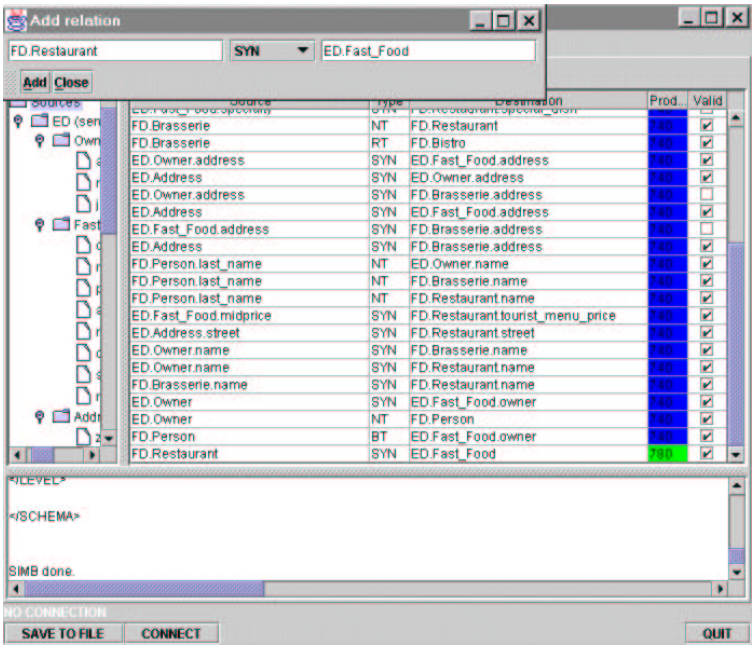

Figure 4.6: SI-Designer SIM: relationship are validated and new relationships inferred

- how to allow users to run query managers using the integration structures created by SI-Designer.

We needed a fast, reliable and easy solution to save and communicate the integration knowledge that is carried by many *complex* memory data structures.

Our choice was to use Java Object Serialization , sparing ourselves the worry of defining description languages or data interchange specifications.

We supported serialization in the main code of SI-Designer (i.e., the class *SI-Designer*) allowing the designer to save, whenever he wants, the status of the session. Once saved, it is possible to start a new SI-Designer session specifying a serialized status using the option:

```
java SI-Designer -l /path/to/the/seriealizedStatus.mms
```

We also used serialization to exchange data using the CORBA connections. The idea was to use strings containing serialized Java Objects. We did it using a *base 64* coding technique to overcome problems due to different charset representation. Each time we serialize an object we transform the resulting binary stream in a *base 64* codes sting. Deserializing, at first we decode the *base 64* string in a binary stream that can be deserialized. We use this technique when saving SI-Designer status and when communicatating between the SLIM module and the WordNet CORBA interface.

The main disadvantage in using java serialization is that, especially in developing phases, once a class c is modified, all old serialized status containing the c class become incompatible with the new recompiled java code. This mean that all existing *integration* must be redone.

We are currently studying and developing tools for *automatically* serializing any seri-

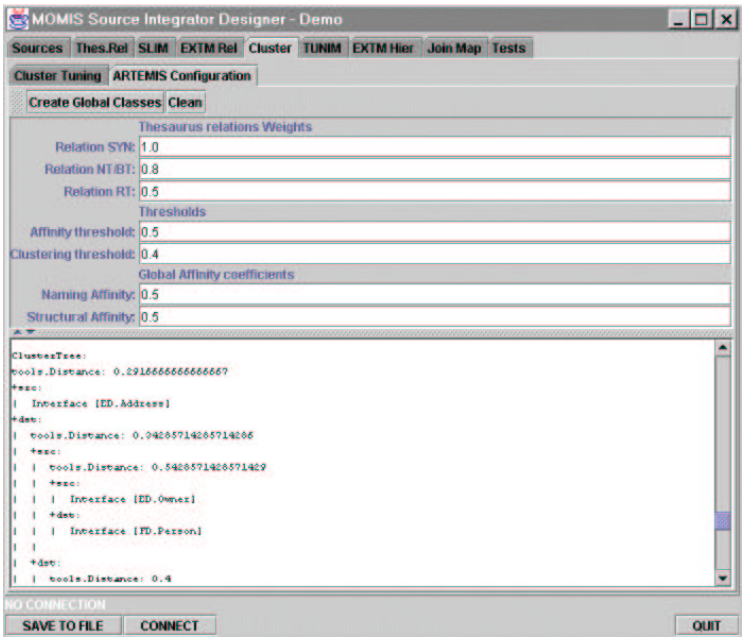

Figure 4.7: SI-Designer the ARTEMIS clustering parameters

alizable java Object in XML (even if in *Sun* there is an analogous project).

Using XML we expect the following advantages: less of a problem passing through different versions of serialized java classes, human readability of the serialized code (if needed we can manually modify or create a status) and, above all, better portability for integrating information. Using XML easy parsing capabilities, and XML translation languages like XSL, it will be easy to exchange integration knowledge with applications requiring them like other mediators.

4.4.3 The Common Thesaurus Editor module

This module, an example of which is given in Figure 4.6, allows the designer to browse and edit relationships defined in the Common Thesaurus.

It shows relationships in different colors according to the module producer of the relationships. For example, relationships extracted from schema are shown in *dark gray*; terminological relationships from WordNet in *blue*, inferred relationships in *red*, and designer manually added relationships in *green*.

Moreover, the thesaurus editor make it possible to show the relation ordered by source, by type (SYN, NT, BT, RT), by destination or by producer. One need only to click on the corresponding header to sort the relationships on the chosen column.

Edit capabilities allow the designer to remove any relationship from the thesaurus, or, add explicitly new relationships.

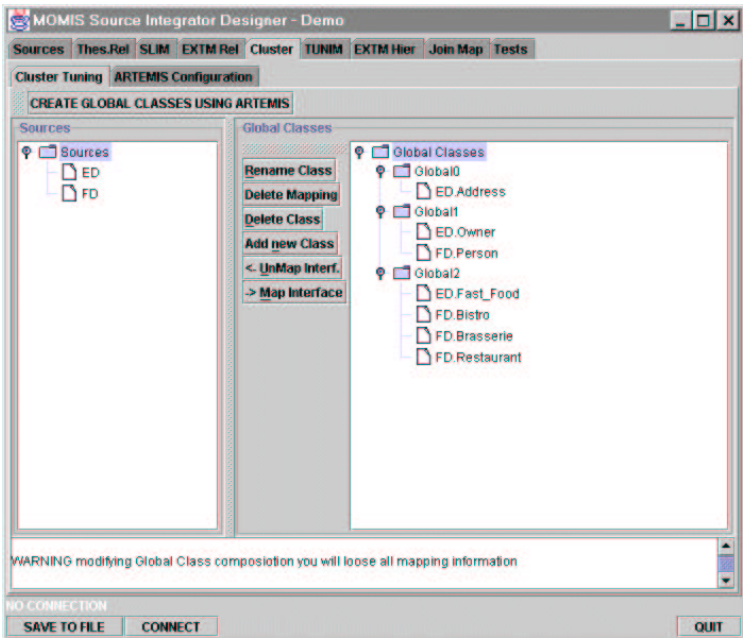

Figure 4.8: SI-Designer the clusters produced by ARTEMIS as proposed global classes

4.4.4 The ARTEMIS module

In this section implementation related problems and solutions are presented. The theory related to ARTEMIS was presented in section 2.3.1.

A lot of information about implementation like the detailed description of all the methods or the description of the objects private variable is also omitted; these details are available in the documentation extracted from the source code by `javadoc`.

In designing the ARTEMIS I adhered to the following guidelines:

- ARTEMIS must be a package,
- all the algorithms must be located in a *well interfaced* object,
- development should be as fast as possible,
- the source code should be as readable as possible.

To build a package was not a problem. Moreover, the architecture of SI-Designer requires that modules be developed in packages. To develop the prototype quickly and get the code readable I relied on a strongly Object Oriented architecture and developed a few tools for managing distance graphs.

Object part of the ARTEMIS package

The main class implemented has been called *Artemis* and contains all ARTEMIS computation algorithms. Its interface is the following:

- *public Artemis(GlobalSchemaProxy schemaProxy)* is the constructor. An ARTEMIS object contains a reference to the *GlobalSchemaProxy*. In this way it is alwais

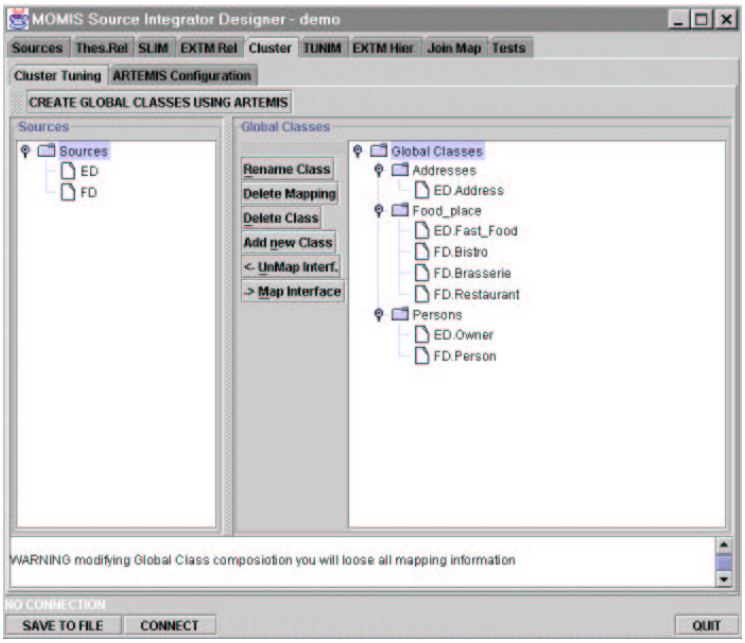

Figure 4.9: SI-Designer global classes after the designer tuning

able to access to the current schema to get/save the ARTEMIS status or to get thesaurus relationships.

- *void saveStatusInSchema()* Save the status of this Artemis Object into the schema reachable by *schemaProxy*;
- *void doClustering()* Call all computing routines getting the clustering. This is only one shortcut to perform the steps provide by calling the methods in sequence: *computeInitialDistanceMatrix*, *computeNameAffinity*, *computeStructuralAffinity()*, *computeGlobalAffinity()*, *computeClustering()* and *computeClustersFromClusterTree()*.
- *void computeInitialDistanceMatrix()* Computes the Initial Distance Matrix. This method simply translates the relationship present in the thesaurus in *affinity*, according to the coefficient chosen by the designer.
- *void computeNameAffinity()* Computes the Name Affinity using an interactive algorithm. This algorithm will find the maximum affinity between each element trying any possible path (see below for a better description).
- *void computeStructuralAffinity()* Computes the Structural Affinity from the Schema structure and the naming affinity matrix (see section 2.3.1 for a theoretical description of this algorithm.
- *void computeGlobalAffinity()* Computes the Global Affinity from the Structural affinity matrix and the Naming affinity matrix.
- *void computeClustering()* Computes the affinity tree from the Global affinity matrix.
- *Void computeClustersFromClusterTree()* From the affinity tree produced by *computeClustering* this method divides local classes in clusters.
- *static void populateGlobalClassesFromClusters()* From clusters (vector of vec-

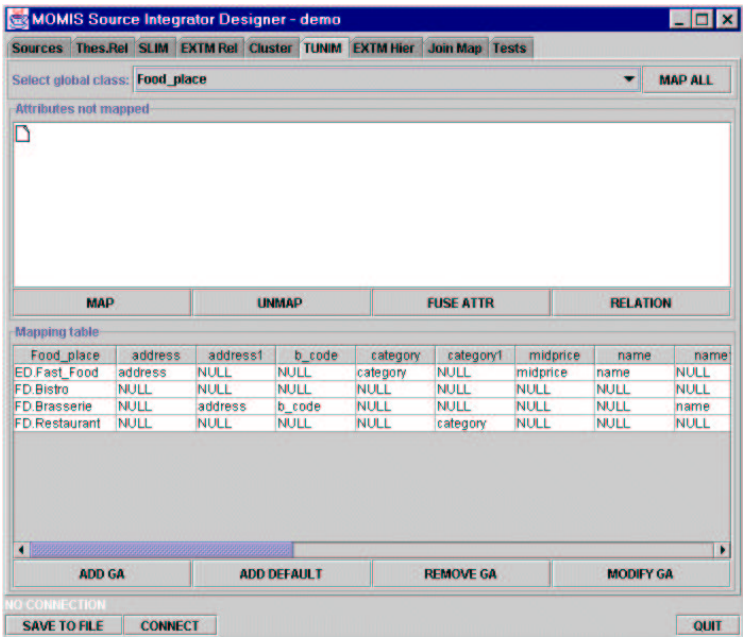

Figure 4.10: SI-Designer the TUNIM module, a first simple attribute mapping

tor of Interfaces - the local classes) populates Global classes.

- *java.util.Vector getClusters()* Returns a Vector of Vectors of Interfaces.
- *ArtemisStatus getStatus()* Returns the Status object.
- *public String toString()*

The object *ArtemisStatus* simply contains the configuration parameters for ARTEMIS such as the clustering threshold or the weight to use for each kind of relationship (SYN,NT,BT,RT). An object of the class *ArtemisStatus* is saved in the schema *additional information* to store/retrieve the ARTEMIS status.

All ARTEMIS computation algorithm are based on distances between elements, I defined the *Distance* Object, which simply stores a generic *distance* (represented as a floating point values) between two Java objects. In addition, I created the *DistanceMap* class and the *DistanceMapSymmetrical* that inherits from *DistanceMap*. Each instance of the *DistanceMap* class can manage a set of *Distance* objects and is suitable to represent directed graph. Instances of the *DistanceMapSymmetrical* manages distances considering them as symmetrical and is suitable to represent undirected graph. The method of the class *DistanceMapSymmetrical* are the same of the *DistanceMap* but overridden for managing symmetrical connections.

The first step in the ARTEMIS computations is to transform all thesaurus relationship between schema element into distances (according to the *status* settings). By doing this we can utilize algorithms for symmetrical distance graph.

The following section describes the most significant techniques implemented in the ARTEMIS module.

