GDAŃSK UNIVERSITY OF TECHNOLOGY
Faculty of Electronics,
Telecommunications and Informatics

Paweł Kapłański

Ontology-Aided Software Engineering

PhD Dissertation

Supervisor:
prof. Krzysztof Goczyła,
Faculty of Electronics,
Telecommunications and Informatics
Gdańsk University of Technology

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This dissertation is dedicated to my wife Katarzyna.
It would not have happened
without her encouragement, support and love.

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NOTATIONAL CONVENTIONS AND SYMBOLS

$\mathcal{AL}$	Attributive Concept Language
$\mathcal{ALC}$	Attributive Concept Language with Complements
$\mathcal{DLP}$	Description Logic Programs
$\mathcal{EL}$	EL Family of Description Logics
$\mathcal{SHIQ}$	Description Logic SHIQ
$\mathcal{SHOIQ}$	Description Logic SHOIQ
$\mathcal{SROIQ}$	Description Logic SROIQ
$\mathcal{SROIQB}$	Description Logic SROIQ with Cheap Boolean Constructors
$\top$	Top Concept
$\bot$	Bottom Concept
{a,b,..}	Enumerated Individuals
$C \sqcap D$	Intersection of Concepts/Roles
$\exists r.C$	Existential Restriction
$C \sqsubseteq D$	Concept/Role Subsumption
$s \circ r$	Role Chain
$\neg C$	Negation of Concept/Role
$C \sqcup D$	Union of Concepts/Roles
$\forall r.C$	Universal Restriction
$\exists r.Self$	Self Restriction
$\leq n\ r.C$	Number Restriction
r^-	Inverse Role
A-Box	Assertion Box
EBNF	Extended Backus–Naur Form
ExpTime	solvable (deterministic) in $O(2^{p(n)})$ time [p(n) is a polynomial]
LALR	Look-Ahead Left To Right
N2ExpTime	solvable (non-deterministic) in $O(2^{2^{p(n)}})$ time [p(n) is a polynomial]
NExpTime	solvable (non-deterministic) in $O(2^{p(n)})$ time [p(n) is a polynomial]
PTime	solvable (deterministic) in O(p(n)) time [p(n) is a polynomial]
R-Box	Role-Box
T-Box	Terminology-Box

1. INTRODUCTION

Language is a part of social technology for enhancing the benefits of cooperation, reaching agreements, making deals and coordinating our activities. The programming language is an artificial language, so it also fits into above definition - it allows for sharing the benefits of collaborative programming, reaching business agreements and coordinating the work of all the people involved in development of software intensive systems [Elli96]. Moreover, the usage of language gives the possibility of sharing ideas which coined together provide the prosperity that we couldn't have before we acquired the language itself. The computer language allows us additionally to communicate with the machine; however the existence of different natural languages slows the flow of ideas between the groups and thus forces isolation; differences in computer languages, their grammars and semantics, differentiate groups of programmers.

Engineering can be defined as the creative application of scientific principles to design or develop structures, machines, apparatus, or manufacturing processes. The software engineering is defined as application of a systematic, disciplined, quantifiable approach to the development, operation, maintenance of software, and the study of these approaches; that is, the application of engineering to software [Abra04]. But even if software engineering was meant to be an application of scientific principles, at the end of 1960's the Software Crisis [Dijk72] was identified and large IT projects have been plagued by overcrowding and budget blackouts. In 1995, The Standish Group published the "CHAOS" report [Stan95] that contained following observations:

- 31.1% of projects have been cancelled before they even got completed
- 52.7% of projects went over time and/or over budget, at an average cost of 89% of their original estimates
- 16.2% of software projects have been completed on time and on budget
- In larger companies only 9% of the projects came in on time and on budget with approximately 42% of the originally proposed features and functions
- In small companies 78.4% of the software projects got deployed, with at least 74.2% of their original features and functions

To cope with the Software Crisis, researchers brought forth multiplication of loosely-related software technologies, techniques, notations, paradigms, idioms and methodologies. Nowadays, the industry practices focus on the software engineering, trying to optimize it in both the quality and time dimensions. In the meantime, agile software development [Larm03] methodology, that focuses on the sociological and psychological aspects of software development process rather than on engineering and (in the meantime), created the split between industry practice and academic

research in the field. Agile methodologies introduced the foundation for novel approach to software production process that is opposed to software engineering, but (from the same reason) it lacks the ability to take advantages of formal methods (which are essential in the software engineering). Without formal methods it is impossible to rise to the challenges appearing in modern (more and more) complex software systems. Therefore, despite the progress in software development methodologies, the critical situation in the field remained extensively unchanged. Developers continue to produce monstrous complex systems that suffer from many complications that came from (among the others):

1. *Lack of understanding:* In order to understand the software structure, one is required to have a background knowledge in the field of a computer science, especially in software modeling. Analytic documents (e.g.: requirement specification, software design) function as a formal basis and they are often directed particularly to the systems designers. The business users, who may actually be the owners of the systems, are not considered (within the process) as recipients of the analytic documents. In consequence, strategic decisions that are made by the authorities[1] often reveal a lack of information about the real state of the software product that is developed within the organization (those decisions are generally based on consultations). Going further, in a complex software system, without the aid of methods and tools it is very difficult to trace and understand the impact of even a slight design change.
2. *Lack of knowledge management:* Software industry is knowledge oriented industry. While experienced programmers are leaving, the inexperienced ones are joining the company. In such an environment and without knowledge management it is almost impossible to maintain and create software with good quality in limited time and budget [Nata02]. The preservation of knowledge about the software is often underestimated. This is mainly due to the unavailability of tools that support the knowledge management in software houses.
3. *Problems with quality assurance:* Quality assurance has an important position within the software development process nowadays. Writing automated tests for a program requires the knowledge of programming and therefore programs that test other programs also suffer from the same problems as programs to be tested.

Those problems can be solved only by using formal software development methodologies and tools. Over thousands of years there evolved the only one, common language of ideas – the formal symbolic language of Logics. Logics give us the possibility to communicate in an unambiguous manner with the assistance of machines, which can perform automated reasoning. (Formal) Methods & Tools are nowadays widely recognized as a key macro-trend in modern Software engineering. This macro-trend brought forth (among the others) the Unified Modeling Language (UML) [Rumb05] which became a standard software modeling language. While UML is typ-

[1] Authorities are understood here as all the people responsible for business related decisions (e.g.: project managers, end-users that pay for the software product, private equity owners etc…)

ically used as a graphical modeling language, it can be used with Object Constraint Language OCL [Warm99] – the formal specification language.

The issue of bridging the gap between theoretical bases and industrial needs is expected to be solved by Common, Object Oriented Software Engineering Language (the formal language yet understandable by overall software engineering Community) – a core idea of the SEMAT initiative [Jaco12]. Executable UML [Mell02] (a formal subset of UML) is built over the set of tools that allow conversion of some of the UML+OCL artifacts into mathematical formalism. However desired Common Software Engineering Language (as it states in [Jaco12]) should also be able to express relevant practices, patterns, and their composition and therefore should be an implementation of a Pattern Language [Alex77] [Busc07a]. The Language should also be extendible and customizable, allowing the description of individual practices. It should allow preserving consistency between design and implementation of Software System, support automatic verification of key aspects and design constraints of Software System and increase traceability between requirements, design and implementation. What is more, it should be cheap[2] for organization that is going to use it. Last but not least – its usage should improve the quality of the software products.

1.1 HYPOTHESIS AND APPROACH

This thesis is located between the fields of research on Artificial Intelligence (AI), Knowledge Representation and Reasoning (KRR), Computer-Aided Software Engineering (CASE) and Model Driven Engineering (MDE). The modern offspring of KRR - Description Logic (DL) [Baad03] is considered here as a formalization of the software engineering Methods & Tools. The bridge between the world of formal specification (governed by the mathematics) and the world of software development is realized by the adaptation of Controlled Natural Language (CNL) as a verbalization of DL. To establish the previously mentioned bridge we, are required to make a step backwards to the Semiotics. We found out that software development process can be represented by a formal semiotic system, that fulfills the laws of Semiotics and allows for interpreting the semantics of signs in a formal way.

The aim of this thesis is to prove that:

1) **It is possible to define a Common, Object Oriented Language by using the Controlled Natural Language as a verbalization of Description Logic.**
2) **Introduced language is understandable for people and can be automatically processed by machines. It can also be used in many areas of software development where natural language is currently used.**
3) **The language can be used to aid the software production process with ontology engineering.**

The invented formalism is named **Ontology-Aided Software Engineering (OASE)**. The language (combination of CNL and DL) that is a centre of OASE is called

[2] The cost of introduction should be relatively small to the total cost of software product aided with the language.

OASE-English as it is a controlled subset of English that is designed especially for OASE.

World Description (A-Box)	Terminology (T-Box)	Integrity Constraint (IC)
John is a man.	Every man is an animal.	John must be a programmer.
Sophie is a giraffe.	Every giraffe is an herbivore.	Leo must be carnivore.

Figure 1. Examples of World Description, Terminology and Integrity Constraints in OASE-English

Modern, formal ontology engineering principle suggests the separation of ontology into two parts:

- Terminology (T–Box), that contains the terminological knowledge in the form of axioms defined by concepts and roles (conceptualization of terms in the world – the global axioms and core taxonomy) and
- World Description (A–Box), that includes assertions on instances of concepts coupled by roles (a set of expressions about instances that are related to the particular entity of analyzed problem).

On the knowledge base that includes both T–Box and A–Box, it can be automatically checked whether any of the Integrity Constraints (IC) is kept. IC is used to ensure the accuracy and consistency of data in a relational database, however in terms of knowledge representation it is a kind of modal expression, that can be validated by the theory prover (see Figure 1 for some examples).

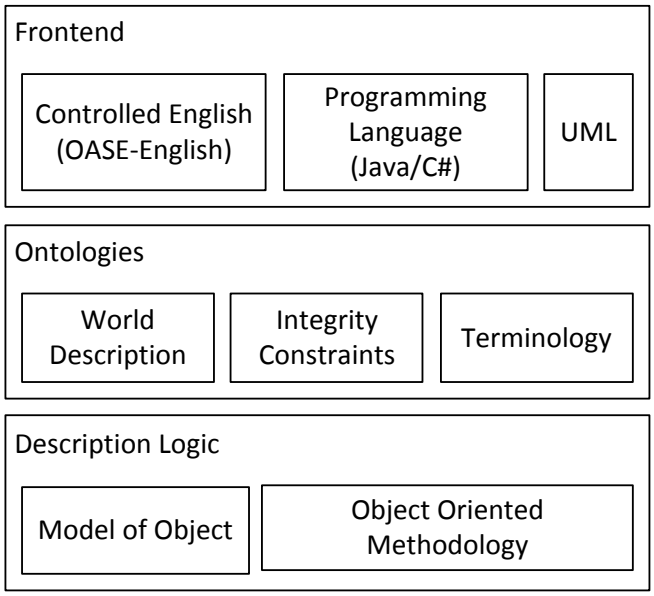

Figure 2. OASE Reference Model

The thesis proves that an object-oriented program built on top of the object-oriented design ontology[3] forms a World Description (A-Box) of the particular ob-

[3] A hierarchical structure of design constructs.

ject-oriented program[4]. The object-oriented design ontology is a Terminology (T-Box), as it consists of general rules e.g.: polymorphism and encapsulation. The requirements (e.g.: usage of the design patterns, architectural limitations, usage of generic structures, etc…) are represented by Integrity Constraints (IC).

The OASE Reference Model forms a stack (see Figure 2) in the way that OASE extends the object-oriented method by adapting modern knowledge representation methods. Description Logic in OASE is chosen as a formal specification language. Object-oriented programming, if formalized in DL, forms strictly defined upper-level ontology for subtyping, instantiation and other object-oriented constructs.

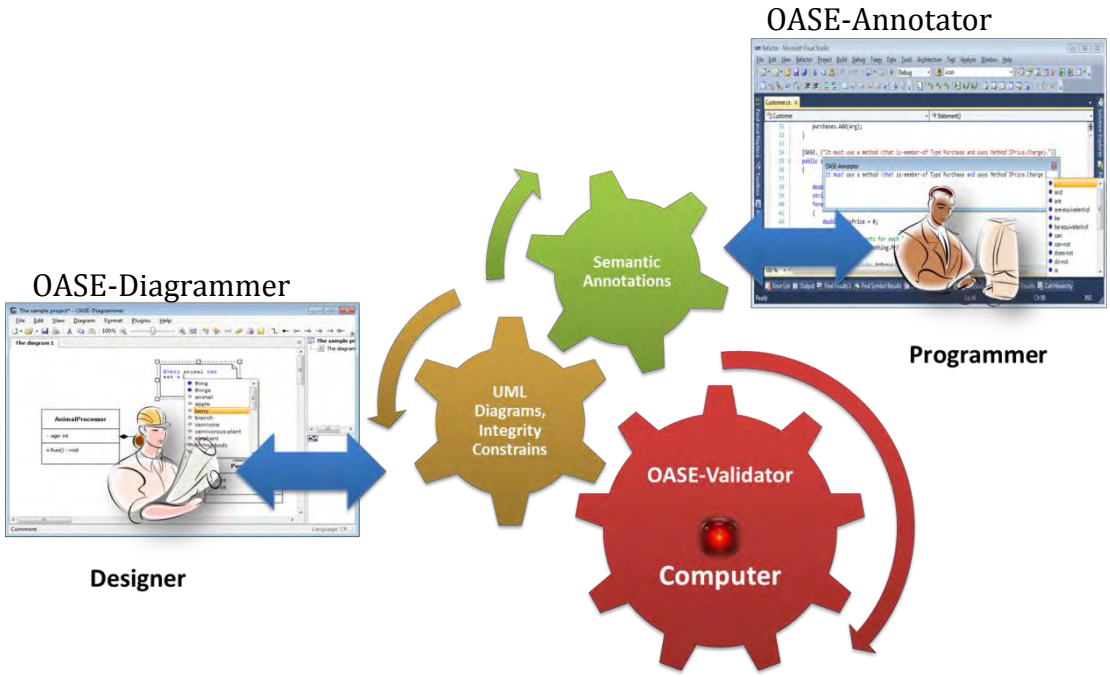

Figure 3. OASE-Toolkit in action

As a proof of the concept, the OASE-Toolkit has been implemented. Figure 3 presents the most typical use case that can be realized using the OASE-Toolkit. The design of the program (created and maintained by the designer) in UML and its source code (made by the programmer) are together transformed into DL via fully automated process. The requirements (functional – in UML, and non-functional – in OASE-English) are transformed into form of terminology (T-Box) and modal expressions (IC) that need to be obeyed by the software products. The source code of the program (developed by programmers) is transformed by the OASE-Toolkit into world description (A-Box). The computer using DL reasoning services (a specialized theory prover) automatically maintains the overall knowledge base and communicates with all of the stakeholders if any inconsistencies were found. OASE-English

[4] In other words: program entities form a structure of design constructs (derived from object-oriented design ontology) using various relations that may exist amongst these constructs. This structure can be seen as a model of knowledge about those entities and therefore it forms ontology.