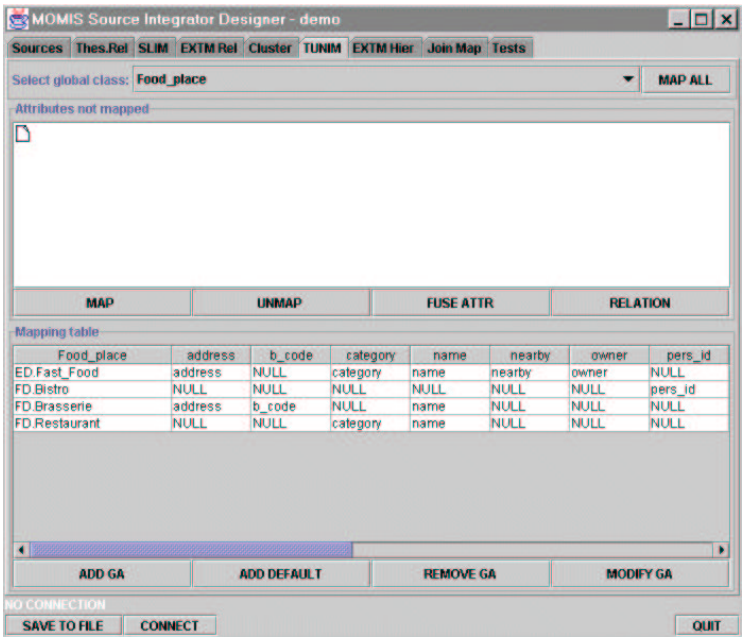

Figure 4.11: SI-Designer a tuned global class mapping table

The algorithm to compute naming affinity

The naming affinity computation requires the computation of the path that maximizes the *affinity* between all nodes of the graph. Maximum affinity is the SYN affinity and has value 1; minimum affinity is absence of affinity and is associated to the value 0. For example, given the elements e_1, e_2 and e_3 where the only affinity between them are $A(e_1, e_2) = 0.8$ and $A(e_2, e_3) = 0.5$, the affinity $A(e_1, e_3)$ has value 0.4 given by the product of $A(e_1, e_2) * (e_2, e_3)$. In the implementation, the affinity is called *distance* (since it is most usual to work with distances in graphs) and a single affinity value between two elements is represented by a *Distance* object.

The problem of computing all maximal affinity between all nodes is the same of finding the minimum distance (following any path) between all nodes of a distance graph. There are only two differences:

- the goal is to find *maximum distance*
- the distance on a path is computed making the product of the distances instead of the sum.

As an algorithm to compute such *distance*, I chose an iterative algorithm that, instead of recursively exploring the graph searching for the *minimum* path, tries to find the shortest local distance considering ever 3 node at a time. At each step we consider all possible combinations of 3 nodes A,B and C, if the distance (A,C) passing by B, computed as $D(A, B) * D(B, C)$ is *better* than the distance $D(A, C)$ the distance $D(A, C)$ is replaced with the new one. The algorithm iterates these steps until there are no changes in the distance graph.

The demonstration that this works can be done by absurdity. Imagine that the algorithm

has finished and that a path p_1 exists from A to C passing by the point B that gives a distance better than the distance $D(A, C)$. The absurdity is that the algorithm is terminated! In fact, evaluating the points A,B and C the algorithm finds a better distance and will replace as $D(A, C)$, this graph modification require that the algorithm performs a new iteration on the graph and cannot be terminated.

Tree representation as composition of *Distance* objects

The algorithm that builds the clustering tree uses the *Distance* objects to represent the built tree. In fact, a *Distance* object relates two tree branches indicates the distance between them. Leaf nodes of the tree are graph elements, while non leaf nodes of the graph are *Distance* objects. For example, consider the graph in Figure 4.12; the tree is composed by 3 leaf schema elements connected by distance elements that carry the *affinity* information.

```
distance2 - 0.5
          +-- distance1 - 0.8
          |             +-- element1
          |             +-- element2
          +-- element3
```

Figure 4.12: An example of Artemis tree expressed using *Distances*

This graph means that between *element1* and *element2* there is affinity 0.8 and that between these and *element3* there is affinity 0.5.

The *toString* method and the *DistanceMapSymmetrical* class

In Figure 4.13 and Figure 4.14 part of the output of the *Artemis.toString* method output is shown. This method simply calls the *toString* method for each local object of *Artemis*. We can therefore see the *ArtemisStatus* status; the initial distance matrix (which simply reports the thesaurus knowledge); the Affinity matrix, which has a lot of computed distances; the Structural Affinity matrix; the Global Affinity matrix; the generated cluster tree; and the proposed clusters. The *toString* representation of a *Artemis* shows all computation steps and allows the computation steps to be traced.

Distance and *DistanceMapSymmetrical* classes manages distances between any kind of Java object. The result of the *toString* method of a *Distance* object contains the *toString* representation of both the related objects.

Other objects in the ARTEMIS package - the graphical interface

The other objects contained in the ARTEMIS package are GUI specific objects.

Figure 4.7 shows the panel that allows the designer to tune the ARTEMIS module. Through this panel we can modify the ARTEMIS computation parameters, and at bottom the results calculated step-by-step are indicated.

In figure 4.8 the panel for global classes/cluster tuning is shown. Such panel allows the designer to modify the name and the content of each single global class, adding

```
Global Affinty matrix:
  Elements: 13
    e0 Interface [Computer_Science.CS_Person]
    e1 Interface [Computer_Science.Course]
    e2 Interface [Computer_Science.Location]
    e3 Interface [Computer_Science.Office]
    e4 Interface [Computer_Science.Professor]
    e5 Interface [Computer_Science.Student]
    e6 Interface [University.Department]
    e7 Interface [University.Research_Staff]
    e8 Interface [University.Room]
    e9 Interface [University.School_Member]
   e10 Interface [University.Section]
   e11 Interface [tax_position_xml.ListOfStudent]
   e12 Interface [tax_position_xml.Student]
  src-| e0 | e1 | e2 | e3 | e4 | e5 | e6 | e7 | e8 | e9 |e10 |e11 |e12 |
   e0 |    |0.2 |0.1 |0.2 |0.73|0.68|0.2 |0.56|0.1 |0.60|0.2 |0.2 |0.56|
   e1 |0.2 |    |0.25|0.12|0.25|0.25|0.12|0.25|0.25|0.25|0.58|0.12|0.25|
   e2 |0.1 |0.25|    |0.25|0.12|0.12|0.06|0.12|0.5 |0.12|0.25|0.06|0.12|
   e3 |0.2 |0.12|0.25|    |0.25|0.16|0.08|0.16|0.25|0.16|0.12|0.08|0.16|
   e4 |0.73|0.25|0.12|0.25|    |0.59|0.16|0.44|0.12|0.46|0.25|0.16|0.44|
   e5 |0.68|0.25|0.12|0.16|0.59|    |0.16|0.43|0.12|0.68|0.25|0.25|0.61|
   e6 |0.2 |0.12|0.06|0.08|0.16|0.16|    |0.25|0.06|0.16|0.12|0.08|0.16|
   e7 |0.56|0.25|0.12|0.16|0.44|0.43|0.25|    |0.12|0.39|0.25|0.16|0.38|
   e8 |0.1 |0.25|0.5 |0.25|0.12|0.12|0.06|0.12|    |0.12|0.32|0.06|0.12|
   e9 |0.60|0.25|0.12|0.16|0.46|0.68|0.16|0.39|0.12|    |0.25|0.25|0.64|
  e10 |0.2 |0.58|0.25|0.12|0.25|0.25|0.12|0.25|0.32|0.25|    |0.12|0.25|
  e11 |0.2 |0.12|0.06|0.08|0.16|0.25|0.08|0.16|0.06|0.25|0.12|    |0.25|
  e12 |0.56|0.25|0.12|0.16|0.44|0.61|0.16|0.38|0.12|0.64|0.25|0.25|    |
```

Figure 4.13: An example from `Artemis.toString()` output, the Global Affinity matrix

or removing local classes. By using this graphical interface the designer can build his own global classes from scratch or tune the ones proposed by **MOMIS**.

The main objects used are two *DynamicTree*, which contains as main nodes, respectively, *NodeSource* and *NodeGlobalClasses* objects. Both *NodeSource* and *NodeGlobalClasses* are *DefaultMutableTreeNode* objects (this means that are nodes managed by a Jtree Swing component) that contain as children *NodeInterface* objects. A *NodeInterface* represent a local classes and can be either in the Tree of the classes to be mapped (organized by sources) or in the mapped interface tree (organized by global classes). All routines for mapping or un-mapping interface simply move *NodeInterface*nodes from one tree to the other. At the end of the Designer tuning, the Global Class tree is parsed and new Global Classes data structure are created.

Actually the two sub-panels of the clustering module, the one for Global classes tuning and the one for the ARTEMIS algorithm tuning, are designed to be two independent modules and could appear as main SI-Designer pads since they are totally independent from each other. Both read status through the *GSProxy* and both generate Global Classes. I developed the *ClusteringPanel* specifically to unify these two panels. This object acts as a sub SI-Designer panel propagating the *saveStatus* and *Update* method to the single modules.

4.4.5 The test module

The test module has been developed for testing routines during the execution of SI-Designer. Since it is a SI-Designer module it can access all integration information.

The GUI is rather simple and is composed only of a *big* text area (used to display the output of the test routines) and a tool-bar that contains the buttons connected to the test routines.

Two functions are permanently placed in this panel:

- the *Schema.toOlcd* method. The method is called on the main schema object and

```
ClusterTree:
tools.Distance: 0.25
+src:
|  tools.Distance: 0.25
|  +src:
|  |  Interface [Computer_Science.Office]
|  +dst:
|  |  tools.Distance: 0.3214285714285714
|  |  +src:
|  |  |  tools.Distance: 0.5833333333333334
|  |  |  +src:
|  |  |  |  Interface [Computer_Science.Course]
|  |  |  +dst:
|  |  |  |  Interface [University.Section]
|  |  |
|  |  +dst:
|  |  |  tools.Distance: 0.5
|  |  |  +src:
|  |  |  |  Interface [Computer_Science.Location]
|  |  |  +dst:
|  |  |  |  Interface [University.Room]
|  |  |
|  |
|
+dst:
|  tools.Distance: 0.25
|  +src:
|  |  Interface [University.Department]
|  +dst:
|  |  tools.Distance: 0.25
|  |  +src:
|  |  |  Interface [tax_position_xml.ListOfStudent]
|  |  +dst:
|  |  |  tools.Distance: 0.5666666666666667
|  |  |  +src:
|  |  |  |  Interface [University.Research_Staff]
|  |  |  +dst:
|  |  |  |  tools.Distance: 0.6428571428571428
|  |  |  |  +src:
|  |  |  |  |  Interface [tax_position_xml.Student]
|  |  |  |  +dst:
|  |  |  |  |  tools.Distance: 0.6857142857142857
|  |  |  |  |  +src:
|  |  |  |  |  |  tools.Distance: 0.7333333333333334
|  |  |  |  |  |  +src:
|  |  |  |  |  |  |  Interface [Computer_Science.CS_Person]
|  |  |  |  |  |  +dst:
|  |  |  |  |  |  |  Interface [Computer_Science.Professor]
|  |  |  |  |  |
|  |  |  |  |  +dst:
|  |  |  |  |  |  tools.Distance: 0.6875
|  |  |  |  |  |  +src:
|  |  |  |  |  |  |  Interface [Computer_Science.Student]
|  |  |  |  |  |  +dst:
|  |  |  |  |  |  |  Interface [University.School_Member]
|  |  |  |  |  |
|  |  |  |  |
|  |  |  |
|  |  |
|
```

Figure 4.14: An example from `Artemis.toString()` output, the Clustering Tree

returns a *olcd* description of the global schema. This description is ready to be sent to ODB-Tools to perform schema validation or relationship inference.

- the *Schema.toOdl* method. The method is called on the main schema object and returns an ODL$_{I^3}$ description of the integrated schema containing the complete description of the local sources, the thesaurus (expressed as a list of relationships), and the generated mapping tables.

  This description could (but does not work yet) be passed as input to the ODL$_{I^3}$ parser that should reallocate almost totally the data structures that describe the integration. This cannot be a total reconstruction since information like the SI-Designer module status (like the SLIM element annotation) cannot be expressed in ODL$_{I^3}$ and will be lost.

4.5 Implementation and experimentation considerations

Some activities performed in **MOMIS** for information source integration have an element of subjectivity, being an intuitive process, because the knowledge and experience of the designer can be a requirement to ensure that the integration is proceeding correctly. In particular, the specification of inter-source relationships, both intensional and extensional, and the various tuning activities are of this kind.

Our effort has been concentrated in helping the designer by providing interactive functionalities and allowing the designer to have easy access each time to as much information possible about source and integration process.

In the following, we give th main feedbacks of the experimentation of **MOMIS** tools on practical integration examples. The good quality of affinity evaluation relies on both the correctness of the intensional relationships and on the parameters (i.e., strengths, weights, thresholds) used in the calculation of the coefficients and their relative values.

ARTEMIS has been experimented on different sets of conceptual database schemas to select a set of default values (i.e., the ones working satisfactorily in most cases) for the various parameters (strengths, thresholds, weights) intervening in the affinity and clustering stages. The values of terminological relationship strengths in the Common Thesaurus and of affinity weights and thresholds used in the examples of this paper correspond to these selected default values. Default values, however can be dynamically varied by the designer when necessary in order to tailor the affinity calculation to the specific integration contexts.

As a consequence, most difficult tasks involved in the integration process result simplified, in that semantically related information is automatically identified and the designer is asked for a validation of the proposed results or, for ambiguous situations, for a selection among a set of pre-defined choices.

Moreover, the possibility of interacting with the tool to vary default parameter configurations and compare their results allows the tuning of the integration process. The experimented interaction with WordNet was satisfactory in sources integration when the schemata to be integrated have “meaningful names”; in this case, most of the terminological inter-schema relationships are obtained, thus avoiding a lot of boring work for the designer. However, for many legacy applications adopted names are not meaningful. In this case, the automatic extraction of intra-schema relationships and the aid of the system in checking consistency of explicitly given relationships are good aids for the designer.

A deeper discussion of the experimentation results of the use of strengthened terminological relationships and affinity-based clustering of ARTEMIS for the integration of heterogeneous data schemas in the Italian Public Administration domain, is given in [CAV00, CA99a].

With respect to the **MOMIS** prototype, we implemented it in Java, relying on the portability of such language. We obtained a portable software application. The **MOMIS** prototype runs on Unix machine as well as Windows machine without having to recompile a single class. Also communications (CORBA connection) are quite transparent, and it works well regardless of the execution platform. Using Java we obtained portability but we lost performances. The most resource consuming algorithms in **MOMIS** are the search for lexical relationships in WordNet and the validation/inferential algorithm (SimB). Such algorithms, with a schema of 37 interfaces in 3 sources and 247 attributes, in a distributed environment (SI-Designer running on a Windows Ma-

chine Pentium III 600Mhz, servers, running on a Solaris Sparc 433Mhz) takes about 70 seconds to extract 1016 new lexicon-derived relationships, while the execution of the SimB algorithm takes about 240 seconds to execute and infers 40 new relationships. ARTEMIS (running on the Pentium) takes about 15 seconds proposing 23 global classes.

Chapter 5

Conclusions

In this document, we have presented a semi-automated approach to information extraction and integration of heterogeneous information sources. The ODL$_{I^3}$ language is introduced for information extraction and integration, by taking into account also semistructured information sources. A Description Logic module (ODB-Tools engine) provides inference capabilities to construct a Common Thesaurus of inter-source relationships, the WordNet lexical database is used as knowledge base to add information for the integration in form of lexicon derived relationships, and a cluster generator module (ARTEMIS tool environment) provides capabilities to identify candidates global classes of the integrated global view. The proposed approach has been implemented in the **MOMIS** prototype following a conventional wrapper/mediator architecture. **MOMIS** provides a set of tools and associated techniques for performing semantic integration. **MOMIS** provides several techniques and associated tools for helping the designer in the integration of heterogeneous information sources by means of an application with a graphical interface, called SI-Designer. SI-Designer interfaces all the employed tools with the goal of allowing an interactive and customized use of **MOMIS** techniques by the designer based on the specific requirements of a given integration process.

Future research will be devoted to the development of the Query Manager component of **MOMIS** with query optimization and "answer composition" functionalities, based on definition of extensional axioms and integrity constraints defined on global ODL$_{I^3}$ classes. One of the original aspects of the Query Manager will consist of employing Description Logics-based components (i.e., ODB-Tools) to perform semantic optimization steps both on global and local queries, to minimize the number of accessed sources and the volume of data to be integrated as the result of sub-query execution.

Research in **MOMIS** will also face the problem of the Automatic Integration, where we will study techniques to eliminate (at least in some applications) the role of the integration designer. To automate the integration we will move the annotation capabilities on Wrappers and we will extend the ODL$_{I^3}$ (language and data structures) to support annotations. Furthermore, we will consider using Mobile Agents as tool to discover *interesting data sources*.

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Chapter 6

Part II - Information Retrieval with the Keynet system

This part presents the results obtained in the *information retrieval* (IR) research activity at the *Northeastern University* (Boston, MA - USA) under the supervision of Professor Kenneth Baclawski during my six-month stay in the USA.

In particular, a set of algorithms to efficiently compare **Keynet** system objects in order to speed-up the information retrieval are presented.

Also presented is a technique to classify documents with respect to a given query and a technique to aid the user in *refining* the query.

To this end we developed:

- an intersection algorithm for graphs
- an indexing and classification technique based on the intersection with the *query graph*
- a tool for *superquery* classification calculus of a set of documents that satisfy the given query. This study does not present any result about *precision* and *recall* (these are indexes used to measure the information retrieval system performances) because we did not have any already annoted collection on which to measure these indexes (for example, an annotated collection is the *Tipster's collections*).

6.1 The Keynet system

The **Keynet** system is designed for IR from a corpus of information objects in a single subject area. It is well suited for non-textual information objects, such as scientific data files, satellite images and videotapes. For example, the literal content of a satellite image does not include the geographic coordinates of the boundaries of the image or other cartographic abstractions. Some kinds of textual document, such as research papers in a single discipline, can also be supported. With current technology, **Keynet** can support very high-performance IR from a corpus having up to several million objects at approximately the same level of performance as smaller corpora.

A **Keynet** system requires the development of a subject-specific concepts *ontology* that is understandable to a literate practitioner of the field. A **Keynet** ontology represents

knowledge using a directed graph of conceptual categories and relationships among them. **Keynet**, further, assumes that each information object (*document*) in its corpus has been annotated with a content label that indicates what portion of the subject-specific ontology relates to the content of the object (*keynet structure*).

Tools have been developed and tested working in a biomedical context. The Unified Medical Language System (UMLS) developed by the National Library of Medicine is the reference ontology [HL93] for this context.

Both content labels and queries have the same data structure called *the keynet structure*. A *keynet* may be regarded as a kind of semantic network [Lev92] , although in practice it is semantically intermediate between keywords and semantic networks. The keynet framework generalizes many commonly used mechanisms for information retrieval, such as: subject classification schemes, keywords, document abstracts, reviews, content labels for non-textual information objects, properties such as author or date of publication, ranges of text strings, such as "wild card" match strings, and ranges of quantities. The **Keynet** system allows a uniform treatment of these disparate techniques in a system that permits a great deal of flexibility compared to traditional database and information retrieval systems. For example, one can combine all of the above mechanisms in a single system and easily add new features to the ontology, such as new attributes and keywords. In addition, the **Keynet** framework allows for sequences of concepts linked by relationships and expressed in natural language using phrases, clauses, sentences and paragraphs.

A content label is similar to an abstract or review of a document both in size and in being separately accessible from its corresponding information object. Using a tool such as M&M-Query System [BF93], a content label can be generated by the author of the information object with no more effort than is now taken to write the abstract or to select the keywords.

6.2 Graphs in Keynet system

Both queries and content labels are represented as graphs of concepts. To represent nodes of each graph in main memory we use the following data structure, called *the keynet structure*. This structure is used to store keynet information ad for communication in the **Keynet** cluster of computers. This is the structure of the contents:

- **Ontology Identifier**. Each ontology is assigned a unique integer identifier.
- **Major version number**. Since ontologies can evolve over time, a version number is used to distinguish both major and minor versions of an ontology. Minor versions differ from one another only by the addition of new concepts, conceptual categories and relationship types. Major versions may differ in more substantial ways, including the splitting of categories, merging of categories, as well as more complex alterations in the ontology.
- **Minor version number**.
- **Count**. Since the **Keynet** system is distributed, keynets have to be transmitted between nodes of the network. During the transmission the count field specifies that the keynet has been split into a number of pieces as specified in this field. Normally the value of this field is 1.
- **Sequence number** When a keynet is in several pieces, this field will have the sequence number of this piece. The values range from 0 to one less than the count field above.

- **Vertex count** This is the count of the number of vertices that will be specified in the list immediately following this field.
- **Vertex list** This is a set of zero or more vertex specifications. Each vertex specification consists of three integers as follows:
  - **Vertex id** Each vertex of a keynet has a unique identifier within the keynet.
  - **Type id** Each vertex has a type or conceptual category. The types and their identifiers are listed in the ontology.
  - **Instance id** A vertex may be instantiated using one of the instances given in the ontology. Instance identifiers are nonzero integers. If this field has value 0, then the vertex has not been instantiated.
  - **Outgoing Edge list** This is a set of all the edges with this vertex as source.
  - **Incoming Edge list** This is a set of all the edges with this vertex as destination.
- **Edge count** This is the count of the number of edges that will be specified in the list immediately following this field.
- **Edge list** This is a set of zero or more edge specifications. Each edge specification consists of three integers as follows:
  - **Source vertex** This is the vertex identifier of the source of this edge in the keynet.
  - **Destination vertex** This is the vertex identifier of the destination of this edge in the keynet.
  - **Edge type id** Each edge has a type. The edge or relationship types and

A *keynet structure* k is basically a graph $k : (V, E)$ where the couple of *vertices* and *edges* is associated respectively to the couple of *concepts* and *relationships* among concepts of the ontology.

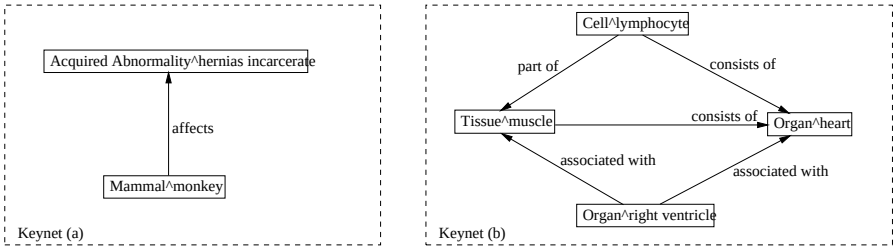

Figure 6.1: Example of keynet graphs

In figure 6.1 two examples of *keynet structure* are shown. *Keynet (a)* represent the text: "*Monkeys can suffer from hernias incarcerate.*" and *Keynet (b)* represents the text "*The right ventricle is contained in the heart, both of which primarily consist of muscle tissue. Lymphocytes are associated with both the right ventricle and the heart.*"

In figure 6.2 two examples of *keynet structure* for representing *query* are shown. *Keynet (q1)* derives from the text "*What antibodies lyse (lysis) lymphocytes in vivo?*" and *Keynet (q2)* derives from the text "*What marrow transplant protocols use monoclonal antibodies to deplete recipient lymphocytes? "*

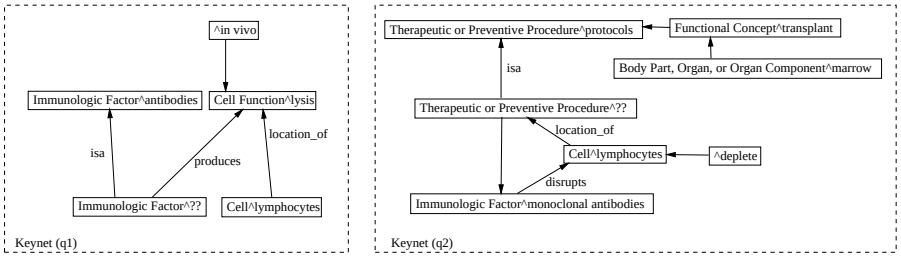

Figure 6.2: Example of keynet graphs for queries

6.3 The Keynet search engine architecture

The purpose of **Keynet**[1] is to assist in retrieving information objects from a corpus of them. These information objects need not be textual and may be physically located anywhere in the network. Retrieval is accomplished by means of a content label for each information object. These content labels are stored in a repository at the **Keynet** site. The structure of the content labels is specified by an information model or ontology. The content labels are indexed by means of a distributed hash table stored in the main memories of a collection of processors at the **Keynet** site. These processors form the search engine. Each content label contains information about locating and acquiring the information object. The **Keynet** system is only concerned with finding information objects; users are responsible for actually acquiring (and presumably paying for) information objects.

To see more precisely where all of these components reside, and how they are connected to one another, refer to Figure 6.3. The user's computer is in the upper left position. A copy of the ontology is kept locally at the user site. As this will require from several hundred megabytes to a few gigabytes of memory, it would generally be stored on a CD-ROM. The ontology is also the basis for the user interface to the search engine. Queries must conform to the format specified by the ontology, and are sent over the network to a front-end processor at the **Keynet** site. Responses are sent back over the network to the user's site, where they are presented to the user using the ontology. The prototype system uses a connectionless communication protocol so that no connection is required for making a query, and also so that the responses need not be sent back from the same computer that originally received the query.

At the **Keynet** site, the front-end computer is responsible for relaying query requests to one of the search engine computers. The reason for having a front-end computer is mainly for distributing the workload but it also helps to simplify the protocol for making queries. The search engine itself is a collection of processors (or more precisely server processes) joined by a high-speed local area network. The search engine processors will be called nodes. The repository of content labels is distributed on disks attached to some of the nodes. The index to the content labels is distributed among the main memories of the nodes. The prototype differs from the **Keynet** architecture only in that it randomly generates the repository as well as queries sent to it.

Since a connectionless communication protocol is unreliable, it is necessary for the user computer to re-send the query if there is no response after a timeout period. The **Keynet** protocol is stateless and idempotent, and so it works well with a connection-

[1] from [BS94d]

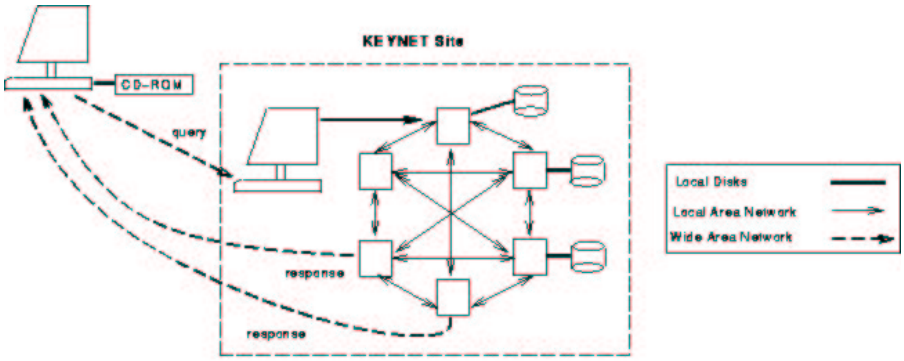

Figure 6.3: Example of keynet graphs

less communication service. There is a similar protocol for registering information objects by sending content labels to the **Keynet** site, but this is not explicitly shown in Figure 6.3.

6.4 Graph comparison functions

Introduction

In the theory of graphs, a *graph* G consist of a finite nonempty set V of elements that are called *vertices* or *points*, together with a set E of distinct ordered (for the *directed graphs*) or unordered (*not directed graphs*) pair of points that belong to V. Each element e of the set E is said *edge*.

A vertex is said *labeled* when each vertex can be be identified uniquely by a label lv. In the same way, we can say an edge is *labeled* when the edge can be uniquely identified by a label le.

The *keynet structure* is a *directed* graph with labeled vertices and labeled edges. In a *keynet structure* it is not required that labels uniquely identifies vertices or edges. This means that vertices or edges that shares the same label are allowed. This is due to the nature of the concepts described in a document, i.e., in *keynet structure* a vertex represents a *concept* in a document.

A concept may be introduced and referred in a document more than once. This produces a single *keynet* vertex. But, in a document the same concept can also be introduced in more than one different context and this requires more *equals* vertices to be represented.

Comparison functions

To categorize graphs and use efficient algorithm we need to define a comparison function. Since our algorithms are based on comparing sorted list of vertices or edges, such function must define an order relationship among objects.

For example, in the **Keynet** system the label for a vertex is given by the *concept identifier*[2]. If we assume that the *concept identifier* for a vertex is an integer number, the

[2]The *concept identifier* for a vertex is the identifier of the ontology concept represented by the vertex.

comparison function between two vertices can be easily defined as the function "*algebraic difference between the concept identifier of the two vertices*" $f_{cv}(v_1, v_2) = v_1.c_{id} - v_2.c_{id}$.