(being the language of communication) allows for communication with the system, furthermore it is integrated into both: programming language (via annotation and assertions) and UML (in the form of UML notes). Such a system of tools given us the opportunity to examine usability of OASE in software manufacturing process.

During the research on OASE, it was discovered that OASE-Toolkit forms a foundation for applications and itself is useful for developing software components. The following applications of OASE were recognized:

1. Inferred UI - the automatically generated user interface for data-centric applications (with algorithm that crawls over the inferred taxonomy).
2. Auto-implemented requirement - requirement specified in CNL can be automatically used by the software system as a software component.

Within OASE method the architecture and design patterns are becoming clear both in the terms of terminology and semantics. The other field of the usage of OASE-English is a human-machine interface which works between the software system and developers. The system can identify the errors that occur in the middle of programmers-work, by using OASE-English to interact with the engineers, who can fix the problems found by the system itself (with the full support of natural language). This mission is supported by OASE-Annotations/OASE-Assertions which have a form of formal annotations/assertions written in OASE-English directly within the source code.

1.2 OUTLINE

This paper starts with introduction presented in the current chapter (chapter 1).

In chapter number 2, we describe the Ontology Engineering with a special emphasis on semiotics and semantics. We present the state of the art in the formal semiotic systems done so far. The description logic is presented here as a formal semantics of the usable ontologies that have the property of being decidable. Reasoning tasks and algorithms used to deal with the description logic are presented. Finally, we also discuss the semiotics of software artifacts.

In chapter number 3 we take a closer look at the software development methodologies. The first part focuses on the history and usability of programming languages and their classifications. The software models and approaches to formalize them are also discussed. Next part of this chapter takes into consideration software engineering vs. agile methodologies. Final part deals with the idea of the language of patterns, that resulted from the Christopher Alexander's concept of architectural pattern language [Alex77].

Chapter number 4 introduces the Ontology-Aided Software Engineering (OASE) – the method invented by us, that gives the possibility of dealing with the software-design in means of knowledge engineering and tools (with a special focus on the description logic and OASE-English). OASE-English is a verbalization of DL which is intended to deal with the software design. This chapter presents the software in terms of semiotics, and defines the software in terms of formal semiotic system.

What is also discussed, is the computability and complexity of the software structures. The motivating examples illustrate the case-studies that resulted in the idea of OASE. Next, we present the OASE-English grammar and semantics as well as the OASE-Transformations that bridge the world of software design with the OASE. Another concept presented in this chapter is the OASE-Annotations – the enrichment of programming, that makes use of formal annotations (verbalized in OASE-English). Then, OASE-Assertions (forms of formal assertions useful in debugging purposes of the running program) are presented. Then, the OASE is demonstrated and discussed as a methodology able to describe software design-patterns.

Chapter number 5 presents the tools that were developed to support the OASE. It describes how they work as well as the design and their pragmatic use.

Chapter number 6 presents the innovative components that make use of OASE: Inferred UI – the way to automatically generate UI from the ontology and Self-Implemented requirement – the way to reduce the cost of change in terms of the business-requirements.

The summary of results and suggested future work is presented in chapter 7.

Additionally there are seven appendixes. In the first appendix the details of mapping between OASE-English and description logic is provided. Appendix number 2 presented the details about OASE-Transformation used to convert the object-oriented source code into OASE-English script. In appendix number 3 we present the transformation of Adapter Design Pattern into OASE-English. In appendix number 4 we present the results of the survey that was performed on the group of designers and programmers. Appendix number 5 presents the results of validation experiment carried out on the population of designers and programmers that was aimed to prove the usability of OASE method and exhibit the ways to its improvement. Appendix number 6 presents the description of the Clinical Decision Support System that was implemented by us as a case study that was done to prove the usefulness of OASE-Toolkit components as being useful in stand-alone applications. Appendix 7 presents the purpose of OASE web-page (www.oase-tools.net) that is an entry-point for a community interested in OASE.

2. ONTOLOGY ENGINEERING

The aim of this chapter is to show the related work done so far in the field of semiotics and formal knowledge modeling. This chapter presents the current state of the art in the field and also defines the basic concepts that are going to be used within the rest of this thesis.

2.1 SEMIOTICS

The chart based on a drawing from Sir Roger Penrose book (see Figure 4) [Penr05] schematically illustrates three worlds within which we live. The *Physical World* – our living place - can be thought of as a projection of a part of the *Platonic World* – the world of eternal Truths.

Platonic world is the world of signs that we use to describe Physical World of concepts that forms a model of reality. Those models are created by using signs written in a specific way (syntax), equipped with formal meaning (semantics[5]) and used by agents[6] to refer to things in the world and to share their intentions about those things with other agents (pragmatics[7]).

The *Mental World* is a projection of the Platonic World that exists in our brains[8].

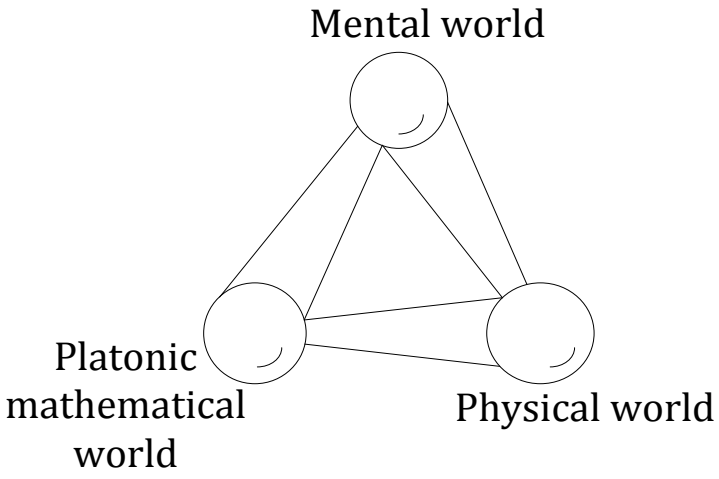

Figure 4. Three Worlds (based on [Penr05])

The common method, of gaining knowledge that we all use, starts with specifying (using signs) its elements (that represents the physical beings) which can be as-

[5] Semantics is the formal science of the conditions of the truth of representations.
[6] Agent is the participant of a situation that carries out the action in the situation.
[7] John F. Sowa: Ontology, Metadata, and Semiotics [http://users.bestweb.net/~sowa/peirce/ontometa.htm]
[8] The brain however is a part of Physical World, so the Platonic World can be grasped during mental activities.

cribed with some properties (analyzed in terms of relations and grouped in concepts in our minds - classes/sets). Charles Sanders Peirce (1839–1914) founded semiotics as the 'formal doctrine of signs' [Peir31]. The word 'semiotics' is derived from the Greek sēmeiōtikos (σημειωτικός), (interpreter of signs, or sign reader) and semiotics covers the whole cycle of a sign, from its creation, through its processing, to its use, with a great emphasis on the effect of signs usage. It is common to divide signs into three types [Chan07] (citation with examples):

1) *Icon*: that is linked to its object by qualitative characteristics. For example, a map is an icon because it shares some quality (spatial organization) with its object. A photograph is iconic because it is linked to its object.
2) *Index*: that denotes its object by being physically linked to it, or affected by it. For example, smoke is an index of fire, and a knock at the door is an index of someone's presence on the other side.
3) *Symbol*: that has no qualitative or physical link to its object. It is "conventional"; that is to say that it is defined by social conventions. Most of the words are symbols. For example, if the word "dog" was replaced in English by the word "cat" and vice versa, there would be no change in the meanings we could convey. However it would be impossible to use a photograph (an icon) of a dog to represent a "cat".

There are three distinct fields of semiotics: syntax, semantics and pragmatics. Charles W. Morris [Morr38] made semiotics more widely recognized as a science of signs, to which he made many important contributions, largely from a behavioral standpoint. According to Morris, pragmatics deals with the origin and effects of the signs usage within the behavior in which they occur. Semantics deals with the signification of signs in all modes of signifying. Syntax deals with the combination of signs with no regard for their specific signification or their relationship to the behavior in which they occur. Semiotics treats the language, of which texts are composed, as a system of signs which conveys the meaning to the reader.

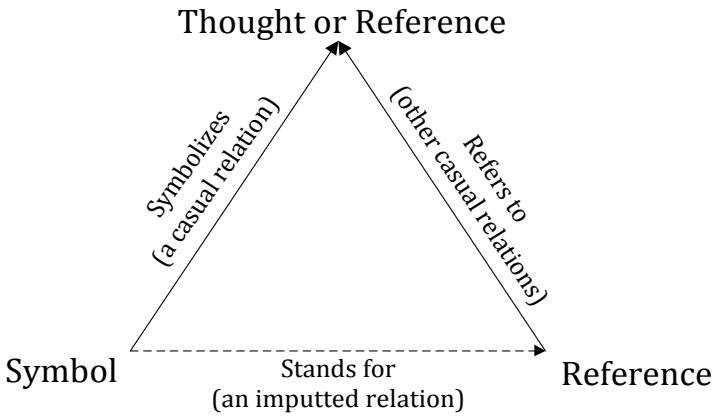

Figure 5. The semiotic triangle (based on Ogden and Richards 1923 [ORGR94])

The semiotic triangle (also known as the meaning triangle) is a model of how symbols are related to the objects they represents. The symbol represents the

thought or the reference and stands for reference to physical object (see Figure 5). Each corner of the meaning triangle came from one of those worlds.

2.2 ONTOLOGIES

In philosophy or epistemology, knowledge is indefeasible, justified and true belief [Brad79]. In Knowledge Representation (KR), knowledge is about 'any kind of belief a rational person might hold' and it is considered subjective and evolving. Formal Knowledge Representation allows to build complex Ontologies - Knowledge Bases[9] (KB), that nowadays attempts to be used in almost every area of endeavor (everyday life), due to the fact that computers are intensively used to manage them. The technological evolution brings KB from the human-readable form (where KB acts as an archive of searchable information) into the more-and-more computer readable form[10] which allows automated, deductive reasoning (semantic knowledge bases) and is caused by the ability of computers to provide formal methods and tools to manage the knowledge. Important impact on this area is made by innovation in the field of Knowledge Representation and Reasoning (KRR).

The version of the Semiotic Triangle developed by J.F.Sowa (called Sowa's meaning triangle) deals with Objects, Concepts and their Symbols, and allows us to represent those three entities with corresponding relations between them in a form of logical expressions or graphs that can be stored and processed by a machine. Therefore, the Sowa's meaning triangle brings the original semiotic triangle near to the logic. It transforms the relationship between a symbol and a though or a reference, to a relation between a symbol, a concept and an object (see Figure 6). Sowa's meaning triangles can connect to each other [Sowa00].

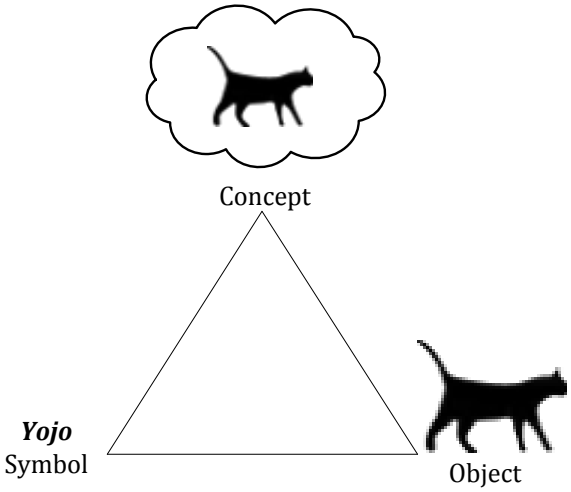

Figure 6. The Sowa's meaning Triangle (based on [Sowa00])

The upper corner (the placeholder for the concept) of the meaning triangle from the Figure 6, can be connected to the right-bottom corner (the placeholder for an

[9] A database that provides computerized collection of knowledge as well as its organization, and retrieval.
[10] The Internet for example, long ceased to be a simple directory of pages; however today it is considered to be a giant semiotic system. It is a set of streams of signs and meanings generated by ordinary people for other ordinary people, and processed by the huge number of computers.

object) of the newly created meaning triangle. In such a case, the Concept from the first triangle becomes the Object in the newly created one and in the second triangle the Meta-Concept (the Concept about other Concepts) appears in the top corner. If, in another case, the right-bottom corner (the placeholder for an object) of the newly created meaning triangle is connected to the left-bottom corner of the triangle from Figure 5 (the placeholder for a symbol), the symbol becomes the object of conceptualization; therefore, in such a case it is possible to conceptualize the symbolism of the original triangle.

The process of transformation of a textual archive into the semantic KB generates difficulties that we need to overcome in order to effectively exploit the benefits of this trend and make use of the innovations that it creates. To understand the structure of semantic KB, one is required to have a background in the field of an artificial intelligence, knowledge representations and knowledge modeling. It is also recommended to know the supporting tools that are generally organized around the graphical knowledge modeling tools (based on iconic representation, in a form of a graph e.g. Protégé [Genn03]). It is difficult to identify a structure of knowledge for a stakeholder that is not familiar with such a graphical knowledge modeling language.