Two edges are equals when the *edge label*, the *source vertex* and the *destination vertex* are equals.

Using the comparison function among vertices and a function that compares the edges label we can define the comparison function among edges, for example, evaluating the three attributes in the following order: (1) the edge label, (2) the source vertex and (3) the destination vertex.

$$f_{ce}(e_1, e_2) = \begin{cases} 0 & if \begin{cases} e_1.src.l == e_2.src.l \\ e_1.dst.l == e_2.dst.l \\ e_1.l == e_2.l \end{cases} \\ < 0 & if \begin{cases} e_1.src.l < e_2.src.l \; or \; (\\ e_1.src.l == e_2.src.l \; and \; (\\ e_1.dst.l < e_2.dst.l \; or \; (\\ e_1.dst.l == e_2.dst.l \; and \\ e_1.l < e_2.l))) \end{cases} \\ > 0 & if \begin{cases} e_1.src.l > e_2.src.l \; or \; (\\ e_1.src.l == e_2.src.l \; and \; (\\ e_1.dst.l > e_2.dst.l \; or \; (\\ e_1.dst.l == e_2.dst.l \; and \\ e_1.l > e_2.l))) \end{cases} \end{cases}$$

Matching algorithm

The matching[3] algorithm compares two graphs and creates the intersection graph.

Since we defined comparison functions for vertices and edges we can assume that the lists of vertices and edges are sorted. So we can apply the algorithm to find equals elements in two ordered list (that is quite fast), the list of vertices and the list of the edges.

This algorithm performs, in the worst case, $n_1 + n_2$ comparison where n_1 and n_2 are the length of the the two sorted list (see Figure 6.4).

6.5 Classification and indexing of a query result set

Introduction

We developed this tool to categorize query results. The goal is to build a tool that quickly give an idea to the users of the contents of the query result set. Since the *graphical User Interface* shows the keynet graphical representation of the query, our proposal is to show to the user all documents that match the query categorized by the "*type of matching*".

The **Keynet** system, using its distributed hash table, is able to retrieve from the database all the documents that *roughly* match the query. The tool presented in this section

Each vertex of any *keynet* structure that represent the same concept refers to the same ontology object by such identifier.

[3] In the graph theory a *matching* is a subset of the edges in which no vertex appears more than once. We use another meaning for the the term *match*. For us, two graphs *match* when they carry the same information.

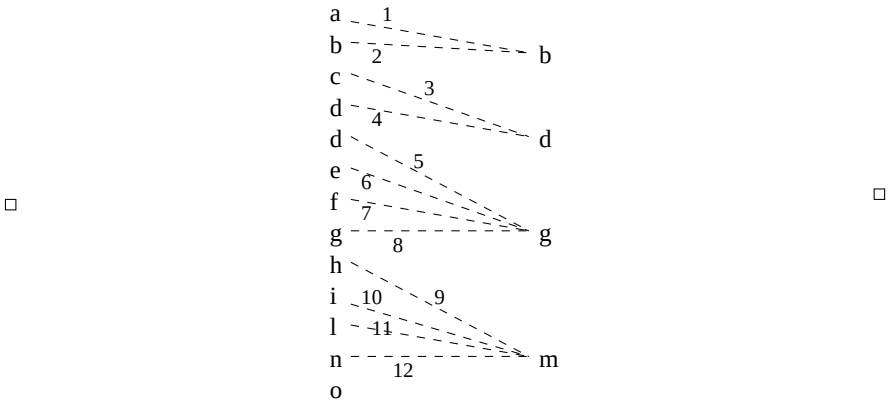

Figure 6.4: Comparisons in comparing sorted lists

categorize these documents according to the following rules:

1. Let the *representative graph* for a document be the intersection between the *query* and the document himself. We assume the *representative graph* expresses the *type of matching*
2. One category is identified uniquely by a *"representative graph"* that is itself a **Keynet** structure.
3. One category contains a list of *all and only* the documents that share the same *"representative graph"* characterizing the category.

This implies that given a document and a query, each document belongs to a uniquely identified category.

Categorizing the document and showing for each category the *representative graph* and other statistical information such as the number of documents in each category, the average ranking weight[4] of the documents gives the user an overall idea of the kind of documents has been retrieved by the query.

The classifier

A *category* is a couple (an object) $c : (k, L_k)$ that relates a keynet structure k with a list of other keynet structures L_k.

A *categorizer* object must manage a list of *categories*. The main operations for a *categorizer* are:

1. insert a document d in the *categorizer* specifying its representative graph g.
2. provides a way to access to the categories and to the document list of each category.

Now we describe the easiest way to insert a new document d characterized by the graph g in a categorizer. Let us call this process the *naive approach*.

We search a graph that is equal to g within the characteristic graphs of the categories. *If found*, let c be the category with the characteristic graph equals to g. The category c

[4] At present, the ranking of documents is performed by using the *cosine* weighting technique [Sal89],

is the category for d and we add d to the list of document of c.
If not found, we create a new category c with g as characteristic graph and d in the list of documents. Then we add c to the list of categories of the categorizer.

The main problem of the *naive categorizer* is that it is too slow. Each time we have to insert a new document we perform an average of $n_c/2$ graph comparison, where n_c is the number of categories. Moreover, comparing two graphs is a expensive operation because we have to compare all edges and vertices of both graphs.

An indexed classifier

We want a classifier that reduces the number of vertex and edge comparison in order to speed up the classification process.

It is possible to substitute the comparison among vertices (or edges) with the comparison among references to categories (for example a pointer to a category object or a category identifier) and we will show how to do it.

Let us introduce a simplified representation of the **Keynet** graph model.

Let $\mathbb{O}$ the reference ontology for a **Keynet** system. Here is described a simplified representation for the ontology:

$$\mathbb{O} = (\mathbb{V}_o, \mathbb{E}_o, \mathbb{R}_o)$$

Where $\mathbb{V}_o$ is the set of nodes (or concepts) of the ontology
$\mathbb{R}_o$ are the type of relationships allowed by the ontology among ontology nodes and
$\mathbb{E}_o$ is the set of edges (relationships among nodes) composing the ontology. Note that

$$\mathbb{E}_o \subseteq \{(v_1, r, v_2) : v_1, v_2 \in \mathbb{V}_o, r \in \mathbb{R}_o\}$$

A **Keynet** graph $\mathbb{G}$ can be represented as a subset *with repetition* of the ontology elements. It can be represented by the following couple:

$$\mathbb{G} = (\mathbb{V}_l, \mathbb{E}_l)$$
$$\mathbb{V}_l \subseteq \{(v, n) : v \in \mathbb{V}_o, n \in \{1, 2, ...\}\}$$
$$\mathbb{E}_o \subseteq \{((v_1, r, v_2), n) : v_1, v_2 \in \mathbb{V}_o, r \in \mathbb{R}_o, n \in \{1, 2, ...\}\}$$

The number n is necessary since vertices and edges might appear more than once in a **Keynet** graph.

This kind of representation relies on the *index* technique used to index graphs or categories (in the categorizer we index the categories describing the characteristic graphs of the category).

By definition, **two graphs are equals** when they have exactly (the same number of) the same vertices and (the same number of) the same edges. The equality of two vertices or edges of different graphs is given by the *comparison functions* described in section 6.4 on page 89.

Data structure

The above representation is obtained by maintaining a list of vertices and for each of such vertex v, storing a list of couple $c_n : (c, n)$. In this couple c is an identifier of a category (for example a pointer) and n is the number of times the vertex v appears in the characteristic graph of the category c. To save memory space and speedup comparisons we assume that if a category does not appear in the list of a vertex v it means that its representative graph does not have the vertex v (this assumption implies that the empty graph, no vertices and no edges, must be treated in a particular manner).

The same representation is maintained for the edges (for each edge is maintained a list

of couples (c, n) category, number). Figure 6.5 are shows the data structures maintained by the classificator.

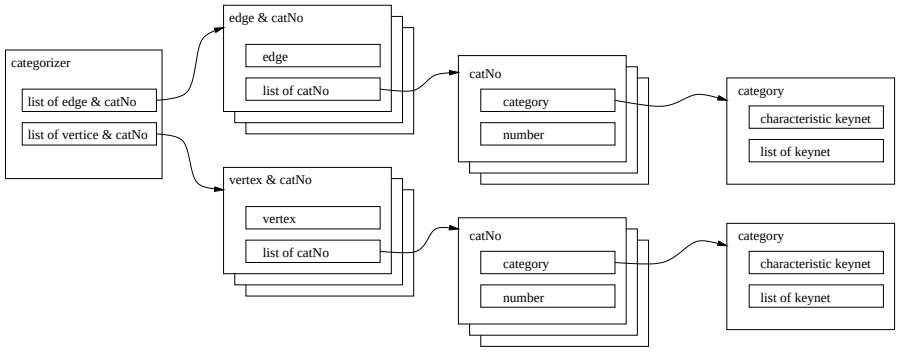

Figure 6.5: Data structures for the classificator

This kind of representation is useful when we try to find a category given its representative graph (this is the first step of the *insert a new document* operation).

To retrieve the category for a given representative graph g we follow the algorithm below according to the following hypothesis:

1. lists of vertices are kept ordered both in the g graph and in the categorizer
2. lists of edges are kept sorted both in the g graph and in the categorizer

The algorithm

The following is the algorithm implemented by the indexed categorizer.

if (g is a *empty graph*)
. *handle the empty category*
else
. *search the category using data structure*
. *compare the edge lists*
. *get the first categorizer e_c edge*
. *get the first graph edge e_g counting the occurrences*
. **do**
. . **if**(*no more edge to compare*)
. . . **exit_do**
. . **endif**
. . *compare the two edges*
. . **if**(*edges match*)
. . . **if**(*is not initialized the l_c category list*)
. . . . *initialize the l_c category list from e_c*
. . . **else**
. . . . *intersect l_c with the e_c category list*
. . . **endif**
. . . **if**(*l_c is empty (no categories)*)
. . . . *the category for g does not exists*
. . . . **exit_routine #1**

. . . **endif**
. . . *get next graph edge e_g counting the occurrences*
. . . *get next categorizer e_c edge*
. . **else_if**(*e_g great than e_c*)
. . . *get next categorizer e_c edge*
. . **else**
. . . *g has an edge not present in the categorizer*
. . . *the category for g does not exists*
. . . **exit_routine #2**
. . **endif**
. **done**
. **if**(*there are other edges in g*)
. . *g has an edge not present in the categorizer*
. . *the category for g does not exists*
. . **exit_routine #3**
. **endif**
. **label #1**
. *compare the the vertices lists*
. *get the first categorizer v_c vertex*
. . *get the first graph vertex v_g counting the occurrences*
. **do**
. . **if**(*no more vertices to compare*)
. . . **exit_do**
. . **endif**
. . *compare the two vertices*
. . **if**(*vertices match*)
. . . **if**(*is not initialized the l_c category list*)
. . . . *initialize the l_c category list from v_c*
. . . **else**
. . . . *intersect l_c with the v_c category list*
. . . **endif**
. . . **if**(*l_c is empty (no categories)*)
. . . . *the category for g does not exists*
. . . . **exit_routine #4**
. . . **endif**
. . . *get next graph vertex v_g counting the occurrences*
. . . *get next categorizer v_c vertex*
. . **else_if**(*v_g great than v_c*)
. . . *get next categorizer v_c vertex*
. . **else**
. . . *g has a vertex not present in the categorizer*
. . . *the category for g does not exists*
. . . **exit_routine #5**
. . **endif**
. **done**
. **if**(*there are other vertices in g*)
. . *g has a vertex not present in the categorizer*
. . *the category for g does not exists*
. . **exit_routine #6**

. **endif**
. **label #2**
. *in l_c there is only one category*
. *and is the category for g*
endif

Basically the category for g is selected intersecting all the list of categories that match all the edges and all the vertices of the graph g. The intersection is performed by initializing the *intersection list* l_c on the first edge or vertex matching, and intersecting this list with the list of the other edge or vertex matching.

To prove the correctness of the algorithm, we have yet to describe the two following steps:

1. *initialize the l_c category list from e_c (or v_c)*

This procedure initializes a list of category l_c used to select the category of a given graph g. The same procedure is used to initialize l_c from a list of categories associated to both an edge of the categorizer (e_c) or to a vertex of the categorizer (v_c).

The list l_c is initialized by copying the categories from the list associated with the edge e_c (or the vertex v_c) according to the following rules:

1. remember that e_c matches e_g and we call this vertex e.
2. the number of occurrences of the edge e_g (or the vertex v_g) in g must match the number associated the category. This means that the graphs of each selected category must have exactly the same number of occurrences of the edges e (or the vertex v) as the graph g.
3. the number of edges and the number of vertices of g must match the respective number of edges and number of vertices of the graph of each selected category.

2. *intersect l_c with the v_c category list*

In the list l_c only those classes that are present also in the list associated with the edge e_c (or with the vertex v_c) are maintained. Moreover, the number of occurrences of the edge e_g (or the vertex v_g) in g must match with the number associated with the category. This means that the graph of each maintained category must have exactly the same number of occurrences of the edges e (or the vertex v) as the graph g.

Proof of correctness

We prove that our *indexing* algorithm finds for g all and only the categories that have as representative graph g_c a graph that matches g.

We assume that two graphs g_c and g match when they have exactly the same vertices and edges and with the same number of occurrences. Two vertices or two edges match according to the *comparison functions* described on page 89. The data structures described on pagee 92 must be correctly maintained as well.

Find only those categories:

We can have different situations that differ from the case where g is the *empty graph*. This case is handled as an exception so we make sure that if the *empty category* is already present, then we will find it. In the following list we will examine all possible ways to select or unselect a category in the algorithm on page 93:

- from the initialization of the list l_c all categories where g_c has a number of edges

or of vertices different than g are dropped.

- *exit #1* g can differ from a g_c because has a different number of occurrences of a given edge. This means that the representative graph g_c of the selected categories has the same number of occurrences of each matching edge for each matching edge.
- *exit #2* and *exit #3* if we find an edge in g that is not present in any g_c, we do not select any category. This means that all selected categories must have at least the same edges of g.
- *label #1* in this point in the list l_c all the categories with g_c with the same number of edges of g are present, the edges are the same and the occurrence is the same for each matching edge.
- *exit #4* g can differ from a g_c because it has a different number of occurrences of a given vertex. This means that the representative graph g_c of the selected categories has the same number of occurrences of each matching vertex, for each matching vertex.
- *exit #5* and *exit #6* if we find a vertex in g that is not present in any g_c, we do not select any category. This means that all selected categories must have at least the same vertices of g.
- *label #2* at this point in the list l_c all categories with g_c are present with the same number of edges of g, the edges are the same and the occurrence is the same for each matching edge and also with the same number of vertices of g, the vertices are the same and the occurrence is the same for each matching vertices.
  This is the definition of matching graphs.

Find all those categories:

The routine of initialization initialize the list l_c with all the categories present in the lists associated with a categorizer edge or vertex. Since these categorizer list are correctly maintained by the categorizer, then, in each list, *all* the categories with the given edge or vertex are present.

Suppose there are two categories that match the given graph g. Both categories, for construction of the data structures, will appear in all the categorizer lists in such a way to describe the graph g.

This means that both categories will be selected by the initialization procedure of the list l_c and will also remain in the list l_c after each category intersection step. Since both of them match the graph g, both will be selected by the algorithm (each of the *exit* points will be skipped).

But in the list l_c there will be only one category. We can prove this by supposing the existence of two different categories c_1 and c_2. If c_1 and c_2 will be selected by the algorithm, it means that both the respective characteristic graphs g_1 and g_2 matches g and this implies that g_1 match g_2. This is impossible for the *definition* of categorizer, which requires that the representative graphs of each category must all be different from the others.

Complexity

To study the algorithm complexity we need to parametrize the data to be processed and to make several assumptions. Our goal is not to express the exact formula, however we want to give an approximation of the algorithm complexity.

We represent our set of graphs to be classified by these characteristic parameters:

- n_g number of graphs to categorize
- n_c number of categories in which such graphs will be classified
- n_v average number of vertices for the graphs in the set
- n_e average number of edges for the graphs in the set

We assume a random, uniform distribution of edges and vertices in each graph and of graphs in the set. We also assume that the cases of repeated vertices (e.g., more than one vertex with the same label) or edges in a graph are rare (the indexing algorithm will run faster with a high number of vertices or edges repetitions). We consider as unit of measure for the calculus of the complexity the comparison between two identifiers and assign the following weight:

- 1 compare two identifiers, by assumption
- 2 compare two graph vertices, because in our case a vertex is identified by a couple of other identifiers. This is an optimistic assumption; a vertex may be identified in a much complex way
- 3 compare two graph edges, because an edge is characterized by two vertices and some other information. An average comparison matches half of these data.

To compare two lists of n elements (of edges or vertices) we assume they are ordered so that this operation can be performed with n comparisons.

Naive algorithm

To search a category we assume it employs average $\frac{n_c}{2}$ graph comparisons. The cost for a graph comparison is $2n_v \cdot 3n_e$.
The complexity for the naive algorithm is given by:

$$3 \cdot n_g \cdot n_c \cdot n_v \cdot n_e$$

Indexing algorithm

To search a category we assume it performs, in the worst case n_e edge comparisons, n_v vertex comparisons and $\frac{n_c}{2} \cdot (n_e + n_v)$ category comparisons.
To insert a category we have to compare n_v vertices, n_e edges and sort $n_c \cdot (n_v + n_e), n_v, n_e$ lists of identifiers.
The complexity for the indexing algorithm is given by:

$$\begin{array}{ll} n_g & \cdot(3n_e + 2n_v + \frac{n_c}{2} \cdot (n_e + n_v)) + \\ n_c & \cdot(3n_e + 2n_v + \\ & n_c \cdot (n_v + n_e) \cdot log_2(n_c \cdot (n_v + n_e)) + \\ & n_v \cdot log_2(n_v) + n_e \cdot log_2(n_e)) \end{array}$$

The most important operation (i.e., *find a class* function) can be performed in a $O(n)$ of the number of the graph.

Tests

The test were computed on a linux machine; the time has been measured using the *C* function `times`.
We ran two kinds of test sets using random generated graphs with different topologies.

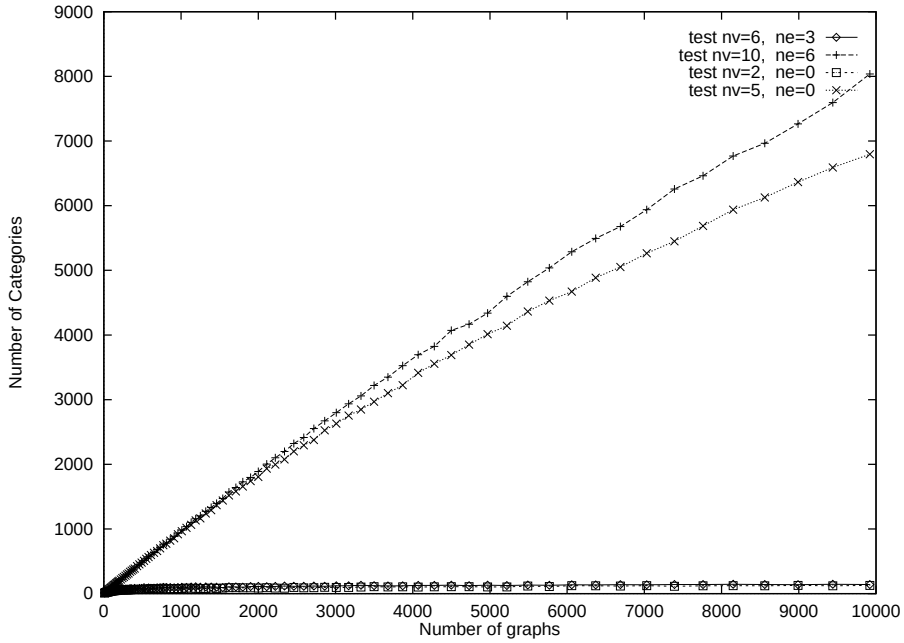

Figure 6.6: Number of categories in the tests

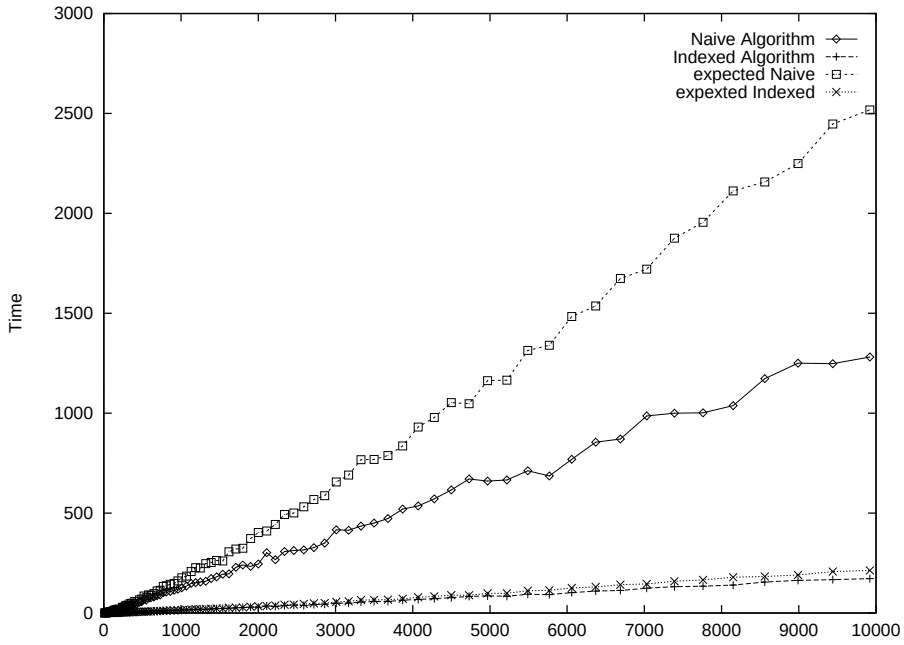

Figure 6.7: Time evaluation for a query *abc* with 6 vertices and 3 edges

1. A first test set (*abc*) is composed by graphs with only 3 vertices (labels 'a', 'b' and 'c') repeated several times. For the edges, only one kind of label exists, so the number of edges is very small 3^2. In these tests the most characterizing data

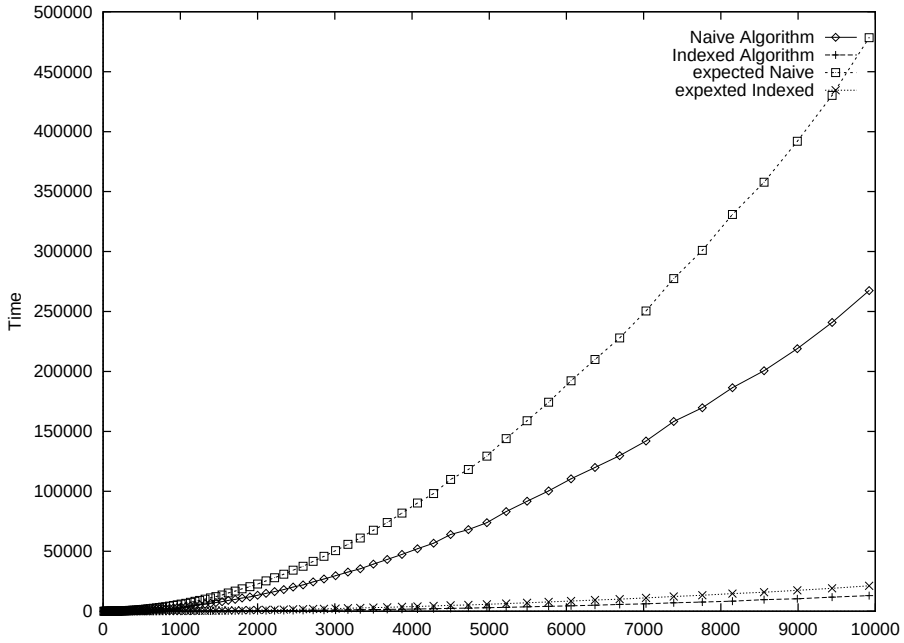

Figure 6.8: Time evaluation for a query *abc* with 10 vertices and 6 edges

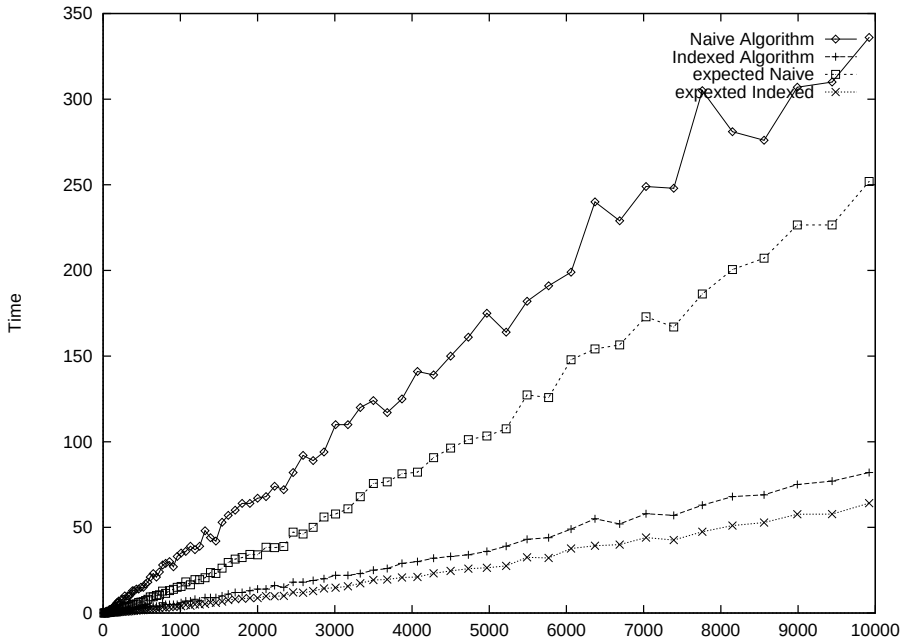

Figure 6.9: Time evaluation for a query *a..z* with 2 vertices and 0 edges

of a graph is the number of repetitions of a given vertex or edge.
These tests correspond to the graph in Figure 6.7 and 6.8.
Figure 6.7 is obtained by categorizing this set of graphs using a query with 6

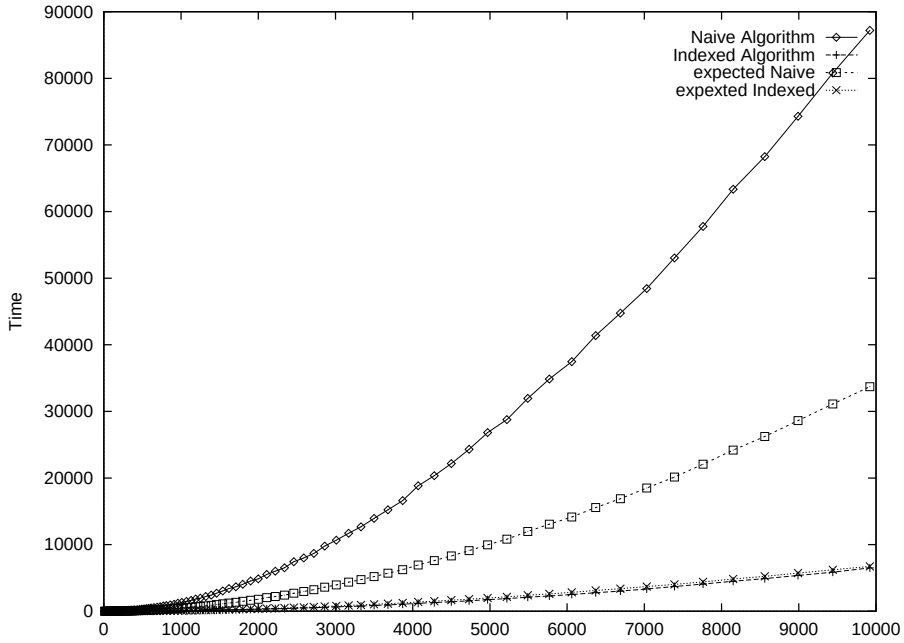

Figure 6.10: Time evaluation for a query *a..z* with 5 vertices and 0 edges

vertices and 6 edges. This produces categories with average 6 vertices and 3 edges matched. Figure 6.8 is obtained by categorizing this set of graphs using a query with 15 vertices and 25 edges. This produces categories with average 10 vertices and 6 edges matched.