On the other hand, without the support of formal methods it is almost impossible to trace and understand the impact of knowledge parts on each other in complex KB. Formal methods allow one for analyses of such a complex KB, however, obtained results still require a special way of announcing it to the interested stakeholders. Minsky's Frames had a great impact on the area of KR in this field. Minsky says that "When one encounters a new situation (or makes a substantial change in one's view of the present problem) one selects from memory a structure called a Frame. This is a remembered framework to be adapted to fit reality by changing details as necessary" [Mins75].

2.3 KNOWLEDGE EXPRESSION

Five primitives (see Table 1) are available in natural language and have direct semantic correspondence in First Order Logic (FOL) [Barw77]. Any notation that is capable of expressing those five primitives in all possible combinations must include all of FOL axioms as a subset [Sowa00], therefore if equipped with the above five primitives the language is powerful enough to represent every computation.

Existence is a way of providing the language with an ability to express the assertions about the world – the number of truths that must be followed. In the Following example developed by J. F. Sowa [Sowa00], one can say that e.g.: "Yoyo exists.", w.r.t. semiotic triangle it means that there exists an object, and the symbol 'Yojo' stands for this object (or we can also say that the object is called[11] 'Yojo'). Mental representation - a concept[12] - of the object is symbolized by the symbol (name) 'Yojo' and forms the relation between the symbol and the concept. What is more - due to the

[11] If X stands for Y then Y is called X.

[12] A concept (substantive term: conception) is a cognitive unit of meaning—an abstract idea or a mental symbol sometimes defined as a "unit of knowledge".

relations mentioned in the preceding sentence - the concept relates to the object (according to Sowa's semiotic triangle). The symbol 'Yojo' is here an identifier for the specific object – a name for a single instance. If we replace 'Yojo' with a symbol 'cat' then symbolized concept will change the meaning. The concept symbolized by 'cat' refers to many particular objects and we formally interpret this concept (in terms of a set), as the logical function with one free variable (according to FOL), as a class (according to UML) or as a Type (according to theory of types [Chur40]).

Primitive	Informal Meaning	English Example
Existence	Something exists.	Something is a dog.
Coreference	Something is the same as something.	Woman means the same as a person that is a female.
Relation	Something is related to something.	The dog has fleas.
Conjunction	A and B.	Mary and John.
Negation	Not A.	The dog is not a cat.

Table 1. Five semantic primitives (after [Sowa00])

Type-token distinction is a distinction that separates an abstract concept from the objects which are particular instances of the concept. For example, the particular bicycle is a token of the type of thing known as "The skateboard." whereas, the skateboard in a particular place at a particular time, that is not true of "the skateboard" as used in the sentence: "The skateboard has become more popular recently." Types are usually understood ontologically as being abstract objects. The symbol 'Yojo' stands for a single physical object, however there can also exist another objects called 'Yojo', therefore the concept symbolized by 'Yojo' forms a set too. Moreover, the particular object can have many other names e.g.: 'Tom', 'Kitti',… [13] so it is necessary to explicitly provide the information about the way symbols are assigned to objects.

Both symbols, 'Yojo' and 'cat', symbolize the concepts that have semantics of sets. The difference between these two concepts can be only seen if we apply the semantics. Semantics of the first concept (related to the physical object) is connected with the identification, while the semantics of second one (linked to an abstract object) is related to generalization. There exist concepts associated with the most general abstract objects – the top concepts - (symbolized by symbols like e.g.: 'thing'), that refer to every particular object (the set of objects that refers to all objects in the world) and therefore they cannot be used in term of identification. Concepts that are

[13] Some ontology engineering languages use UNA (Unique Name Assumption) to omit this limitation of symbols.

used to identify the physical (or virtual) objects (in ontology engineering discipline) are called instances, leaving the place for concepts that are used for generalization.

Concept subsumption represents all cases where there is a need to specify the order in terms of set inclusion, e.g.: “Every cat is a mammal.” We say that one concept subsumes the other one if the set described by the first concept is a subset of the other. We say "Every tree is a plant" and it means that every single object referenced by a concept which is symbolized by ‘tree’ is also referenced by concept symbolized by ‘plant’ (see Figure 7 where very simple ontology of plants and trees is presented. Venn diagram in the figure represents concept subsumption between a concept of a plant and a concept of a tree. Arrows represent part-whole relationship between parts of a tree and the tree as a whole). One can say: “If something is a tree then it is a plant too.”, or “All trees are plants”. Those three **patterns of sentences** are equivalent; however sentence: “A tree is a plant.” can mean (regarding to context) both: subsumption between trees and plants, or the fact that there exists an object that is referenced to concept symbolized by the symbol ‘tree’ and this particular object is also referenced to concept symbolized by the symbol ‘plant’. Second meaning is clearly in opposition to the concept subsumption case, as it deals with single, particular instance, therefore we speak that “A x is a y”’ sentence pattern is ambiguous. It is because its meaning depends on the default context that we agree upon, and if used by autonomous agents, can lead to a misunderstanding[14].

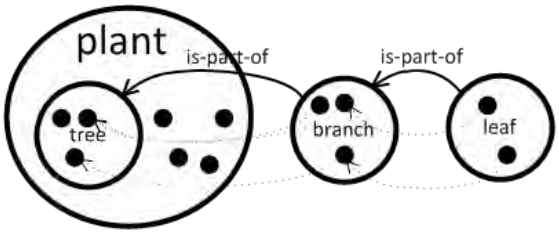

Figure 7. Concept subsumption and relations between objects (the case of trees)

The instance (as any other concept) can be subsumed by other concepts, e.g.: “Yojo is a cat.” It is a correct sentence; however if one instance subsumes another, then it means that they are equivalent - they must relate to the same object. It is not a case for concepts. If we say that "Every tree is a plant" it does not implicate that "Every plant is a tree". It is a common mistake to misuse the concept subsumption where concept equivalence is appropriate. For example, sentence: "Every boy is a young-male-man" expresses the case that all boys are young-male-men, however it is also meant to mean that all young-male-man are boys . This is due to the fact that in this case the language has limitations of expressiveness for **equivalence** and is used with a great support of human (the agent that uses it) experience. Language is a way of communication; therefore we tend to come short the message size and usual-

[14] Other popular example of ambiguous expression in English is “I see the girl with a telescope”. It can be interpreted either as: “I see [the girl with a telescope].” or “[I see the girl] with a telescope”. There is no way to determine what interpretation is correct without support of the surrounding context.

ly use only subsumption, leaving the place for the listeners intelligence to infer the precise meaning of the sentence. The concept equivalence can be formularized as a pair of concept subsumptions, e.g.: “Every boy is a young-male-man and every young-male-man is a boy as well” or using the symbol correspondence: "The symbol ‘boy’ is equivalent to the symbol ‘young-male-man’." Sentence: “Every boy is equivalent to every young-male-man.”, means that every single object represented by the symbol ‘boy’ is equivalent to all of the objects represented by the symbol ‘young-male-man’, what is not the case and we need to be aware of such misunderstanding in order to be precise.

In opposite to the subsumption of concepts there is often a need for specifying that two symbols stand for different objects. **Disjoint concepts** represent all those cases where concepts are mutually-exclusive, e.g.: “No man is a woman” or “The disjointness of a man and woman is a fact”. It can be visualized by the Venn diagram (see Figure 8) where the fact of disjointness of herbivore and carnivore is presented). The fact that two concepts are different might not appear to be as much important as the subsumption is, however if not specified, there is no way to infer some kind of implicit knowledge that results from facts. Databases are usually equipped with a **closed world assumption,** which means that every fact that is not deducted to be true, is false. In case of ontology engineering (and to some extend[15] in case of the natural language) we are dealing with an **open world assumption** – the situation when some fact is unknown and does not implicate any additional facts.

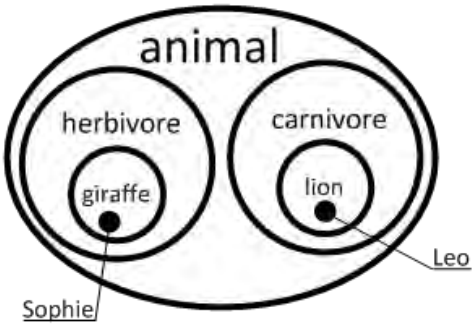

Figure 8. Disjoint Concepts (the animal case)

Human mind interacts with the physical objects. It is also able to deal with the virtual beings. The term “virtual”, in philosophy, has been defined as “that which is not real” but may display the salient qualities of the real. Mental representations and virtual object form concepts in our minds. A powerful method that allows us to link abstract objects with the virtual objects is called “**materialization”**. We tend to use the virtual being like tax, temperature, position etc. and make an assumption about them in the same way as we do with the physical objects. Every property of an object can be materialized as a standalone virtual being, e.g.: instead of saying that “The Sun is hot”, we can say that: “The Sun has high temperature” and use a virtual object

[15] In communication with natural language we often tend to use understatements and we know how to deal with them.

called ‘temperature’. The software is made of virtual beings as there is no single way in physical world to map the software artifacts. We can make computation on transistors, on DNA, or in quantum computing environment, still using the same virtual beings like ‘procedure’, ‘stack’ or ‘database’. The materialization allows the abstract objects to become the virtual objects e.g.: abstract object called ‘cat’, if materialized, becomes a virtual being in a world of species like dogs, fishes etc… Due to the materialization, we can use a ‘cat’ as a single and unique appearance of particular species and do the conceptualization around other ones as if it was an instance of some more-general concept. The way that we materialize the concept is especially important in formal ontology engineering, where we need to make a decision what is an instance and what is a concept basing on the pragmatic needs that stand behind the scene.

Concepts can be linked to other ones by relations. A relation has the semiotic triangle; however it is often difficult to find the physical representation of a relation[16], therefore they are frequently represented by the virtual beings. Relations link the concepts to provide the meaning (semantics) of one in terms of the others. The most commonly used relations are the binary ones. When we say “Tom loves Jerry” the relationship “loves” connects the meanings of this two objects and adds a semantics of “loving one by another” to this connection. The ternary relation “give” involves three objects: the giver, the given and the gift. In natural language those two kinds of relations are the most common ones, however it is possible to imagine the relationship that requires more stakeholders[17]. It is worth to note that $\mathcal{SROIQ}$ DL (considered here) deals solely with binary relations. This limitation can be omitted by simulation n-ary relations as concepts.

Relations can apply to the concepts in a restricted way: “Pawel has two legs”, “One cat (that is a brown-one) has red eyes”, “Mary is married to John” or “John knows a programming-language”. We can say that “Pawel has two legs” which states that Pawel is a subconcept of two-legged-thing, on the other hand we can say that “Pawel has at-most two legs.”, which means that Pawel is a subconcept of objects that has at most two legs. Both expressions are examples of number restrictions. Every restriction can be seen as a special case of either a number restriction or a restriction on negation of number restriction; two most commonly used are called: “**existential restriction”** (one object is related to at least one other object of a specific kind) and “**universal restriction**” (objects can only be related to objects that have a specific type). Logically, universal restriction is a complement in terms of De Morgan’s laws of existential restriction.

Very important relationship that is commonly used is a part-whole relation. The part-whole relation is transitive “If X is-part-of Y and Y is-part-of Z then X is-part-of Z too”. We can make “If then” sentence pattern more general by applying it to any two relations. E.g. “If X loves Y that is-made-of Z then X loves Z” (see Figure 9 where

[16] Relations mostly represent processes, collaborations

[17] E.g. the “proportion” relation requires four stakeholders e.g. in sentence: “Eggs to water and sugar to milk must be added in the same proportions.”

the fact of loves and the substance of lover is considered). We call this case: complex role inclusion. Relations can also be symmetric (e.g.: brotherhood) and reflexive – if they are related to the object itself automatically (e.g.: is-equal-to).

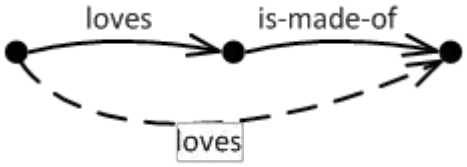

Figure 9. Complex Role Inclusion (the case of love)

If one concept is subsumed by two other concepts, then we can express this situation either by using two subsumption sentences, or with "**and"** operator, which creates the concept that is their intersection. On the contrary, we can say that two concepts are disjointed or use the **complement of concept** and utilize the subsumption to express that the first one is subsumed by complement of the second. To create the complement of a concept we use **"not"** operator.

The pragmatic usage of language also involves expression of possibilities and necessities that we use to specify contracts. We tend to use the special modal words e.g.: must, should, can, is-obligated-to. To deal with modal worlds the extension to the "single world approach" is required. We can adopt the mental constructions of all **possible worlds** whose characteristics or history differs from our own. For example, works of fiction generally describe some kind of alternative universe, which differs from our own to a greater or lesser extent. However, we require that these alternative universes are logically consistent. There may be alternative universes where Columbus did not discover America, but there are no alternative universes where 1 + 1 = 3. The extent to which alternative universes actually exist is a deep metaphysical question with strong connections to theology and physics. However, for our purposes we will assume that anything that can be imagined without any contradiction, is a valid alternative universe. The common modern interpretation of possible worlds is the modal logic notation developed by Saul A. Kripke [Krip80]. If we say that "Every man must have name.", then it means that we need to equip every single instance of concept symbolized by 'man' with the concept symbolized by 'name'. If for some men it is not true, then we say that constraint is not held. In terms of possible worlds, it means that every instance of a concept symbolized by 'man' is associated with some instance of concept symbolized by 'name'. This is a necessity constraint, the other possibility is, e.g.: "Every man can have a dog". The necessity constraint should hold in at least one possible world.