2. The second test set (*a..z*) is composed of graphs with a more realistic distribution of vertices (the vertices allowed are 26 and repetitions are allowed, too). Also, the number of allowed labels for the relationships are 3 so the number of allowed edges is $26^2 \cdot 3$.
   These tests correspond to the graph in Figure 6.9 and 6.10.
   Figure 6.9 is obtained by categorizing this test set of graphs using a query with 6 vertices and 5 edges. This produces categories with an average of 2 vertices and 0 edges matched. Figure 6.10 is obtained by categorizing this test set of graphs using a query with 15 vertices and 42 edges. This produces categories with an average of 5 vertices and 0 edges matched.

Figure 6.6 summarizes the number of categories extracted by classifying the test set for each, varying the test type and the number of graph of the test set.

The estimated time for the *indexed* algorithm has been computed using the formula of page 97 without adding the *insertion times* of the news categories.

6.6 Query refinement

Refine the query Q means to write a more selective query Q_1 the results of Q_1 are a subset of the results of Q. In the following we say *extend* a query to mean *refine* the query. This is because the refinement of a **Keynet** query is done by adding vertices or

edges to the orginal query graph.

Our goal is to design a tool that assists the user in query refinement.

We propose a tool that given a query and a list of document that exactly matches the query, the tool behaves like a *categorizer* that classifies documents according to all possible ways the query can be refined.

This tool is useful when the number of documents returned from the query is high (for example more than 150 documents).

We define a *supergraph graph* of a given *query* computed on a given *document* as the union of the query graph and an edge that is not part of the query but is part of the document. In Figure 6.11 an example of supergraph extraction comparing a query and

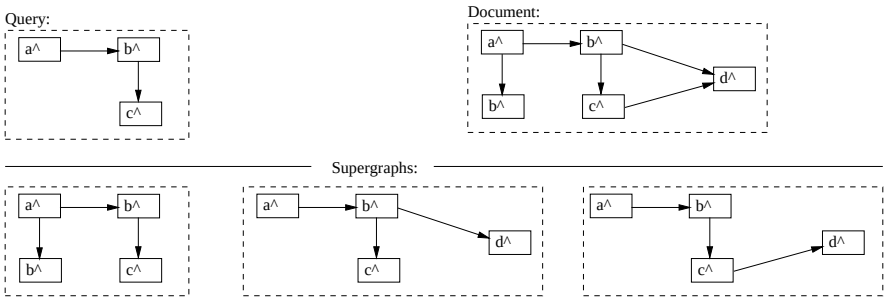

Figure 6.11: Supergraph extraction

a document is shown.

Imagine that the user submits a query that is associated to too many documents. In this case, the GUI of the system will show the *keynet* graph of the query and allow the user to explore ways to refine the query. Clicking on a concept (a vertex) of such graph will pop up a list of all relationships that extend such concept (with all related information such as number of document, average *weight*, ...). The user can refine the query choosing one concept, then a relationship and then a concept again.

The process can obviously be iterated and the new query *extension* can be recomputed using the document in the document list of the chosen relationship).

This way to browse the database starting from the given query allows the user to *learn* about the distribution of the documents in the database.

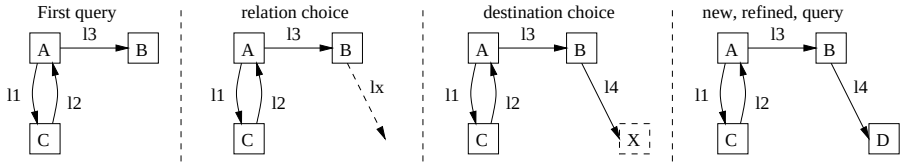

Figure 6.12: Query refinement process

Figure 6.12 the steps for *keynet* query refinement are shown.

Contents: In this section we present two procedures: one to extract all possible extensions of a query from a document, and one to handle the association among all possible extension of a query and the associated document.

Edge matching for the supergraph problem

Here we describe how to perform the matching between a query graph and a document in order to extract all new edges that *extends* the query.

The problem

Let $Q(V_q, E_q)$ the query graph and $D(V_d, E_d)$ the document graph we want to use to extend the query Q.

Let e a generic edge and, let $e.src$ and $e.dst$ the source and destination vertices of e.

We want to extract the set of *output* edges $O \subset E_d$, $o \in O$ where:

1. $\exists v \in V_q : o.src == v$ or $o.dst == v$

Where the relationship $==$ is calculated using the comparison function of page 89.

The algorithm

If for each vertex $v \in V$ of a graph $G(V, E)$ are maintained the list of ingoing and outgoing edges we can apply the following algorithm.

1. compare the vertices of the document (d) with the vertices of the query ((d))
2. for each matching vertex copy the reference (the pointer) of the ingoing and outgoing edges in a list of *duplicated* edges.
3. sort the extracted edges and delete the duplicated edges.

Complexity

We make the following assumptions:

- n_{vd} number of vertices of the document graph
- n_{vq} number of vertices of the query graph
- n_{ed} number of edges of the document graph
- n_{eq} number of edges of the query graph

We can distinguish the following steps and corresponding costs:

sorting vertices of document and query: $n_{vd} * log(n_{vd}) + n_{vq} * log(n_{vq})$

extracting edges with duplicates: $n_{vd} + n_{ve} + 2 * \alpha * n_{ed}$

sorting and deleting duplicated edges: $2 * \alpha * n_{ed} * (1 + log(2 * \alpha * n_{ed}))$

Where $\alpha \in [0, 1]$ is a parameter of the graph to compare.

α is the probability for a document to have a vertex in common with the query. If we suppose uniform distribution in edges correlation, and given that the document and the query shares the query vertices, then $\alpha = \frac{n_{vq}}{n_{vd}} + \frac{n_{vd} - n_{vq}}{numberOfCorpusVertices - n_{vq}}$.

When $\alpha = 1$ this means that all the edges of any document will be selected by the current query.

Data structure for supergraph categorizer

In this section we describe a procedure for supergraph extraction that fulfills the following requirements:

1. It processes several documents comparing them with a unique given query.
2. For each document, we want to handle (generate and memorize) all possible *supergraphs* of the document according to the given query.

3. Given a supergraph, we want to know which documents share the given supergraph.
4. Given a vertex of the query we want to know what the possible supergraphs are that involve such vertex. Therefore, given a vertex, it is possible to select a way to extend (refine) the query, and then the list of document with the selected extension will be available.

We assume that the following statements are true:

- a graph is a couple $G : (V, E)$ where V is a list of vertices and E is a list of edges
- for each vertex $v \in V$ the list of edges ingoing and the list of edges outgoing from the vertex v are maintained
- functions to compare edges and vertices have been defined. Such functions make it possible to uniquely define an *order* relationship among edges and among vertices.

Observe that any supergraph of a given query can be described as the union of the query graph and an edge that extends the query but does not belongs to the query. This means that *a subgraph for a given query is completely defined by an extension edge*. This allows us to save memory and cpu time in handling supergraphs.

The proposed data structure to store and classify query supergraphs is implemented memorizing:

superquery is a *graph* that contains the query graph and all (not duplicated) edges that extend the query in the processed documents.

categories is a list of *category* object. A category object associates an edge with a list of documents and knows if the vertex belongs to the query. In the list *categories* there will be a category for each *superquery* edge. And in each *category*'s list of documents, there will be a list of all documents that contains the category edge.

By maintaining this data structure it is easy to extract information about the extension of the query starting from a given vertex of the query. All the edges that extend the category are given by the union of the *ingoing* and *outgoing* edges from the selected vertex in the *superquery* graph. The list of documents associated to each single selected edge is stored in the category characterized by that edge.

6.7 Related work

We worked in a *specific* branch of Information Retrieval, we developed tools to handle knowledge in the **Keynet** system. For more information about **Keynet** system see [BS94a, BS94b, BS94d, BF93, BS94c]. The **Keynet** system uses the *cosine* weighting technique to rank documents described in [Sal89].

Basically we work with labeled directed graphs and these are treated in the *graph theory*, but our tools are designed for retrieving information. Since the graphs are labeled, we defined a order relationship on vertices and edges and used such order relationships for comparing graphs. To handle the graph isomorphism problem, we looked at the algorithm presented in [Ull76].

The architecture of the graph categorizer is a simplification of the architecture of the **Keynet** system [BS94c][BS94d].

Query refinement

[VWSG97] introduces the *concept recall*. This is an experimental measure of an algorithm's ability to suggest terms that are semantically related to the user's information need; it also presents a fast algorithm for terms suggestions with the goal of improving the *precision*. Such algorithm is based on term weighting among the terms of the documents that match the query.

[LCHH97] presents a *visual query interface* for querying multimedia databases that allows users to pose queries using icons and menu in a drag-and-drop fashion. This interface translates the visual query in CSQL, a query language with additional predicates for image matching and semantic-based query condition. This is a tool to help users query a multimedia database in an "exploratory" fashion.

[JFS98] presents an improvement of the *unsafe* (or *approximate*) query algorithm of [Per94]. It modifies the query evaluation based on the current contents of the buffers, and this speeds up the retrieval in query refinements.

In contrast with [LH99] and [VWSG97], whose motivation is to enhance information retrieval by developing models with the ability to diagnose a user's informational goals, our approach is not based on probability but relies on the structure of the **Keynet** system.

6.8 A graphical user interface for Keynet visualization

This section describes a tool (`KNEditor`) developed by myself for **Keynet** visualization over text documents. The goal of this tool is to let the user perceive by intuition how concepts are correlated in the showed text.

The description of this graphical interface should aid to explain, through example, what a **Keynet** is.

Guideline: in designing this application I tried to reduce the redundancy of information stored in the memory data structure. The application was also designed to provide text editing functions (text insert or delete).

The application is a now *keynet viewer* application. It can load a Keynet and it allows the user to navigate interactively through relationships.

6.8.1 Specifications

Graphical layout

The GUI is composed of four windows that display the following information:

- list of concepts
- list of relationships
- properties of the selected items
- the document viewer, shows the text and the keynet graph of the document.

In the document viewer window we adopt the following conventions:

- a word related to a *concept* is displayed in blue.
  A concept is represented by a **small blue dot** over the text at the beginning of the word, all relationships arrows starts and ends on that point.

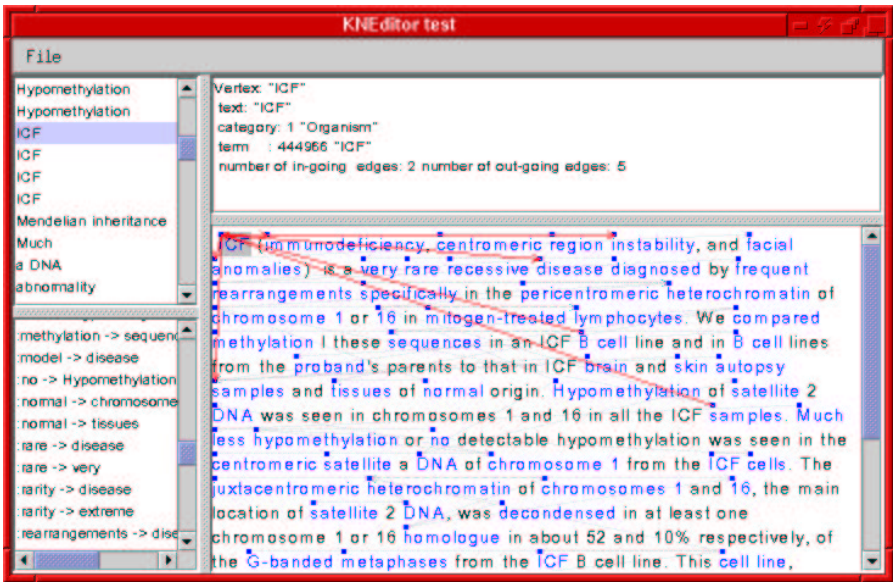

Figure 6.13: Screen shot of the *KNEditor* application

- a *relationship* is shown in red
  Relationships are represented with *arrows* from the starting concept to the end concepts.
  Unselected relationships are visualized as translucent arrows; selected ones are displayed as filled red arrows (highlighted).
- *plain text* is shown as black text over white background
- *highlighted* text is represented with a light gray background.

The *KNEditor* allows the user to (1)*select a concept*. This will highlight the concept and related relationships and show the concept properties. (2) *selecting a relationship*, will highlight the relationship and related concepts and show the relationship properties. (3) *selecting a region of text* will highlight the region.

6.8.2 The ontology

Ontology access

We need to access the ontology (1) in order to extract the names of the category/terms/relationship given the ID; (2) to extract the ID of the category/terms/relationship given the name; (3) to extract all possible relationships among two concepts given the concepts, and let the user choose the preferred one.

I need an accurate description of the ontology.

Since the ontology database is 1.6 gigabytes, we need a fast and efficient way to access to the ontology (e.g., using a database or preparing reverse indexes).

For the development proposal we do not have such kind of ontology interaction, but the temporary solution is to read categories/terms/relationships from the file containing the keynet annotation files and store them in three files:

- _categories.txt
- _terms.txt
- _relations.txt

Such files act as a (very simple) ontology proxy.
The ontology interaction and the user's ability to edit a **Keynet** description are the main features to be implemented.

6.8.3 Implementation notes

Figure 6.14 the object structure of the tool is shown. It is fully written in Java.
This section adresses the different problems faced during the implementation.

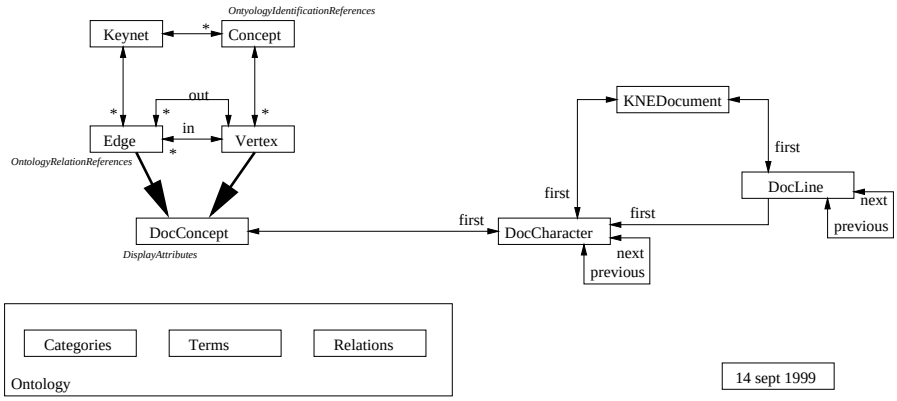

Figure 6.14: Architecture of the application

Text representation

The text (`KNEDocument`) is a double chained list of characters (`KNEDocCharacter`). Each character has several properties, such as: the value (the character to display), the text color and the background color, the font, then the width, height and ascent sizes.
I wrote a routine for formatting text that divides the text in the several lines[5] used only for visualization, according to the display area available the height and width of each single character and the line separators (EOL characters)
Lines are stored in a double-chained list of lines. A line contains at least one word (obviously only if the line has at least one word before the EOL). The line layer is used also to speed up character identification from the windows coordinates when the user clicks over the text.