2.4 CONTROLLED ENGLISH

The history of Controlled English (CE) starts from Jorge Orwell's idea of "new-speak" described in famous novel "1984" [Orwe90]. Controlled English was successfully used by large corporations to standardize the language used for internal communication e.g.: Caterpillar Technical English [Kamp98], IBM Easy English [Bern97], Boeing Simplified English [Wojc90] etc. The novel approach to CE supported by KRR requires that CE has restricted grammar and vocabulary, in order to reduce the ambiguity and complexity inherent in natural language. In the last years, this branch of CE established itself in various application fields (mostly as an interface of knowledge bases) as a powerful knowledge representation language that is readable for humans and processable by computers. Attempto Controlled English (ACE) [Fuch90] is very expressive CE and it is the one that is mostly used. ACE can be translated into a non-decidable subset of FOL. It also provides its subset called ACEOWL [Kalj07] that can be translated into $\mathcal{SROIQ}$ Description Logic (formal foundation of OWL2).

This thesis presents the CE that was intended to be useful in software development process, called **OASE-English**. The research for CE described here was inspired by ACEOWL. The grammar of OASE-English was implemented using LALR(1) top-down parser generator [Rose69] and equipped with additional features that are not available within ACEOWL. Additional features include "A is equivalent of B" construction that corresponds to $A \equiv B$ DL expression, and allows the use of parentheses and also the production of more complex expressions in CE. The use of LALR(1) top-down parser is burdened with limitations of readability offered by ACEOWL, however those limitations are not as low according to the evaluation made within this thesis. Even if there exist sentences of OASE-English that are not a valid expressions in ACE (and even in English), the EBNF grammar of the OASE-English is designed to be as close to the natural English as possible, and can be translated to OWL2 format and back easily. Moreover, due to the fact that OASE-English is implemented by using LALR(1) parser, the effective predictive editor that supports OASE-English is applied in the efficient manner (however using Grammatical Framework [Rant04] or Codeco [Kuhn10], that is a grammar framework behind ACE, it is possible too).

2.5 DESCRIPTION LOGICS

The foundation of Description Logic (DL) [Baad03] together with concept of the Semantic Web was discussed by Tim Berners-Lee [Bern01] and was intended to provide a mathematical background for the new wave of self-adapting services (successors of web services) called the semantic services. DL was selected, because it is able to describe knowledge about the world around us in a formal way, and it is yet understandable by human – because it correspond to semiotic triangle approach developed by Sowa [Sowa00]. There exists a variety of other formalisms, that have the similar properties (e.g. F-Logic [Kife05]). All of them represent the knowledge of its domain - „world" - by defining given concepts within one domain (its terminolo-

gy), so that later, by using these concepts, it can be described by these objects (instances of concepts) and their properties. Nevertheless, from the pragmatic point of view decidability is a fundamental property for us and DL is decidable. Decidability ensures that reasoning tasks within DL can be made in finite time and space on modern computers that follow the laws of Touring Machine. Reasoning tasks include concept classification, which is a hierarchical arrangement of concepts within the notion of inclusions. Another one is classification of instances to the certain concepts. Some dialects of DL (e.g. $\mathcal{EL}^{++}$ [Baad06]) ensure that they can be done in polynomial time, other - more expressive ones (e.g. $\mathcal{SROIQ}$ [Horr06b]) use optimization techniques for most common cases so as to reduce the computation limits. Nevertheless, the ontological framework, in order to be useful, needs to be responsive[18] and therefore the selection for the formalism is a curtail requirement for ontology modeling with DL.

Formally DL is a subset of FOL, equipped with decidable reasoning tasks. In DLs, the domain of interest is modeled by means of concepts, objects and relationships between them, that are binary relations in-fact[19]. DL is made around semiotics in terms of:

1. *The syntax.* The specification of the construction of complex concepts and relation expressions.
2. *The semantics.* The specification of the construction of knowledge base, in which properties of concepts and relations are asserted,
3. *The pragmatics*. Provided by the DL toolkits implements algorithms of automatic knowledge discovery and which were proved to be decidable.

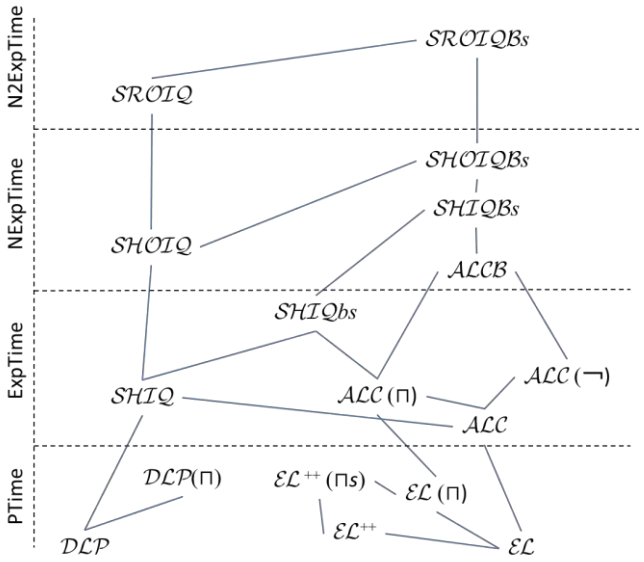

Figure 10. Overview of complexities and expressivity relationships of DLs after [Rudo08]

[18] Responsiveness is the ability of computer system to perform assigned function within the required time interval.

[19] This is a quite big limitation to the expressiveness e.g.: the 'give' relation presented earlier.

Description logic dialects differ in syntax constructors that are to be used and the names of the dialects come from the combination of constructor identifiers (see Table 2). The more constructors are allowed, the more expressible DL dialect is; however the more expressible DL is, the complexity of reasoning goes higher too[20] (see Figure 10).

We define the static knowledge as knowledge that is decidable. Computability separates what is a static structure from what is a dynamic behavior, in the terms of properties of artifacts created during software development process. The static structure must be decidable; otherwise the static structure will only be an initial state of more complex dynamic behavior. In such a case static structure could not be analyzed in separate to the behavior. The fact that the DL allows for separation between static and dynamic aspects of software systems is a fundamental assumption of this thesis.

	Name	Syntax	Semantics
$\mathcal{EL}^{++}$	top	$\top$	$\Delta^{\mathcal{I}}$
	bottom	$\bot$	$\emptyset$
	nominal	$\{a\}$	$\{a\}^{\mathcal{I}}$
	conjunction	$C \sqcap D$	$C^{\mathcal{I}} \cap D^{\mathcal{I}}$
	existential restriction	$\exists r.C$	$\{x \in \Delta^{\mathcal{I}} \mid \exists y \in \Delta^{\mathcal{I}} : (x,y) \in r^{\mathcal{I}} \wedge y \in C^{\mathcal{I}}\}$
	concrete domain	$p(f_1,...,f_k)$ $for\ p \in \mathcal{P}^{D_j}$	$\{x \in \Delta^{\mathcal{I}} \mid \exists y_1,...,y_k \in \Delta^{D_j} : f_i^{\mathcal{I}}(x) = y_i\ for\ 1 \le i \le k \wedge (y_1,...,y_k) \in p^{D_j}\}$
	CGI	$C \sqsubseteq D$	$C^{\mathcal{I}} \subseteq D^{\mathcal{I}}$
	RI	$r_1 \circ ... \circ r_k$	$r_1^{\mathcal{I}} \circ ... \circ r_k^{\mathcal{I}} \subseteq r^{\mathcal{I}}$
$\mathcal{SROIQ}$	negation	$\neg C$	$\Delta^{\mathcal{I}} \backslash C^{\mathcal{I}}$
	disjunction	$C \sqcup D$	$C^{\mathcal{I}} \cup D^{\mathcal{I}}$
	universal restriction	$\forall r.C$	$\{x \in \Delta^{\mathcal{I}} \mid (x,y) \in r^{\mathcal{I}} \Longrightarrow y \in C^{\mathcal{I}}\}$
	Self concept	$\exists s.\mathsf{Self}$	$\{x \in \Delta^{\mathcal{I}} \mid (x,x) \in s^{\mathcal{I}}\}$
	qualified number restrictions	$\le n\ s.C$	$\{x \in \Delta^{\mathcal{I}} \mid \#\{y \in \Delta^{\mathcal{I}} \mid (x,y) \in s^{\mathcal{I}} \wedge y \in C^{\mathcal{I}}\} \le n\}$
		$\ge n\ s.C$	$\{x \in \Delta^{\mathcal{I}} \mid \#\{y \in \Delta^{\mathcal{I}} \mid (x,y) \in s^{\mathcal{I}} \wedge y \in C^{\mathcal{I}}\} \ge n\}$
	inverse role	r^-	$\{(x,y) \in \Delta^{\mathcal{I}} \times \Delta^{\mathcal{I}} \mid (y,x) \in r^{\mathcal{I}}\}$
	universal role	U	$\Delta^{\mathcal{I}} \times \Delta^{\mathcal{I}}$
$\mathcal{SROIQB}_S$	role negation	$\neg r$	$\{(x,y) \in \Delta^{\mathcal{I}} \times \Delta^{\mathcal{I}} \mid (x,y) \notin r^{\mathcal{I}}\}$
	role conjunction	$r \sqcap s$	$r^{\mathcal{I}} \cap s^{\mathcal{I}}$
	role disjunction	$r \sqcup s$	$r^{\mathcal{I}} \cup s^{\mathcal{I}}$

Table 2. Semantics of constructors in $\mathcal{SROIQB}_S$

The interpretation of DL is strictly defined in mathematical terms, however to be useful for public, it needs a verbalization that is as close to the natural language as possible. Controlled Natural Languages (CNL) tries to fill this gap. Very expressive CNLs like ACE [Fuch90] can be used to verbalize DL, most of OWL2 standard can be translated into a subset ACEOWL. It was recently shown [Kuhn09] that ACEOWL is more natural for people than formal-looking description logic verbalizations (like

[20] Description Logic Complexity navigator: http://www.cs.man.ac.uk/~ezolin/dl/

Manchester [Horr06a]/Sydney [Creg07] OWL Syntax). OASE-English - the language invented by us, has the similar properties like ACEOWL, however it is designed especially to be practically useful in the field of software development, therefore its pragmatics is different from the pragmatics of ACEOWL, which aim to be a general purpose of OWL2 verbalization.

2.5.1 DEFINITION OF DESCRIPTION LOGIC

Knowledge base, described by general means of DL, is divided into three parts: T-Box (Terminology Box) – which describes terminology of Concepts, A-Box (Assertion Box) which illustrates the assumptions about named instances and R-box (Role Box) which describes the terminology of Roles. Following Pascal Hitzler's definition [Rudo08], this subchapter starts with the very expressive DL called $\mathcal{SROIQB}_S$[21]. We define other dialects of DL by limiting constructors that are allowed.

Let's start from the definition of four disjoint sets: individual names N_I, concept names N_C, simple role names N_R (containing the universal role $\cup \in N_R$) and non-simple role names N_{R^n}. Let's $N_R := N_{R^s} \cup N_{R^n}$

Definition 1.

A $\mathcal{SROIQB}_S$ R-Box for N_R is based on a set $\mathbf{R}$ *of atomic roles defined as*

$\mathbf{R} := N_R \cup \{R^- | R \in N_R\}$, *where we set* $Inv(R) := R^-$ *and* $Inv(R^-) := R$ *to simplify notation. Lets distinguish simple atomic roles* $\mathbf{R}^s := N_{R^s} \cup Inv(N_{R^s})$ *and non-simple atomic roles* $\mathbf{R}^n := N_{R^n} \cup Inv(N_{R^n})$. *Let's use the symbols R, S, possibly with subscripts, to denote atomic roles.*

Definition 2.

For $\mathcal{SROIQB}_S$ the set of Boolean role expressions $\mathbf{B}$ *is defined as follows:*

$\mathbf{B} := \mathbf{R} | \neg \mathbf{B} | \mathbf{B} \sqcap \mathbf{B} | \mathbf{B} \sqcup \mathbf{B}$. *The set* $\mathbf{B}_s$ *of simple role expressions comprises all those role expressions containing only simple role names. Moreover, a role expression will be called "safe", if in its disjunctive normal form, every disjunction contains at least one non-negated role name.*

Definition 3.

A generalized role inclusion axiom (RIA) is a statement of the form $S_1 \circ \ldots \circ S_n \sqsubseteq R$, *where each* S_i *is a simple role expression or a non-simple atomic role, and where R is a non-simple atomic role. A set of such RIAs is a generalized role hierarchy. A role hierarchy is regular, if there is a strict partial order* $\prec$ *on* $\mathbf{R}^n$ *such that*
$S \prec R \Leftarrow\Rightarrow Inv(S) \prec R$, *and every RIA is of one of the forms:*
$R \circ R \sqsubseteq R$, $R^- \sqsubseteq R$, $S_1 \circ \ldots \circ S_n \sqsubseteq R$, $R \circ S_1 \circ \ldots \circ S_n \sqsubseteq R$, $S_1 \circ \ldots \circ S_n \circ R \sqsubseteq R$ *such that* $R \in N_R$ *is a(non-inverse) role name, and* $S_i \prec R$ *for* $i = 1,\ldots,n$ *whenever* S_i *is non-simple.*

Definition 4.

A role assertion is a statement of the form Ref(R) (reflexivity), Asy(S) (asymmetry), or Dis(S,S′) (role disjointness),where S and S′ are simple roles. A $\mathcal{SROIQB}_S$ R-box is the union of a set of role assertions together and a role hierarchy. A $\mathcal{SROIQB}_S$ R-box is regular if its role hierarchy is regular.

[21] The $\mathcal{SROIQ}$ DL equipped with cheap Boolean role constructors.

The knowledge specification mechanism (*semantics*) - the second component of the description logic foundation - determines how to construct the DL knowledge base. The DL knowledge base is made of DL expressions that indicate the logical connection between different (possibly complex) concepts, instances and roles.

Definition 5.

Given a $\mathcal{SROIQB}_S$ R-box, the set of concept expressions **C** *is defined as follows:*

- $N_C \subseteq \mathbf{C}, \top \subseteq \mathbf{C}, \bot \subseteq \mathbf{C}$,
- if $C,D \in \mathbf{C}$, $R \in \mathbf{R}$ a simple role expression or non-simple role, $V \in \mathbf{B}_S$ a simple role expression, $a \in \mathbf{N}_I$, and n a non-negative integer, then $\neg C$, $C \sqcap D$, $C \sqcup D$, $\{a\}$, $\forall R.C$, $\exists R.C$, $\exists V.\text{Self}$, $\leq_n V.C$, and $\geq_n V.C$ are also concept expressions.

Definition 6.

The symbols C, D will be used to denote concept expressions. A $\mathcal{SROIQB}_S$ T-box is a set of general concept inclusion axioms (GCIs) of the form $C \sqsubseteq D$. An individual assertion can have any of the following forms: $C(a)$, $R(a,b)$, $\neg S(a,b)$, $a \neq b$, with $a,b \in N_I$ individual names, $C \in \mathbf{C}$ a concept expression, and $R,S \in \mathbf{R}$ role switch S simple. A $\mathcal{SROIQB}_S$ A-box is a set of individual assertions. A $\mathcal{SROIQB}_S$ knowledge base $\mathfrak{K}$ is the union of a regular R-box, and an A-box and T-box.

The formal interpretation of DL follows the interpretation of FOL:

Definition 7.

An interpretation $\mathcal{I}$ consists of a set $\Delta^{\mathcal{I}}$ called domain (the elements of it being called individuals) together with a function $\cdot^{\mathcal{I}}$ mapping:

- *individual names to elements of $\Delta^{\mathcal{I}}$,*
- *concept names to subsets of $\Delta^{\mathcal{I}}$, and*
- *role expressions to subsets of $\Delta^{\mathcal{I}} \times \Delta^{\mathcal{I}}$.*

The function $\cdot^{\mathcal{I}}$ is inductively extended to a role and concept expressions, as shown in Table 2. An interpretation $\mathcal{I}$ satisfies an axiom ϕ if we find that $\mathcal{I} \models \phi$:

– $\mathcal{I} \models V \sqsubseteq W$ *if* $V^{\mathcal{I}} \subseteq W^{\mathcal{I}}$,
– $\mathcal{I} \models V_1 \circ \ldots \circ V_n \sqsubseteq W$ *if* $V_1^{\mathcal{I}} \circ \ldots \circ V_n^{\mathcal{I}} \subseteq W^{\mathcal{I}}$ ($\circ$ *being overloaded to denote the standard composition of binary relations here),*
–$\mathcal{I} \models Ref(R)$ *if* $R^{\mathcal{I}}$*, is a reflexive relation,*
– $\mathcal{I} \models Asy(V)$ *if* $V^{\mathcal{I}}$ *is antisymmetric and irreflexive,*
– $\mathcal{I} \models Dis(V,W)$ *if* $V^{\mathcal{I}}$ *and* $W^{\mathcal{I}}$ *are disjoint,*
– $\mathcal{I} \models C \sqsubseteq D$ *if* $C^{\mathcal{I}} \subseteq D^{\mathcal{I}}$.

An interpretation $\mathcal{I}$ satisfies a knowledge base $\mathfrak{K}$ (we also say that $\mathcal{I}$ is a model of $\mathfrak{K}$ and write $\mathcal{I} \models$), if it satisfies all axioms of $\mathfrak{K}$. A knowledgebase $\mathfrak{K}$ is satisfiable if it has a model. Two knowledge bases are equivalent if they have exactly the same models,

and they are equisatisfiable if either both of them are unsatisfiable or both are satisfiable.

2.6 DIALECTS

Going further with the definitions of subdialects, we obtain $\mathcal{SROIQ}$ from $\mathcal{SROIQB}_s$ by disallowing all junctors in role expressions. Further details on $\mathcal{SROIQ}$ can be found in [Horr06b]. Several syntactic constructs, that can be expressed indirectly, (especially role assertions for transitivity, reflexivity of simple roles, and symmetry) are omitted here. Moreover, the $\mathcal{SHOIQ}$ is obtained from $\mathcal{SROIQ}$ by discarding the universal role as well as reflexivity, asymmetry, role disjointness statements and allowing only RIAs of the form $R \sqsubseteq S$ or $R \circ R \sqsubseteq R$. Then, we obtain $\mathcal{EL}^{++}$ from $\mathcal{SROIQ}$ by disallowing conjunction in role expressions.

Definition 8.

An atomic role of $\mathcal{EL}^{++}{}_{(\sqcap s)}$ is a (non-inverse) role name. An $\mathcal{EL}^{++}{}_{(\sqcap s)}$ role expression is a simple role expression containing only role conjunction. An $\mathcal{EL}^{++}{}_{(\sqcap s)}$ R-box is a set of generalized role inclusion axioms (using $\mathcal{EL}^{++}{}_{(\sqcap s)}$ role expressions and non-simple atomic roles), and an $\mathcal{EL}^{++}{}_{(\sqcap s)}$ T-box is a $\mathcal{SROIQB}_s$ T-box that contains only the concept constructors: $\sqcap$, $\exists$, $\top$, $\bot$, and only $\mathcal{EL}^{++}{}_{(\sqcap s)}$ role expressions.

2.7 REASONING

The third part of DL foundation (*pragmatics*) is an automated reasoning which includes tasks like:

1. To form taxonomic DAG (Directed Acyclic Graph) of all atomic concepts in terms of concept subsumption.
2. To determine subconcepts and individuals of specific complex concept.
3. To determine all direct atomic subconcepts (children) or direct individuals of specific complex concept.
4. To check whether two complex concepts are in subsumption relation.
5. To check whether complex concept is satisfiable (can have instances).
6. To check whether instance is included in specific complex concept.

All these tasks are supported by specialized decidable theory provers called reasoners described in next sections.

2.7.1 STRUCTURAL SUBSUMPTION

Structural subsumption is based on syntax tree evaluators. Syntax tree evaluators are usually very fast (in terms of computation), however they provide the promising results (polynomial time of evaluation) only in certain (though very gen-

eral) situations. The reasoner for $\mathcal{EL}^{++}$ [Baad06] has proven that the syntax-tree evaluator, which has polynomial complexity, can be useful in wide area of interests.

Structural subsumption is an algorithm that tries to infer the implicit knowledge, basing on comparison between the syntactical structure of normal forms of DL expressions. It is divided into two steps:

1) Normalization. Every DL expression from KB is rewritten into normal form with the specific algorithm. It can be done in PTime for some DL dialects (e.g.: $\mathcal{AL}$[22], $\mathcal{EL}$++).
2) Comparison. The direct comparison of the normal forms is performed (PTime in terms of computation).

The good explanation of idea of subsumption algorithm over $\mathcal{AL}$ logic is presented in [Gocz11], [Baad03]. For $\mathcal{EL}$++, it is presented in details in [Baad06]. Structural subsumption algorithms for selected DLs are PTime. This property of the structural subsumption has big implication in terms of its practical implementations, especially in task of reasoning over big ontologies.

2.7.2 TABLEAU ALGORITHM

Every reasoning task can be transformed to the problem of checking for the existence of the model of KB. Tableau algorithm [Baad03] tries to build the model of KB in a systematic way. The model of KB is understood here as a specific A-Box that follows the strict algorithmic rules of its creation and is built basing on the structure of KB. E.g. $C \sqsubseteq D$ is true if it can be transformed to $C \sqcap \neg D \equiv \bot$ and it is true if the concept $C \sqcap \neg D$ has no model w.r.t. KB. If during the creation of the model the clash occurs, then the reasoning task returns the success. Otherwise, if every possible model created within the tableau algorithm does not result in a clash, the reasoning task returns failure as a result. Tableau algorithm is very general and it is investigated in terms of its properties. It was proven that this algorithm allows for reasoning over the $\mathcal{SROIQ}$ [Horr06b], however in general, it is hard to do so (see Table 2) in terms of computability. E.g. for $\mathcal{ALC}$ DL, the Tableau algorithm is PSpace.

Plenty of implemented tableau-based reasoners are effective (mostly due to the optimization techniques that build a set of heuristic in order to overcome the common situations). The $\mathcal{SROIQ}$ nowadays, is a DL lying under the OWL2.0[23]. The pragmatic test for tableau-based Reasoners, that is equipped with optimization techniques, shows that it is possible to make it in a reasonable.

Critics say that it is also possible to achieve the optimization techniques into FOL and give a performance results similar to DL Reasoners by using the timeout mechanism.

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[22] $\mathcal{AL}$ (Attributive language) is the core language for every DL which allows Atomic negation (negation of concept names that do not appear on the left hand side of axioms), Concept intersection, Universal restrictions and Limited existential quantification

[23] http://www.w3.org/TR/owl2-primer/

2.7.3 KNOWLEDGE CARTOGRAPHY

Knowledge Cartography approach [Gocz06] [Gocz11] is a set-algebra heuristics that can be easily adapted to modern distributed environment; even if a set of constructors is also limited. It can be implemented in Relational Database Management System (RDBMS). The Cartographic Approach may be effective for the ontologies with large number of assertions. The approach is based on the direct correspondence between the DL and set-theory. It also treats the DL concept as a set and DL instance as an element of the set.

The Knowledge Cartography algorithm first computes the 'descriptors' of all concepts. Descriptors have a direct representation in the form of binary strings. Having computed descriptors, the reasoning tasks are represented as simple matching procedures between binary strings. The binary-string matching is a low-level operation, that can be efficiently implemented in the computer systems, therefore once the descriptors are computed, the reasoning tasks are very effective. Cartographic algorithms have a great possibility to be implemented in massively parallelized environments e.g.: on CUDA[24] architecture.

2.7.4 EXPLANATIONS FOR REASONING IN DL

The idea of "Why?" button that is going to be implemented in semantic-web browser [Sene08] is an answer for a natural, pragmatic need for the explanation of specific implicitly reasoned knowledge. Explanations of DL reasoning tasks are realized by de-facto constructed sets of DL statements that aim to reconstruct the proof of the given theorem (result of the reasoning task) in the most meaningful way.

There exist two ways to produce reasoning justifications: black-box and glass-box. Black-box algorithms use the reasoner solely as a sub-routine and therefore the internals of the reasoner do not need to be modified. Black-box algorithms typically require many satisfiability tests. Glass-box algorithms require non-trivial modifications of the reasoned internals. In other words: a glass-box implementation is specific to a given reasoner and therefore also to a reasoning technique, while a black-box method does not depend on a specific reasoner or reasoning technique. The most widely used approach developed by A. Kalyanpur [Kaly07] is a combination of glass-box and black-box approach that can compute all the reasoning justifications.

2.7.5 MODULAR STRUCTURE OF DL

Instead of considering the entire complex ontology, users may benefit more by starting from a problem-specific set of concepts (signature of problem) from the ontology and exploring logical modules that surround it. Due the fact that DL ontologies are monotonic[25], DL supports modularity and allows for a separation of

[24] Compute Unified Device Architecture (CUDA) is a parallel computing architecture developed by Nvidia. CUDA is the computing engine in Nvidia graphics processing units (GPUs) that is accessible to software developers through variants of industry standard programming languages.

[25] Monotonicity of entailment is a property of many logical systems which states that the hypotheses of any derived fact may be freely extended with additional assumptions.

complex ontologies into smaller pieces (modules), which are easier to maintain and compute by isolated instances of the inference engine. The modularity of DL based ontologies allows constructing the inference engines that are capable to compute large ontologies [Kapl09].

2.8 OTHER IMPORTANT SUBSETS OF FOL

There exists formal specification and modeling languages for object-oriented design which were tailored to allow tool support in software modeling, specification and verification. Two important examples of such language are presented here. One is F-Logic, second is LePUS3.

Minsky's theory of Frames [Mins75] does not offer a formal system. Even though it is worth notice that, there exists an implementation of theory of Frames called F-Logic [Kife89], that directly combines the Frame approach with the object-oriented approach. In contrast to DL, the semantics of F-logic is equipped with closed world assumption, which is in opposition to the DL's open world assumption. Closed world assumption is natural for object-oriented methods. F-logic (in opposition to DL) is generally undecidable [Kife05]. Here, in this thesis, the decidability is considered as a key feature that allows for a distinction between the static structure of the knowledge (and ultimately the software) and the dynamic behavior of running software system.

LePUS3 [Gasp08] is designed to capture and convey the building-blocks of object-oriented design. It is object-oriented design description language especially designed for visualization of complex software structures. LePUS3 is a decidable subset of FOL [Gasp08], and focuses on the vital object-oriented problems (e.g.: representation, visualization and validation of Design Patterns.). In this terms LePUS3 is similar to OASE.

Description Logic was not originally designed to support object-oriented programming, but as it will be shown later, it allows one to deal with it. Reassuming:

1) $\mathcal{SROIQ}$ DL is decidable in opposition to F-Logic.
2) $\mathcal{SROIQ}$ DL is more expressive than LePUS3 (e.g.: $\mathcal{SROIQ}$ DL supports the number restrictions and role hierarchies), and DL has semantics of a natural language.

Therefore; even if F-Logic and LePUS3 are intended to be used as a formal models of object-oriented systems, we decided to use $\mathcal{SROIQ}$ DL as a formal semantic for OASE.

2.9 COMPUTER SEMIOTICS

Semiotics has been an area actively attended by scientists in media studies, educational science, anthropology, philosophy of language and linguistics. Computer semiotics defined by Peter Andersen [Ande90] studies the special nature of comput-

er-based signs and their function. The map developed by P.Andersen shows the areas where semiotics can be used in the field of computer science (see Figure 11).