Saving format vs runtime format (1) The text in the *saving format* can be seen as a list of characters, and in such text a character could be identified by absolute position. The text associated with a concept or with a relationship, can be represented as a couple

[5] A `Document` could be represented as a list of pages and each page as a list of lines. But this *page* layer is not implemented at moment because we assume only small documents will be handled.

of integer values $(position, length)$, where $position$ is the number of the first char in the text and $length$ expresses the number of char of the text.

(2) For the *KNEditor*, this kind of representation is too rigid. We need a more flexible representation that allows characters and concepts to be added without worrying about maintaining coherence between the position and length. So, for the editor we use the object pointers to double link concepts and characters. A character can ber related to a single concept, a relationship or nothing. Moreover and a concept (but also a relationship) maintains a list of characters that represents the text associated with the concept.

Translation

For translating among these two representation (*loading* translate (1)→(2) and *saving* translate (2)→(1)) we require two functions:

1. (*loading*) retrieves a char given the position
2. (*saving*) calculates the relative the position of a given a char as if the text was a list of characters.

To speed up this process we need a *dirty* flag and data structure that is refreshed after loading and before saving (if the *dirty flag* is true), which memorize the starting position of the `Lines` in the document.

Graphical layout management

The graphical layout is generated in an image (with the size of the display area) stored in memory. This image is generated each time something changes in the text, such as window resizing, highlighting or un-highlighting of any object, text scrolling and *Text inserting or deleting* (not yet implemented).

This image is displayed in the *document display area* each time that something changes in the text or each time the window requires repainting.

Concepts, vertices and relationships A *keynet* is a list of *concepts* and a list of *relationships* (called also *edges*) among concepts. I extended this model allowing a concept to be represented by more *text area*[6] in the text. A concept can be recalled by more *text areas*, but a text area can recall a single concept. So I called such text area as *vertex*. A concept thus contains a list of vertices and is identified by a category_id and a term_id from the ontology. To maintain the spatial meanings of the relationship *i* defined *edges* to be relationships between vertices. Obviously, the concepts inherit relationships from the vertices.

DocConcepts Since both vertices and edges have references to text, I introduced the `DocConcepts` class that is used to manage the mapping between the keynet items and the text in the document. A `DocConcepts` object can be a vertex or an edge. Each character of the document has a reference to *DocConcept* object (is null if the character is not related to any keynet item., For this reason, I introduced the *non overlapping rule* among concepts in the text.

[6] A *text area* is a contiguous sequence of characters in the text of the document

How a region of text is identified

The following items require a clever method to identify a region of text:

- current selection of text
- text associated with a *concept*
- text associated with a *relationship*

There are different ways to identify a region: **(a)** specifying the first and the last character pointer. The sequentiality of the selection is guarantee. I do not have to worry about the number of characters in the selection, but I may have some trouble when I delete or move the last char of the selection. **(b)** specifying the first character and the length of the text. The sequentiality of the selection is guarantee. Each time I add or delete a char of the selection I have to increase or decrease the counter of chars (this is not a computationally costfull operation because each char of the selection knows to that it is part of the selection, which makes the operation go fast). **(c)** memorizing in a vector all pointers to text characters. The sequentiality of the selection is not guarantee. Each time I add or delete a char I have to align the whole vector.

Solution
I chose the solution *b*: a starting character plus length of the selection.
During the selection of text, the text associated with a concept or a relationship can be either all selected or all unselected. It is not possible select only a piece piece of text related to a concept or a relationship.

Current cursor Position. The cursor position identify the position of the insertion point. This can be represented by a character pointer. The portion where to insert is after the pointed character. The cursorPostion can have null value, null value means insert new characters at the beginning of the document.

6.8.4 Implemented functionalities

This is a row listing implemented functionalities written during the implementation.

- Speed up the image generation. To print each char, I have to set the following attributes: (1) color (2) font (3) background color.
  In order to speed up the character writing, I can cluster a sequence of character (with the same attributes) and draw a background rectangle and a single string once without setting many times these properties.
- Arrows for the relationships. I also tried arcs but I don't like them.
- Selection vs highlighting policies.
  We have to handle two different kind of selections:
  - *text* selection.
    A text selection can be described as a list of consecutive characters.
  - *concept* (edge/vertices) selection. This is useful in text navigation

  Solution
  Only *unassigned text* (text not related to any concept) can be selected while concepts can only be highlighted. But this will not allow cutting and pasting of portion of text containing concepts.
  To facilitate cutting and pasting I must define an approach that allows the selection of the text related to some concept. The most important thing to do is not to

allow partial selection of a *assigned portion* of text; that is, the text related to a concept can be only or all selected or all unselected.

- Highlight: *How to highlight*:
  - A **vertex** is highlighted by:
    - clicking on the text related to the vertex.
    - selecting the concept that contains the vertex.
    - selecting a relationship that recall the vertex.
  - A **concept** can be highlighted by:
    - clicking on the concept on the concepts list.
    - selecting a vertex.
  - A **relationship** can be highlighted by:
    - clicking on an (highlighted) arrow or
    - clicking on the text related to the relationship.
    - selecting a vertex that this relationship is related.
    - clicking on the relationship on the edges list.

  Events to handle:

  - Click on a **vertex** text. *Action:* Highlight all the relationships connected to such vertex (and the text of the relationship) and *destination* related vertices. Highlight the concept in the *concept list*.
  - Click on a **edge** text or click on a *edge arrow* or click on a edge in the *edge list*. *Action:* Highlight both vertices of such relationship and the text related to the relationship. Each time I highlight a relationship I will move this to the last position in the vector of the relationships. This means that this will be the last to be displayed and the first to be selected.
  - Click on a **concept** in the *concept list*. *Action:* Highlight all vertices of such concept.

  Implementation: I can use a `vector` of the *highlighted concepts* that maintains the list of the currently highlighted items. This speeds up the un-highlighting process.
  I will implement as many functions as the events to handle.

6.9 Conclusions and future work

In this document we presented a set of tools for Information Retrieval relying on graph of concepts. We presented high performance **Keynet** (or, in general, graph) classifier providing description, proof of correctness and a set of tests performed on an implementation. In studying how to comparing graphs with duplicated nodes, the problem arises of *graph isomorphism* in distinguishing among the *equals* vertices relying on graph structure. An open problem is to evaluate if it is worth distinguishing among *equivalent* vertices in order to obtain more knowledge useful for the document retrieval.

We also presented an analysis on how **Keynet** features can be exploited in query refining or database browsing starting from a query. Query refinement by classification is a query classification tool, but it is also an instrument to learn from the search engine, since the document database can be browsed starting from any query. It should be interesting to study how to bring this feature on a term-based search engine (**Keynet** is based on concept graphs).

During my stay in the USA a theory for document ranking specifically for the **Keynet** system was in developement stage. This theory is necessary because in the **Keynet** system the independence of terms is not guaranteed (the **Keynet** system deals with edges and vertices and, edges and vertices in a graph are not independent, e.g., an edge requires the presence of two vertices) and this is one of the main assumptions in the Information Retrieval Theory.

Research on **Keynet** is proceeding developing a module for automating the extraction of a content label from a textual document. It is based on a machine-learning engine able to disambiguate the mapping among terms of the document and the concepts of the ontology.

Appendix A

ODL$_{I^3}$ syntax

Here is the full syntax of the ODL$_{I^3}$ language. This syntax has been automatically generated from the *yacc* definition of the parser of the **MOMIS** prototype.

⟨OdlSpecification⟩	: : =	⟨Definition⟩ **.**
	|	⟨Definition⟩ **;**
	|	⟨Definition⟩ **;** ⟨OdlSpecification⟩
⟨Definition⟩	: : =	⟨TypeDcl⟩
	|	⟨ConstDcl⟩
	|	⟨ExceptDcl⟩
	|	⟨Interface⟩
	|	⟨RuleDcl⟩
	|	⟨ExtRuleDcl⟩
	|	⟨ThesaurusRelation⟩
	|	⟨Module⟩
	|	⟨error⟩
⟨TypeDcl⟩	: : =	**typedef** ⟨TypeDeclarator⟩
	|	⟨ConstrTypeSpec⟩
⟨TypeDeclarator⟩	: : =	⟨TypeSpec⟩ ⟨Declarators⟩
⟨Declarators⟩	: : =	⟨Declarator⟩
	|	⟨Declarators⟩ **,** ⟨Declarator⟩
⟨Declarator⟩	: : =	⟨Identifier⟩
	|	⟨Identifier⟩ ⟨ArraySizeList⟩
⟨ArraySizeList⟩	: : =	⟨FixedArraySize⟩
	|	⟨ArraySizeList⟩ ⟨FixedArraySize⟩
⟨TypeSpec⟩	: : =	⟨SimpleTypeSpec⟩
	|	⟨ConstrTypeSpec⟩

⟨SimpleTypeSpec⟩ ::= ⟨BaseTypeSpec⟩
| ⟨TemplateTypeSpec⟩
| ⟨Identifier⟩

⟨BaseTypeSpec⟩ ::= ⟨FloatingPtType⟩
| ⟨IntegerType⟩
| ⟨CharType⟩
| ⟨BooleanType⟩
| ⟨OctetType⟩
| ⟨RangeType⟩
| ⟨AnyType⟩

⟨FloatingPtType⟩ ::= **float**
| **double**

⟨IntegerType⟩ ::= ⟨LongIntType⟩
| **short**
| **unsigned long**
| **unsigned short**

⟨LongIntType⟩ ::= **integer**
| **int**
| **long**

⟨CharType⟩ ::= **char**

⟨BooleanType⟩ ::= **boolean**

⟨OctetType⟩ ::= **octet**

⟨RangeType⟩ ::= **range** { ⟨RangeSpecifier⟩ }

⟨RangeSpecifier⟩ ::= ⟨SignedIntegerLiteral⟩ **,** ⟨SignedIntegerLiteral⟩
| ⟨SignedIntegerLiteral⟩ **, + infinite**
| **- infinite ,** ⟨SignedIntegerLiteral⟩

⟨AnyType⟩ ::= **any**

⟨TemplateTypeSpec⟩ ::= ⟨ArrayType⟩
| ⟨StringType⟩
| ⟨CollectionType⟩

⟨ArrayType⟩ ::= **array <** ⟨SimpleTypeSpec⟩ **,** ⟨IntegerLiteral⟩ **>**

⟨$$1⟩ ::=

⟨ArrayType⟩ ::= **array <** ⟨SimpleTypeSpec⟩ **>** ⟨$$1⟩ **sequence <** ⟨SimpleTypeSpec⟩ **,** ⟨IntegerLiteral⟩ **>**

⟨StringType⟩ ::= **string <** ⟨IntegerLiteral⟩ **>**
| **string**

⟨CollectionType⟩ ::= ⟨AttrCollectionSpecifier⟩ **<** ⟨SimpleTypeSpec⟩ **>**

⟨AttrCollectionSpecifier⟩ ::= **set**
| **list**
| **bag**

⟨ConstrTypeSpec⟩ ::= ⟨StructType⟩
| ⟨UnionType⟩
| ⟨EnumType⟩

⟨StructType⟩ ::= **struct** ⟨Identifier⟩ **{** ⟨MemberList⟩ **}**

⟨MemberList⟩ ::= ⟨Member⟩
| ⟨MemberList⟩ ⟨Member⟩

⟨Member⟩ ::= ⟨TypeSpec⟩ ⟨Declarators⟩ **;**

⟨UnionType⟩ ::= **union** ⟨Identifier⟩ **switch** **(** ⟨SwitchTypeSpec⟩ **)** **{** ⟨SwitchBody⟩ **}**

⟨SwitchTypeSpec⟩ ::= ⟨IntegerType⟩
| ⟨CharType⟩
| ⟨BooleanType⟩
| ⟨EnumType⟩
| ⟨ScopedName⟩
| ⟨RangeType⟩

⟨SwitchBody⟩ ::= ⟨Case⟩
| ⟨Case⟩ ⟨SwitchBody⟩

⟨Case⟩ ::= ⟨CaseLabelList⟩ ⟨ElementSpec⟩ **;**

⟨CaseLabelList⟩ ::= ⟨CaseLabel⟩
| ⟨CaseLabel⟩ ⟨CaseLabelList⟩

⟨CaseLabel⟩ ::= **case** ⟨ConstExp⟩ **:**
| **default :**

⟨ElementSpec⟩ ::= ⟨TypeSpec⟩ ⟨Declarator⟩

⟨EnumType⟩ ::= **enum** ⟨Identifier⟩ **{** ⟨EnumeratorList⟩ **}**

⟨EnumeratorList⟩ ::= ⟨Enumerator⟩
| ⟨EnumeratorList⟩ **,** ⟨Enumerator⟩

⟨Enumerator⟩ ::= ⟨Identifier⟩

⟨ConstExp⟩ ::= ⟨OrExpr⟩

⟨OrExpr⟩ ::= ⟨XOrExpr⟩
| ⟨OrExpr⟩ **|** ⟨XOrExpr⟩

⟨XOrExpr⟩ ::= ⟨AndExpr⟩
| ⟨XOrExpr⟩ ^ ⟨AndExpr⟩

⟨AndExpr⟩ ::= ⟨ShiftExpr⟩
| ⟨AndExpr⟩ & ⟨ShiftExpr⟩

⟨ShiftExpr⟩ ::= ⟨AddExpr⟩
| ⟨ShiftExpr⟩ >> ⟨AddExpr⟩
| ⟨ShiftExpr⟩ << ⟨AddExpr⟩

⟨AddExpr⟩ ::= ⟨MultExpr⟩
| ⟨AddExpr⟩ + ⟨MultExpr⟩
| ⟨AddExpr⟩ - ⟨MultExpr⟩

⟨MultExpr⟩ ::= ⟨UnaryExpr⟩
| ⟨MultExpr⟩ * ⟨UnaryExpr⟩
| ⟨MultExpr⟩ / ⟨UnaryExpr⟩
| ⟨MultExpr⟩ \% ⟨UnaryExpr⟩