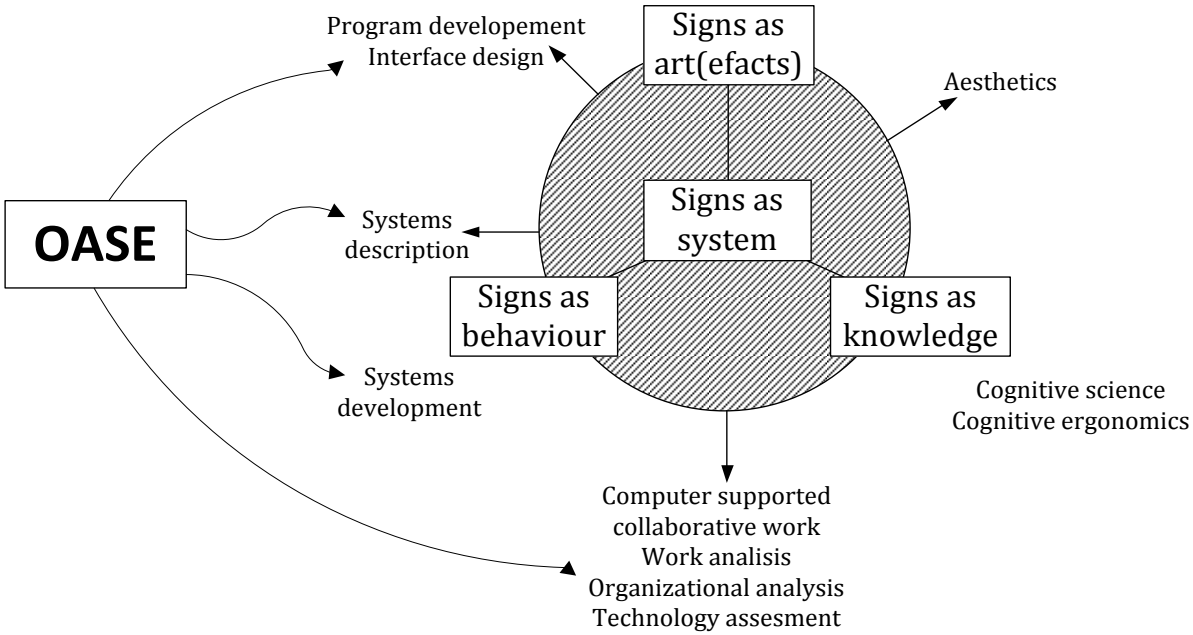


Figure 11. Map of a computer semiotics in context of OASE (based on [Ande90])

P.Andersen proposes viewing the signs as systems that occupy the center [Ande90]. The agent is here considered as a creator, interpreter and referent of signs, a user and reproducer of a common meaning potential and also as a code that utilizes the results of a semiotic labor done by others. In the focus of this box are sign systems as social phenomena. Software system analysis, design and implementation, aim at creating computer based sign systems that will typically be used by a whole organization. In the signs-as-knowledge perspective, the agent is considered as an assemblage of parts: his biological psychophysiological nature and the psychological mechanisms that enable the individual to learn, use and understand signs. Signs-as-art(ifacts) consider agents as innovators of code and meaning potential, as an explorers and inventors of signs. Signs-as-a-behavior view, consider agent as a single, indivisible entity. What is more, the focus is on his interactions with the environment, especially on the part which consists of communication with other agents.

Traditionally, semiotics has been divided into: syntax, semantics and pragmatics which deal respectively with the structures, meanings and usage of signs. Stamper [Stam73] [Liu00] has added another three layers (see Figure 12). After [Ande90] – "Physics gives a handle to deal with the factors governing the economics of signs, which have become important in business contexts. Physical properties can be studied with physics and engineering methods. As a branch of semiotics, empirics studies are statistical properties of signs, in which the object of study is a collection of signals or marks. Social world studies the effects of the use of signs in human af-

fairs, as the process of performing communication acts, which is sometimes a complex process of invoking, violating, and altering social norms. ”

OASE focuses on software development; its design and collaborative work done by the stakeholders (see Figure 11). It tries to implement social, pragmatic, semantic and syntactic layer (see Figure 12) and pretend to be the semiotic system supported by the formal methods.

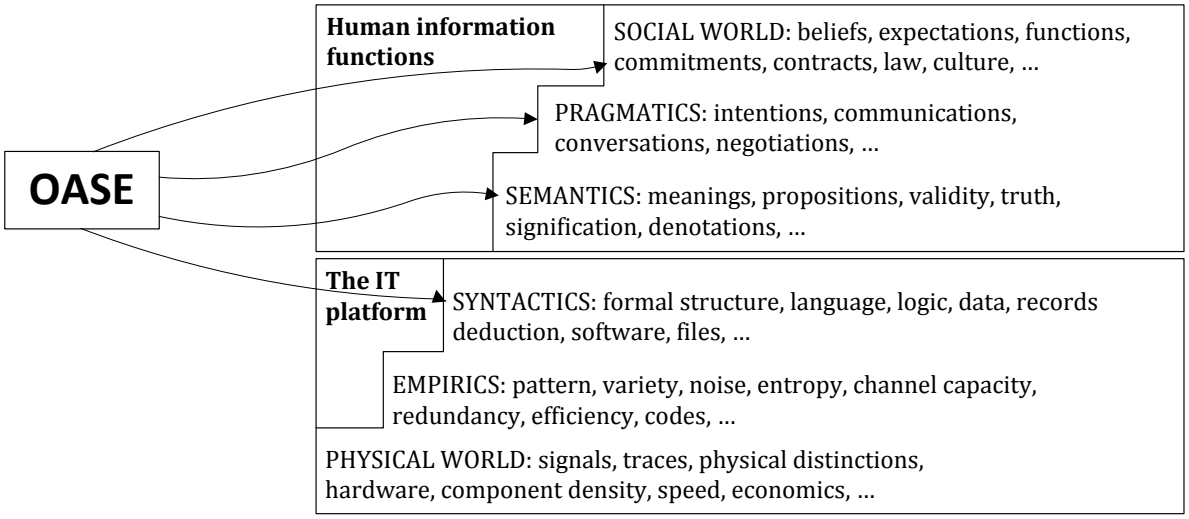


Figure 12. The Computer Semiotic Framework in the context of OASE (base on Stamper [Stam73]).

3. SOFTWARE DEVELOPMENT

The aim of this chapter is to show the range of possible applications of description logic in software development methodologies, and to place the research activities taken in this PHD thesis in the current state of the art. It also presents the relation of software development tasks with the formal knowledge modeling from the previous chapter.

3.1 THE PROGRAM FOR A MACHINE

The computer program is a specification of the machine behavior. To specify it, one can describe how the machine should behave to realize the specified task. If it is specified what the machine should do, then we can say that the computer program is written in imperative manner rather than declarative. Declarative manner specifies the goal in a formal way, leaving the realization to general and powerful automatic[26] process that will invent the optimal way to approach it.

In the 1930s, Church and Turing proposed different ideas for a formal system. Lambda Calculi [Hank04] and Touring Machine [Hopc79], which were ultimately proven to be logically equivalent, are nowadays recognized as precursors of the two main families of the programming languages: *functional* and *imperative* (see Figure 13). The von Neumann architecture, that is a model of modern computer, implements a universal Turing machine. Imperative programming languages were the first that started the evolution and now they are the oldest well known ones. Imperative programming describes the computation in terms of sequence of statements that can change a machine state - in other words, program written in imperative language is a specification for a sequence of commands. What is more, the possibility of changing the state of the machine is the key feature here. The oldest imperative programming language that is still used nowadays is FORTRAN, created in 1954 [Back54]. The rest of the history of imperative languages is as follows: BASIC (1964) [Keme64], Pascal (1970) [Jens85], C (1972) [Kern88], Ada (1978) [Booc87], Smalltalk (1980) [Liu96], C++ (1985) [Stro00], PHP (1994) [Vasw08], Java (1994) [Gosl05], C# (2002) [Herb10].

Good programming language has to keep pace with the progress of technology and at the same time it must respond to market needs.

Object-oriented languages, the novel offspring of imperative languages, lead programmer to use objects as main conceptual constructs employed to build virtual world, which can be easily understood by a human brain. A well written program in object-oriented programming language, models algorithms and data, uses concepts and relationships between them and raises them step-by-step to the next levels of abstraction. At the same time it ensures that these concepts have the properties of

[26] Automatic means here – able to be processed by a computer

physical objects. This approach is similar to the process of ontology engineering based on virtual objects. Simula (1967) [Dahl66] is generally accepted as the first language to support the primary features of an object-oriented language. Another example is C++, a general purpose language developed as an offspring of C, that is equipped (with some limitations) with object-oriented abilities. Platform independence was the motor for Java and C# language, the modern object-oriented languages with the highest impact in the field nowadays.

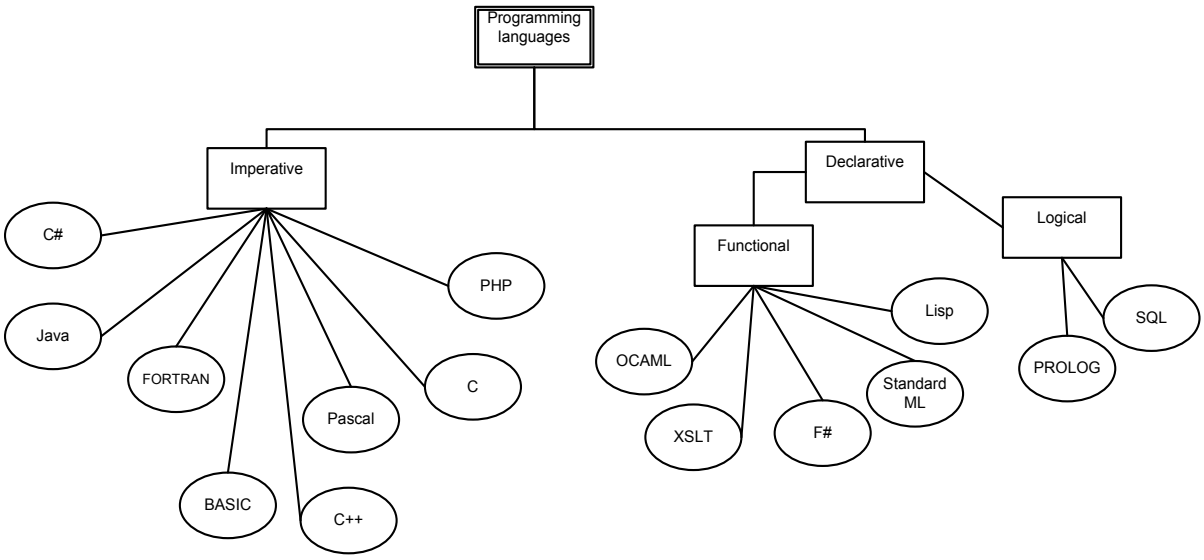


Figure 13. Spectrum of Computer Languages

Object technology, invented in 1965 in a lab of the University of Oslo (together with the Simula Language [Holm94]), is built around three basic concepts: instance, class and superclass, and two basic relations: instance-of and inherits-from. In the 80's the exact meaning of these relations was widely discussed, including the controversies between single and multiple-inheritance. Modern object-oriented languages go beyond those basic concepts by providing more or less general metaclass organization schemes (a class being itself an instance of a metaclass). As a consequence, when we nowadays talk about an object (the instance of a class), the context is (the most) important. In a general context, we usually mean an entity corresponding to the common scheme, but if we need to be more specific, we refer to a C# object, a Java object, a C++ object, an Eiffel [Meye92] object, a CLOS (Common Lisp Object System) [Stee90] object, etc., with respect to their additional properties.

Lisp [McCa65] was the first programming language that used the approach taken from Church's lambda calculus. Functional languages are nowadays adapted to the common mainstream, as they were also processors of modern programming languages. Going back in the history of computer languages, the debates in the late 1960s and early 1970s (about declarative versus procedural representations of knowledge in artificial intelligence) resulted in an introduction of the novel family of programming languages: the logical ones. Logical programming is regarded as sepa-

rate from functional languages as far as functional language is still focused around functions – recursive concepts that realize the task. One of logical languages widely used in computer science is SQL [Date97], which is based on well behaved Codd's relational algebra [Codd70], and has a counterpart in logic. PROLOG [Cloc03] implements the Horn Logic. The mixture of PROLOG and SQL resulted in DATALOG language [Gall78] – subset of PROLOG oriented to databases.

Logic can be used as a computational formalism and also as a data specification language. This fact pushed us to conclude that DL is a great example of formalism that allows both the imperative and declarative languages to cooperate together. We have implemented this idea within OASE methodology.

3.2 SOFTWARE MODELS

The rapid development of software engineering methodologies that has occurred with increasing complexity of computer programs is related to the need for a way to ascribe and analyze the software intensive systems at the time of their formation. In November 1997 the OMG consortium established the standard of software design and analysis. This standard is nowadays well known as a Unified Modeling Language (UML) [Rumb05], and is mainly focused on graphical modeling of software intensive systems with diagrams. To support the design of large-scale industrial applications, sophisticated CASE tools[27], which provide a user-friendly environment for editing, storing, and accessing multiple UML diagrams, are available on the market. The spectrum of UML diagrams is divided into two main branches: structural and behavioral (see Figure 14). Structural diagrams emphasize the things that must be present in the system being modeled. The 'must' means here that we cannot say that the software is realized fully, if it does not implement the diagram of structure. This is dual to diagrams of behavior, which emphasize what must happen in the system being modeled. In the formal way we can distinguish those two classes of diagrams in the meaning of time or modality. While structure diagrams must always be true, the behavioral diagrams must be true in some – strictly defined - circumstances. Therefore, while structural diagram represent specification for "ALWAYS MUST BE …" the behavioral diagram is "IN A SPECIFIC SITUATION THE PROGRAM MUST SATISFY A CONDITION THAT…". This duality led us to think about separation of the diagrams in strict, logical manner. The structural diagram specifies the terminology which must be obeyed, while the behavioral diagram describes the situation that takes place in specific space and time – the world (in terms of modality) description.

UML allows for modeling the structure of relationships between use cases, which can be viewed as behavioral and structural projects requirements. In addition, UML allows the modeling software, that is object-oriented in terms of classes, objects their hierarchy and their collaboration as well. To build the bridge between use-cases and classes (that are explicitly implemented by programmers) is a key task for

[27] e.g.: Rational Rose (made by Rational Software Corporation - now IBM) is used for object-oriented analysis and design), Telelogic TAU (made by Telelogic - now IBM) modeling tool supporting automated code generation and model verification, StarUML (Open Source) – UML modeling tool, etc…

a software designer. Using several use-case diagrams, the software designer tries to build the object-oriented design that fulfills all the requirements specified, trying to preserve non-functional (like: performance, traceability, scalability, etc…) demands given by chosen technology. The work is usually done also by using UML diagrams, but UML diagrams are in fact only graphical artifacts and therefore it is a designer responsibility to preserve consistency of the described here knowledge.

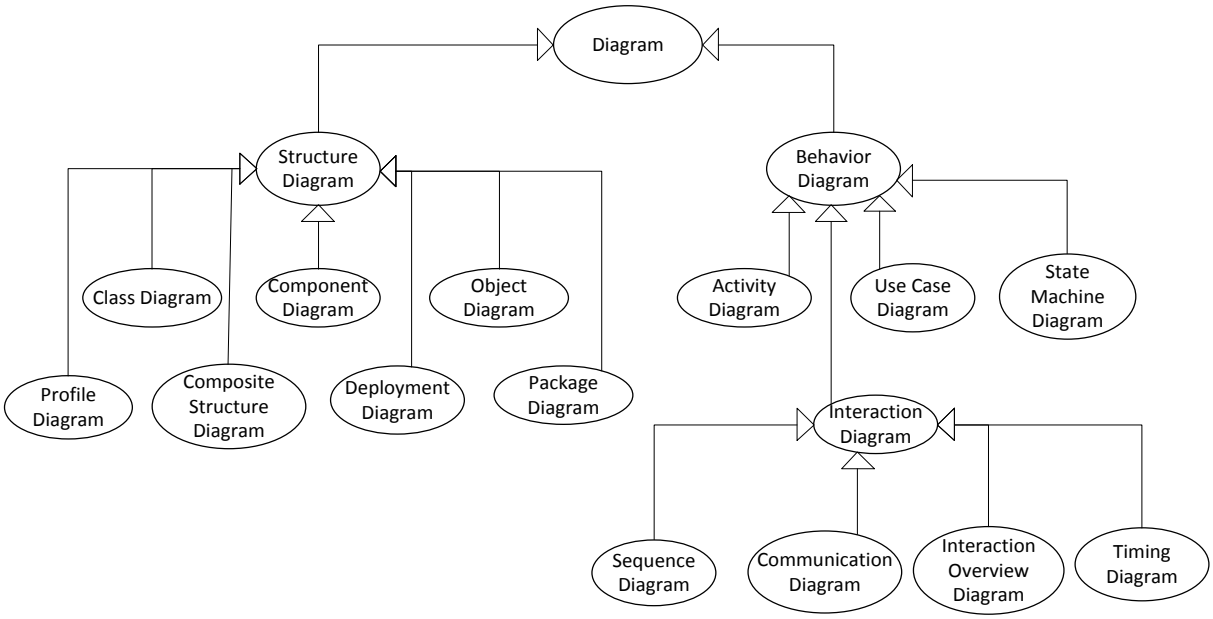


Figure 14. Spectrum of UML diagrams

The architectural view of UML is based on 4+1 View Model[28] - a view model for "describing the architecture of software-intensive systems, based on the use of multiple, concurrent views" [Kruc95]. The views are used to describe the system from the viewpoint of different stakeholders. There are four major views: (1) the logical view that should be delivered by the object model of the design, (2) the development view, which depicts the development environment of a software product, (3) the process view that represents concurrency and synchronization aspects of a design and (4) the physical view that elaborates on the mapping between software and hardware components (see Figure 15). In addition, selected use cases or scenarios are utilized to illustrate the architecture serving as the +1 view.

- The (1) - logical view describes the functionality that the system provides, supported with UML diagrams, including Class diagram, Communication diagram and Sequence diagram, which are used to represent the logical view.
- The (2) development view illustrates the system from a programmer's perspective (and software management) and it uses the UML Component

[28] A framework that defines a coherent set of views to be used in the construction of a system architecture, software architecture, or enterprise architecture. A view is a representation of a whole system from the perspective of a related set of concerns.

diagram to describe system components. UML Diagrams are used to represent the development view, including the Package diagram.

- The (3) process view deals with the dynamic aspects of software, as it explains the system processes, how they communicate, and it also focuses on the runtime behavior of the system. It addresses e.g.: concurrency, distribution, integrators, performance, and scalability. UML Diagrams that represent process view are e.g.: the Activity/Collaboration diagram.
- The (4) physical view depicts the system from a system engineer's point-of-view, as it is concerned with the topology of software components on the physical layer and is represented with UML Diagrams, including the Deployment diagram. The description of architecture is illustrated by a small set of use cases, or scenarios which become a
- +1 view that describes sequences of interactions between objects, and between processes. Those UML diagrams are used to identify architectural elements, to illustrate and validate the architecture design and to serve as a starting point for tests of an architecture prototype. UML Diagrams are used to represent the scenario view, including the Use case diagram.

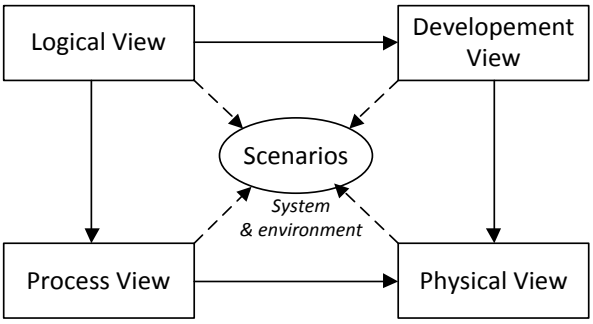


Figure 15. 4+1 Architectural View Model

3.2.1 MODEL DRIVEN ENGINEERING

Modeling is essential to every engineering activity as every action here is preceded by the construction (implicit or explicit) of a model. If the model is incorrect, the action may be inappropriate. According to the definition, a model is an abstraction of phenomena in the real world; a metamodel is yet another abstraction, highlighting properties of the model itself. A model conforms to its metamodel in the way that a computer program conforms to the grammar of the programming language in which it is written.

Model Driven Engineering (MDE) is the successor of CASE tools as well as a unification of methodologies based on UML approach. The architecture of metamodeling (called Model Driven Architecture (MDA), introduced in 2001 by the Object Management Group (OMG)) is the basis for building MDE software systems. MDE can be shortly ascribed in the following comparison: in object-oriented engineering “everything is an object” and in MDE “everything is a model” (see Figure 16).

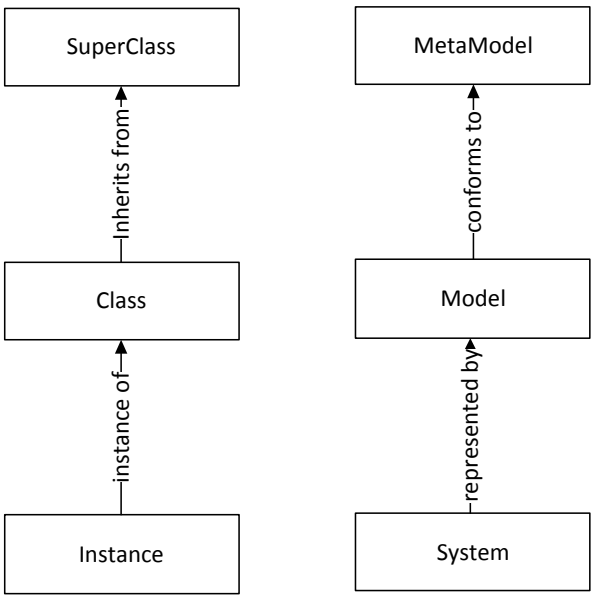


Figure 16. Object-oriented vs. model driven engineering

Every model in software development forms a graph; therefore software modeling activity can be perceived as an activity that tries to construct graphs which model the software conceptualization. The way to transform one graph into another is the key idea that lies behind MDE. For transforming one graph into another there is a requirement of unidirectional function which is realized with graph transformation languages. MDE transformations are realized in our approach by OASE-Transformations.

Support for change propagation QVT is based on the Meta-Object Facility (MOF)[29]. MOF is designed as a four-layered architecture that provides a meta-meta model at the top layer (see Figure 17) called the M3 layer – that itself forms a language used by MOF to build metamodels, (called M2-models) and it is also able to describe itself, so no additional Mn... layers that are required to complete the unification. The most prominent example of a model in M2 is the UML metamodel, the model that describes the UML. These M2 models describe elements of the M1, and thus M1 models as well. Those would be, for example, models written in UML. The last layer is the M0, used to describe real-world objects. Because of the similarities between the MOF M3 models and UML structure models, MOF metamodels are usually modeled as the UML class diagrams. A supporting standard of MOF is XMI[30], which defines an XML-based exchange format for models on the M3-, M2-, or M1-Layer.

MDE requires systematic use of Model Transformation Languages (MTL) [Mens06]. The OMG has proposed a standard called QVT for Queries/Views/Transformations, that is an implementation of MTL, however the model transformation is a general technique that tries to construct one model (lower) from the another (higher) and therefore there exist other, very usable, transformation

[29] http://www.omg.org/mof/
[30] http://www.omg.org/spec/XMI/

languages. As each model is a graph, model transformation is based on graph transformation [Roze97]. The QVT transformation has a support of model integration rules, model consistency checking and uni/bidirectional model transformations for a declarative or operational specifications. It is also equipped with either textual or graphical notation.

The modern MDE vision does not use models only as a simple documentation but as a formal input for software tools implementing precise operations. As a consequence model-engineering frameworks have progressively evolved towards solid proposals like the MDA defined by the OMG. Carrier of information in here is the OWL [HKP+09] which enables the exchange of models (or portions thereof) between different systems, thus ensuring the implementation of the concept of re-use (in the phase of modeling and design system). This approach is similar to the OASE approach. The Ontology Definition MetaModel (ODM) is to make the concepts of MDA applicable to the engineering of ontologies. The features available in UML are mapped here to OWL elements (OWL can be seen as XML representations of DL) (see Figure 18).

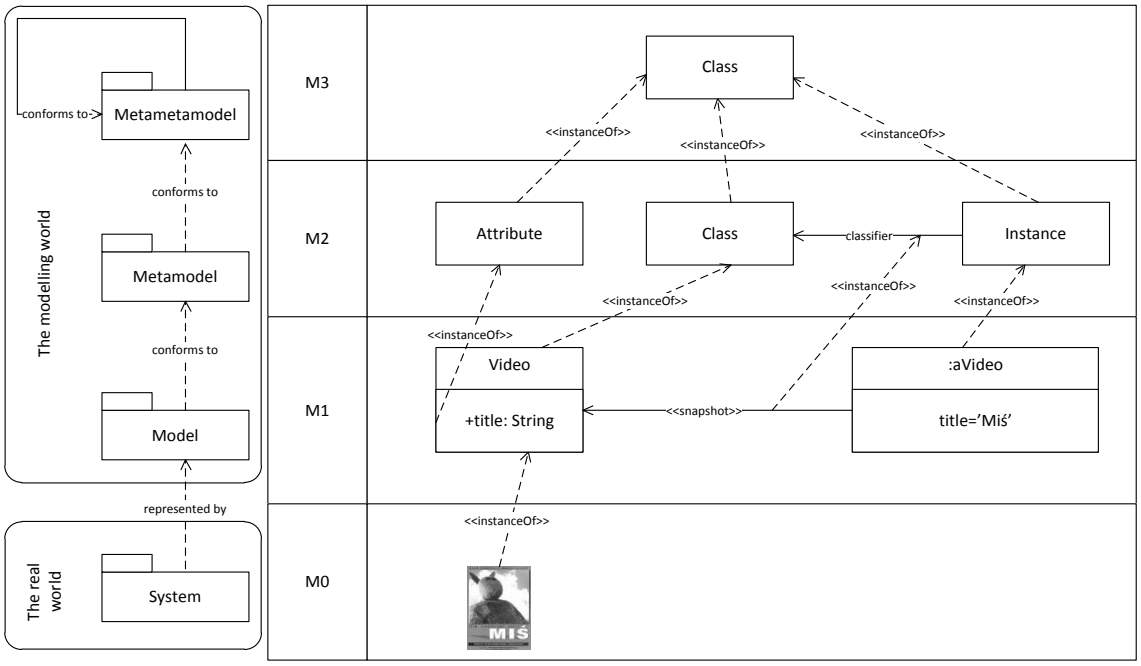


Figure 17. Four layers of the modeling hierarchy

In this thesis we present the viewpoint that this is a direct (usual) mapping. Within OASE we have developed other mapping that e.g.: represents classes as instances that are presented in the next chapter.

UML elements	OWL elements	Comment
class, property ownedAttribute, type	class	
instance	individual	OWL individual independent of class

ownedAttribute, binary association	property	OWL property can be global
subclass, generalization	subclass , subproperty	
N-ary association, association class	class, property	
enumeration	oneOf	
disjoint, cover	disjointWith, unionOf	
multiplicity	minCardinality, maxCardinality	OWL cardinality declared only for range
package	ontology	
dependency	reserved name, RDF:property	

Figure 18. More-or-Less Common Features between UML and OWL[31] – the direct-mapping

3.2.2 SERVICE ORIENTED MODELING

Service-oriented modeling (SOM) [Bell08] is the discipline of modeling of service-oriented systems within a variety of architectural styles. It encourages viewing software entities as 'assets'. It refers to these assets collectively as 'services' that have properties of physical objects e.g.: location, price…, which can replicate and organize themselves. The Service Oriented Architecture (SOA) [Erl05] is an application of SOM defined as "a paradigm for organizing and utilizing distributed compatibilities that may be under the control of different membership domains. It provides a uniform means to offer, discover, interact with and use capabilities to produce desired consistent with measurable preconditions and expectations"[32]. Services evolved as a result of observation, that nowadays we are occupied with loosely coupled, interoperable software, available in a form of small pluggable units rather than large, centralized software. Those pluggable units need to be fault-tolerant pieces of software that are continuously improving their quality basing on business demand. To tackle these challenges, a three-dimensional process of founding architecture is proposed:

I) TOP: Conceptual architecture
   1) Technological Generalization
   2) Metaphorical Application
   3) Taxonomy Establishment

II) MIDDLE: Logical architecture
   1) Asset Utilization and Reuse
   2) Functional Solutions
   3) Architecture Strategies

[31] http://www.omg.org/spec/ODM/1.0/

[32] Web Services [Erl05] [Newc04] are the example of successful application of SOA - built upon the infrastructure of WWW and HTTP protocol.