⟨UnaryExpr⟩ ::= ⟨Signes⟩ ⟨PrimaryExpr⟩
| ⟨PrimaryExpr⟩

⟨PrimaryExpr⟩ ::= ⟨Identifier⟩
| ⟨IntegerLiteral⟩
| ⟨FloatingPtLiteral⟩
| (⟨OrExpr⟩)
| (⟨error⟩)

⟨ConstDcl⟩ ::= **const** ⟨StringType⟩ ⟨Identifier⟩ = ⟨StringLiteral⟩
| **const** ⟨CharType⟩ ⟨Identifier⟩ = ⟨CharacterLiteral⟩
| **const** ⟨IntegerType⟩ ⟨Identifier⟩ = ⟨ConstExp⟩
| **const** ⟨FloatingPtType⟩ ⟨Identifier⟩ = ⟨ConstExp⟩

⟨SignedIntegerLiteral⟩ ::= ⟨IntegerLiteral⟩
| ⟨Signes⟩ ⟨IntegerLiteral⟩

⟨SignedFloatingPtLiteral⟩ ::= ⟨Signes⟩ ⟨FloatingPtLiteral⟩
| ⟨FloatingPtLiteral⟩

⟨Signes⟩ ::= -
| +

⟨ExceptDcl⟩ ::= **exception** ⟨Identifier⟩ { ⟨OptMemberList⟩ }

⟨OptMemberList⟩ ::=
| ⟨MemberList⟩

⟨ScopedName⟩ ::= ⟨Identifier⟩
| **::** ⟨Identifier⟩
| ⟨ScopedName⟩ **::** ⟨Identifier⟩

⟨Interface⟩ ::= ⟨InterfaceDcl⟩

⟨IntView⟩ ::= **interface**
| **view**

⟨InterfaceDcl⟩ ::= ⟨IntView⟩ ⟨Identifier⟩ **:** ⟨InheritanceSpec⟩ ⟨OptTypePropertyList⟩ ⟨OptPersistenceDcl⟩ ⟨SingleInterfaceBody⟩
| ⟨IntView⟩ ⟨Identifier⟩ **:** ⟨InheritanceSpec⟩ ⟨OptTypePropertyList⟩ ⟨OptPersistenceDcl⟩ ⟨SingleInterfaceBody⟩ ⟨InterfaceBodyUnionList⟩
| ⟨IntView⟩ ⟨Identifier⟩ ⟨OptTypePropertyList⟩ ⟨OptPersistenceDcl⟩ ⟨SingleInterfaceBody⟩
| ⟨IntView⟩ ⟨Identifier⟩ ⟨OptTypePropertyList⟩ ⟨OptPersistenceDcl⟩ ⟨SingleInterfaceBody⟩ ⟨InterfaceBodyUnionList⟩

⟨InheritanceSpec⟩ ::= ⟨Identifier⟩
| ⟨InheritanceSpec⟩ **,** ⟨Identifier⟩

⟨OptTypePropertyList⟩ ::=
| **(** ⟨OptSourceSpec⟩ ⟨OptExtentSpec⟩ ⟨OptKeySpec⟩ ⟨OptCandKeySpec⟩ ⟨OptForKeySpec⟩ **)**

⟨OptSourceSpec⟩ ::=
| **source** ⟨SourceType⟩ ⟨Identifier⟩

⟨SourceType⟩ ::= **relational**
| **nfrelational**
| **object**
| **file**
| **semistructured**

⟨OptExtentSpec⟩ ::=
| **extent** ⟨ListExtent⟩

⟨ListExtent⟩ ::= ⟨Identifier⟩
| ⟨ListExtent⟩ **,** ⟨Identifier⟩

⟨OptKeySpec⟩ ::=
| **key** ⟨Key⟩

⟨OptCandKeySpec⟩ ::=
| ⟨CandKeySpecList⟩

⟨CandKeySpecList⟩ ::= ⟨CandKeySpec⟩
| ⟨CandKeySpecList⟩ ⟨CandKeySpec⟩

⟨CandKeySpec⟩ ::= **candidate_key** ⟨Identifier⟩ ⟨Key⟩

⟨OptForKeySpec⟩ ::=
| ⟨ForKeySpecList⟩

⟨ForKeySpecList⟩ ::= ⟨ForKeySpec⟩
| ⟨ForKeySpecList⟩ ⟨ForKeySpec⟩

⟨ForKeySpec⟩ ::= **foreign_key** **(** ⟨ForeignKeyList⟩ **)** **references** ⟨Identifier⟩ ⟨OptRefKeyList⟩

⟨OptRefKeyList⟩ ::=
| **(** ⟨ForeignKeyList⟩ **)**

⟨ForeignKeyList⟩ ::= ⟨Identifier⟩
| ⟨ForeignKeyList⟩ **,** ⟨Identifier⟩

⟨Key⟩ ::= **(** ⟨PropertyList⟩ **)**

⟨PropertyList⟩ ::= ⟨PropertyName⟩
| ⟨PropertyList⟩ **,** ⟨PropertyName⟩

⟨PropertyName⟩ ::= ⟨Identifier⟩

⟨OptPersistenceDcl⟩ ::=
| **persistent**
| **transient**

⟨InterfaceBodyUnionList⟩ ::= ⟨InterfaceBodyUnion⟩
| ⟨InterfaceBodyUnionList⟩ ⟨InterfaceBodyUnion⟩

⟨InterfaceBodyUnion⟩ ::= **union** ⟨Identifier⟩ ⟨SingleInterfaceBody⟩
⟨SingleInterfaceBody⟩ ::= **{** ⟨InterfaceBody⟩ **}**
⟨InterfaceBody⟩ ::= ⟨Export⟩ **;**
| ⟨Export⟩ **;** ⟨InterfaceBody⟩
⟨Export⟩ ::= ⟨TypeDcl⟩
| ⟨ConstDcl⟩
| ⟨ExceptDcl⟩
| ⟨AttrDcl⟩
| ⟨RelDcl⟩
| ⟨OpDcl⟩
⟨AttrDcl⟩ ::= ⟨OptReadonly⟩ **attribute** ⟨DomainType⟩ ⟨AttributeName⟩ ⟨OptFixedArraySize⟩ ⟨OptMappingRuleDcl⟩
⟨OptReadonly⟩ ::=
| **readonly**
⟨AttributeName⟩ ::= ⟨Identifier⟩
| ⟨Identifier⟩ **?**
⟨DomainType⟩ ::= ⟨SimpleTypeSpec⟩
| ⟨StructType⟩
| ⟨EnumType⟩
⟨OptFixedArraySize⟩ ::=
| ⟨FixedArraySize⟩
⟨FixedArraySize⟩ ::= **[** ⟨IntegerLiteral⟩ **]**
⟨OptMappingRuleDcl⟩ ::=
| ⟨MappingRuleDcl⟩
⟨MappingRuleDcl⟩ ::= **mapping rule** ⟨MapRuleList⟩
⟨MapRuleList⟩ ::= ⟨MapRule⟩
| ⟨MapRuleList⟩ **,** ⟨MapRule⟩
⟨MapRule⟩ ::= ⟨LocalAttributeName⟩
| ⟨DefaultValue⟩
| ⟨MapAndExpression⟩
| ⟨MapUnionExpression⟩
⟨LocalAttributeName⟩ ::= ⟨LocalClassName⟩ **.** ⟨Identifier⟩
⟨LocalClassName⟩ ::= ⟨Identifier⟩ **.** ⟨Identifier⟩
⟨DefaultValue⟩ ::= ⟨Identifier⟩ **.** ⟨Identifier⟩ **=** ⟨StringLiteral⟩
⟨MapAndExpression⟩ ::= **(** ⟨MapAndList⟩ **and** ⟨LocalAttributeName⟩ **)**
⟨MapAndList⟩ ::= ⟨LocalAttributeName⟩
| ⟨MapAndList⟩ **and** ⟨LocalAttributeName⟩
⟨MapUnionExpression⟩ ::= **(** ⟨MapUnionList⟩ **union** ⟨LocalAttributeName⟩ **on** ⟨Identifier⟩ **)**
⟨MapUnionList⟩ ::= ⟨LocalAttributeName⟩
| ⟨MapUnionList⟩ **union** ⟨LocalAttributeName⟩

⟨RelDcl⟩ ::= **relationship** ⟨TargetOfPath⟩ ⟨Identifier⟩ **inverse** ⟨InverseTraversalPath⟩ ⟨OptOrderBy⟩

⟨TargetOfPath⟩ ::= ⟨Identifier⟩
| ⟨RelCollectionType⟩ **<** ⟨Identifier⟩ **>**

⟨RelCollectionType⟩ ::= **set**
| **list**

⟨InverseTraversalPath⟩ ::= ⟨Identifier⟩ **::** ⟨Identifier⟩

⟨OptOrderBy⟩ ::=
| **{ order_by** ⟨ScopedNameList⟩ **}**

⟨ScopedNameList⟩ ::= ⟨ScopedName⟩
| ⟨ScopedNameList⟩ **,** ⟨ScopedName⟩

⟨OpDcl⟩ ::= ⟨OptOneway⟩ ⟨OperTypeSpec⟩ ⟨Identifier⟩ ⟨ParameterDcls⟩ ⟨OptRaisesExpr⟩ ⟨OptContextExpr⟩

⟨OptOneway⟩ ::=
| **oneway**

⟨OperTypeSpec⟩ ::= ⟨SimpleTypeSpec⟩
| **void**

⟨ParameterDcls⟩ ::= **(** ⟨ParamDclList⟩ **)**
| **( )**

⟨ParamDclList⟩ ::= ⟨ParamDcl⟩
| ⟨ParamDclList⟩ **,** ⟨ParamDcl⟩

⟨ParamDcl⟩ ::= ⟨ParamAttribute⟩ ⟨SimpleTypeSpec⟩ ⟨Declarator⟩

⟨ParamAttribute⟩ ::=
| **in**
| **out**
| **inout**

⟨OptRaisesExpr⟩ ::=
| **raises (** ⟨ScopedNameList⟩ **)**

⟨OptContextExpr⟩ ::=
| **context (** ⟨StringLiteralList⟩ **)**

⟨StringLiteralList⟩ ::= ⟨StringLiteral⟩
| ⟨StringLiteralList⟩ **,** ⟨StringLiteral⟩

⟨ExtRuleDcl⟩ ::= **extrule** ⟨Identifier⟩ ⟨ExtRuleSpec⟩

⟨ExtRuleSpec⟩ ::= ⟨ForAll⟩ ⟨Identifier⟩ **in** ⟨ExtRuleType⟩

⟨ExtRuleType⟩ ::= ⟨ExtRuleIsa⟩
| ⟨ExtRuleBottom⟩

⟨ExtRuleBottom⟩ ::= **(** ⟨LocalClassName⟩ **and** ⟨LocalClassName⟩ **) then** ⟨Identifier⟩ **in bottom**

⟨ExtRuleIsa⟩ ::= ⟨LocalClassName⟩ **then** ⟨Identifier⟩ **in** ⟨LocalClassName⟩

⟨RuleDcl⟩ ::= **rule** ⟨Identifier⟩ ⟨RuleSpec⟩

⟨RuleSpec⟩ ::= ⟨ForAll⟩ ⟨Identifier⟩ **in** ⟨Identifier⟩ **:** ⟨RuleBodyList⟩ **then** ⟨RuleBodyList⟩
| **{ case of** ⟨Identifier⟩ **:** ⟨CaseList⟩ **}**

⟨ForAll⟩ ::= **for all**
| **forall**

⟨RuleBodyList⟩ ::= **(** ⟨RuleBodyList⟩ **)**
| ⟨RuleBody⟩
| ⟨RuleBodyList⟩ **and** ⟨RuleBody⟩

⟨RuleBody⟩ ::= ⟨DottedName⟩ ⟨RuleConstOp⟩ ⟨OptRuleCast⟩ ⟨LiteralValue⟩ ⟨DottedName⟩ ⟨RuleConstOp⟩ ⟨OptRuleCast⟩ ⟨DottedName⟩
| ⟨DottedName⟩ **in** ⟨DottedName⟩
| ⟨ForAll⟩ ⟨Identifier⟩ **in** ⟨DottedName⟩ **:** ⟨RuleBodyList⟩
| **exists** ⟨Identifier⟩ **in** ⟨DottedName⟩ **:** ⟨RuleBodyList⟩
| ⟨DottedName⟩ **=** ⟨SimpleTypeSpec⟩ ⟨Identifier⟩ **(** ⟨DottedLiteralList⟩ **)**

⟨DottedLiteralList⟩ ::= ⟨DottedLiteral⟩
| ⟨DottedLiteralList⟩ **,** ⟨DottedLiteral⟩

⟨DottedLiteral⟩ ::= ⟨OptSimpleTypeSpec⟩ ⟨DottedName⟩
| ⟨OptSimpleTypeSpec⟩ ⟨LiteralValue⟩

⟨OptSimpleTypeSpec⟩ ::=
| ⟨SimpleTypeSpec⟩

⟨RuleConstOp⟩ ::= **=**
| **>=**
| **<=**
| **<**
| **>**

⟨LiteralValue⟩ ::= ⟨SignedFloatingPtLiteral⟩
| ⟨SignedIntegerLiteral⟩
| ⟨CharacterLiteral⟩
| ⟨StringLiteral⟩

⟨DottedName⟩ ::= ⟨Identifier⟩
| ⟨DottedName⟩ **.** ⟨Identifier⟩

⟨OptRuleCast⟩ ::=
| **(** ⟨SimpleTypeSpec⟩ **)**

⟨CaseList⟩ ::= ⟨CaseSpec⟩
| ⟨CaseList⟩ ⟨CaseSpec⟩

⟨CaseSpec⟩ ::= ⟨LiteralValue⟩ **:** ⟨DottedName⟩

⟨ThesaurusRelation⟩	: : =	⟨LocalAttributeName⟩ ⟨ThesRelType⟩ ⟨LocalAttributeName⟩
	|	⟨LocalClassName⟩ ⟨ThesRelType⟩ ⟨LocalClassName⟩
	|	⟨LocalClassName⟩ ⟨ThesRelType⟩ ⟨LocalAttributeName⟩
	|	⟨LocalAttributeName⟩ ⟨ThesRelType⟩ ⟨LocalClassName⟩
⟨ThesRelType⟩	: : =	**syn**
	|	**bt**
	|	**nt**
	|	**rt**
⟨Module⟩	: : =	**module** ⟨Identifier⟩ { ⟨OdlSpecification⟩ }

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