III) BOTTOM: Physical architecture.
   1) Physical Addressing
   2) Non-Functional Solutions
   3) Business Continuity

Conceptual architecture offers mechanisms for describing the proposed technological solution; logical architecture discipline is chiefly concerned with asset reuse, utilization and consumption, while the physical architecture is the resulting tangible architecture construct (that itself is not a purpose of SOM). Architectural concepts in SOM are related to the categories of "machines" like:

1) *Workflow Machine*: based on states of execution, each of which is assigned a certain goal to fulfill.
2) *Connecting Machine*: describes communication methods and mediating mechanisms between various software assets in a distributed technological environment.
3) *Time Machine*: is characteristically associated with time and calendar scheduling of imperative business and technological missions.
4) *Transformation Machine*: fills incompatibility gap between operating systems, communication protocols, data formats, etc.
5) *Rendering Machine*: describes presentation layer solutions that enable users to communicate with backend services.
6) *Data Machine*: enables data manipulation and handling activities, data serving, such as data aggregation, validation, searching, and enrichment.

Each machine is ought to be implemented as a service that has lifecycle composed of circular process: from design to runtime. Going further, services can be seen as software assets analogous to living cell of complex biological organism. In this case, the organism is a metaphor of a complex business system that involves many services in order to satisfy its needs. Cloud computing [Mell09], the modern offspring of grid computing [Li05] is nowadays considered as a field where service-oriented modeling can be used as an effective modeling method. Service-oriented modeling has much in common with object-oriented modeling and MDE, as all of them are trying to use the metaphor of physical objects to represent the software assets. Going further, we can say (paraphrasing MDE metaphor) that in SOM "everything is a service".

We propose the implementations of certain SOM machines in OASE e.g.: Inferred UI developed by us implements Rendering Machine and Self-Implemented Requirement implements Workflow Machine to some extent.

3.2.3 EVOLUTION

Programming is a process of generating domain specific languages that create words in other, higher level languages[33]. MDE is a methodology of building such the domain-specific languages by using the language of MOF meta-metamodel. In SOM

[33] A famous aphorism of David Wheeler is: "All problems in computer science can be solved by another level of indirection." [Spin07]

everything is service and every activity is a service activity, including activities of the people involved.[34]. The language of SOM is a language of services, which is also used by human-beings. We classify languages in the following manner:

1) Computer languages (used by programmers during service life-cycle) including domain specific languages and general purpose ones,
2) Inter-service communication languages (used by services to communicate),
3) Human-service interaction languages (realized by User-Interface),
4) Natural languages (used to communicate between programmers and service users)

The separation between human (the constructor) and machine (the material) is blurred nowadays. In crowd-sourcing services people starts to be services, controlled by machines within large service clusters[35]. To improve communication between human and machine, the innovations in user-computer interactions is needed, especially in natural language processing and human-machine interaction. On the other hand, the software developer without support of machine is not able to construct the software in a right way - moreover, it is starting to be clear that complexity of software requires usage of formal methods, that can form sort of rails on which programmer can be safely conducted over the software development process.

OASE tries to fill this gap.

3.3 FORMAL REPRESENTATIONS OF UML

The expressiveness of the UML constructs can have implicit consequences that may go unnoticed by the designer: like various forms of inconsistencies or redundancies that result in software design breakdown [Bera03]. If used only for documentation purposes, such inconsistencies do not cause a big problem for organization, but if they are used as a part of a MDE, then the quality of the models can influence the quality of the implemented system. This problem is common for software engineering and can be seen as in general consistency preserving problem between software requirements and implementation. Those dangerous inconsistencies are tried to be resolved with the aid of supporting methods&tools.

The Design by Contract (1986) [Mitc02] is aimed to be the most general approach to help software developers to deal with occurring inconsistencies. Design by Contract prescribes that software designers should establish formal, precise and verifiable interface specifications for software entities, including pre-conditions, post-conditions and invariants. These specifications are referred to as "contracts", in accordance with a conceptual metaphor that has conditions and obligations of business contracts. Design By Contract can be used within any computer-language[36];

[34] E.g.: The Amazon Mechanical Turk (MTurk) is a crowdsourcing Internet marketplace that enables computer programmers (known as Requesters) to co-ordinate the use of human intelligence to perform tasks that computers are unable to do yet. It is one of the suites of Amazon Web Services.

[35] A collection of distributed and related services that are gathered because of their mutual business or technological commonalities.

[36] To write program with constraints, it is required to have at least an “assert” instruction built into the language.

however there exist languages (e.g.: Eifel [Meye92]) that use design by contract as a key concept. Benefits of using constraints include the increase of quality of documentation, increase of precision as well as reduced number of misunderstanding, however the interpretations of the action that should be taken after constraint is broken, are divided into two parts: declarative and operational. The operational approach threads broken constraints as a rule to fire the actions [Grah94]. Declarative approach requires that all constraints are hold, and if any of them is broken, then it means that the system does not keep the design – it is critical situation that needs to be corrected by a programmer.

3.3.1 OBJECT CONSTRAINT LANGUAGE

The Object Constraint Language (OCL) [Warm99] follows a declarative approach. OCL is introduced as a formal tool that adds a constraint system on the top of UML. Constraint itself is here a formal Boolean expression, which refers to the entities that take a part that is invariant in time. In general, in working system, all constraints should be preserved. If any particular constraint fails, then it is a signal that the current implementation is not keeping the design assumptions and it is a clear warning that the implementation has to be corrected in a specific area. OCL aims to capture all UML diagrams, including state/activity diagrams, and therefore it allows to describe the runtime constraints of the system.

OCL extends UML and equips the graphical language with a system of constraints. It brings the formal specification language into UML. OCL is aimed to be intuitive for software programmers that have a background in object-oriented programming, so there should be no need for them to study the first order logic or any other mathematical notation. OCL is meant to be adoptable in object-oriented methodologies and to become a standard (provided OMG consortium).

An OCL constraint formulates restrictions on the semantics of the UML specification. Constraints are side-effect-free, so they do not have an impact on the running system, therefore OCL is not a programming language. A constraint (invariant) is an expression that evaluates to Boolean condition and is bound to a specific type (class, association class, and interface) in the UML model – its context. Constraints come here in different forms, like: invariant (constraint on a class or type that must always hold), pre-condition (constraint that must hold before the execution of an operation), post-condition (constraint that must hold after the execution of an operation), guard (constraint on the transition from one state to another).

OCL has a formal semantics and it can be used to reduce the ambiguity in the UML models. In other words, while UML diagrams can be used as a communication channel between software developers, OCL makes it possible to reduce ambiguity in a communication as a specification language for e.g.: invariants for classes and types, pre- and post-conditions for methods, constraints on operations or requirements.

In the similar way OASE-Annotations and OASE-Assertions (see next chapters) attempt to bridge the designer and programmer work. Moreover, because the OASE-Annotations and OASE-Assertions are written in quasi-natural language, the

pragmatic restrictions on the use of formal specifications are limited to minimum (while in the case of user that have read the OASE-Annotations or OASE-Assertions, there is no need for any additional support, the writer has to be equipped with a specific tool).

3.3.2 CRITICISM OF OCL

Despite the numerous benefits, OCL also has some limitations [Vazi00].

1) OCL allows to use operations inside constraints. This feature of OCL allows for modeling of the system behavior in a precise manner; however it is possible to express infinite loop or operation that is undefined. It argues that OCL is close to implementation language and itself needs a verification. Moreover, it can be proven that OCL is Turing-complete language and therefore it is undecidable. Without computability we cannot provide the toolchain that will allow to reason about any expressed model. We address this shortcoming by the usage of Description Logic – a subset of FOL for which the key reasoning tasks are decidable.
2) OCL is not a stand-alone language, but it is a complementary part of UML (the graphical language), and therefore it is always used as a part of graphical models. However there are many advantages of stand-alone constraint language, where the graphical form can be obtained by specialized CASE tools, preserving the access to a textual representation. In such languages, the semantics of constraint language can be easier defined and analyzed by tools e.g.: Alloy [Jack02], VDM++ [Mlle09] or LePus3 [Gasp08]. We address this limitation by using textual representations in form of OASE-English, leaving the graphical representation of knowledge to separate tools.
3) Creators of agile methodologies (e.g.: Martin Fowler [Fowl01]), refuse the usage of OCL, as too complex and non-intuitive. They prefer to use plain English in UML diagram notes instead of OCL. It is worth to expose that the process of bridging the gap between OCL and natural language is already approached with Controlled Natural Languages e.g.: Kristofer Johannisson in [Hhnl02] proves that it is possible to build the bridge between OCL and natural language, using Grammar Framework (GF) [Rant04] approach.

Besides OCL, there aroused many alternative approaches to bridging the gap between MDE and formal methods for UML formalism. They depend on the UML diagram that is going to be formalized (see Figure 19) e.g.:

- for State Machine, Activity, Collaboration or other diagrams that present the behavior of modeled system, the process algebra (ACP, PAP, CCS, LOTOS [Eijk89]), temporal or tree logic (CTL*,LTL) [Pnue77], Petri nets, Model transformation, etc…
- for Class, Package, Use Case Diagram, or other diagrams of static software structure, the ontologies are used in a form of subsets of First Order Logic (e.g.: Description Logic), ρ-Calculus [Cirs03], Lepus3/Class-Z [Gasp08], F-Logic [Kife89] etc…

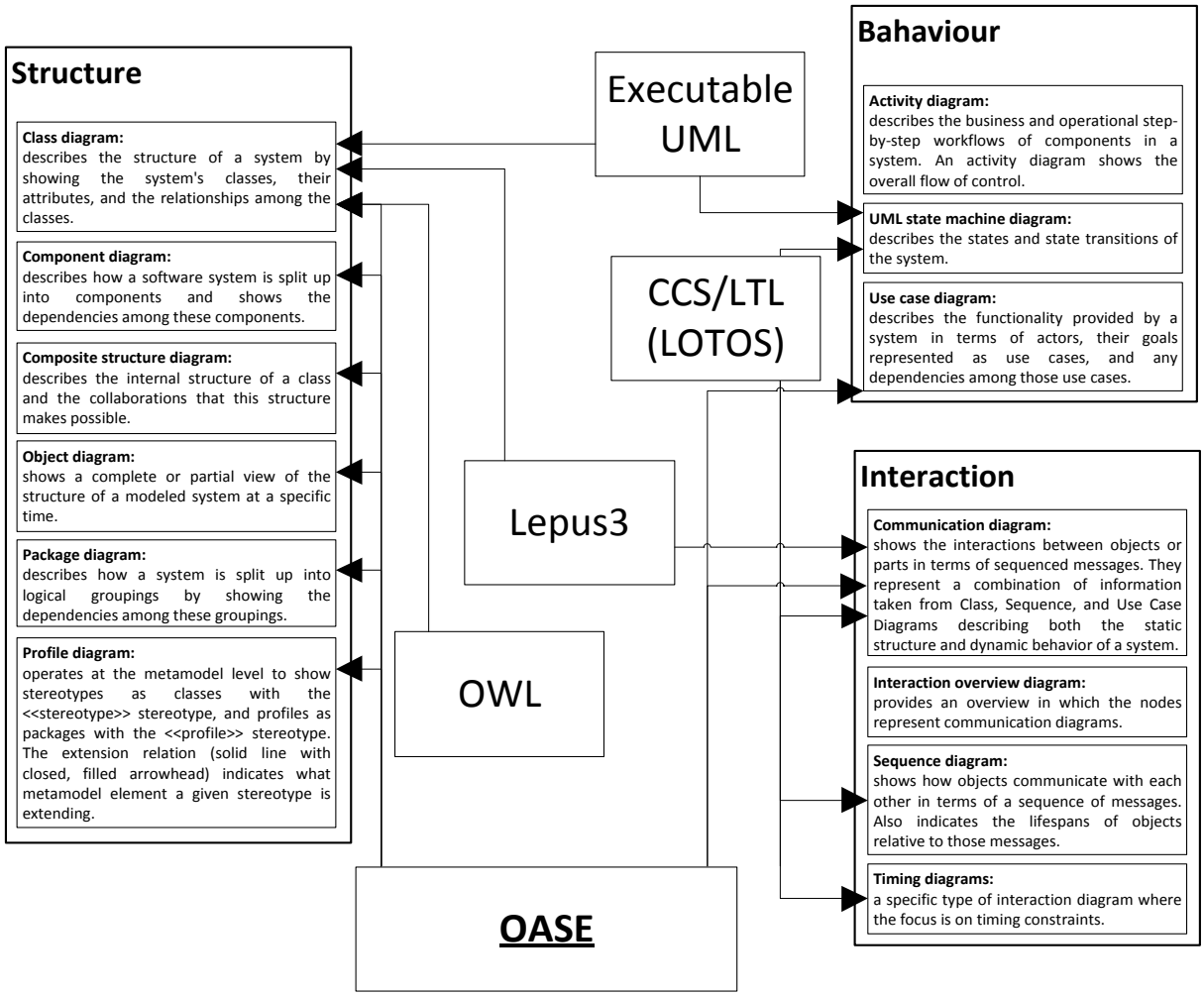


Figure 19. UML diagrams and formalisms that allow to model them in a formal way (including OASE)

3.4 SOFTWARE ENGINEERING

The engineering approach in software development can be seen as a top-down process. Starting from the problem, first of all it has to be deeply understood by analytics before the solution is proposed by designers. Finally it is implemented as a working thing by programmers in a selected programming language. A good example of software engineering approach to software development is the Rational Unified Process (RUP) [Kruc03] [Scha07]. RUP consists of four major steps, that if followed, should result in a software system that fulfills specific technological and market needs. Each step requires the stakeholders to be equipped with specific competences (requirement engineers, analytics, designers, programmer and testers) and tools. RUP was proven to be useful in the development of many complex systems; however it requires the high organizational level of the stakeholders. Even if it is not specified explicitly, it is impossible to build a software by using RUP in organizations that do not have strictly defined hierarchy and communication channels of competitions. Moreover RUP requires knowledge management activities. Therefore RUP is primarily used in big corporations that are able to handle such complex hier-

archies of stakeholders, and are able to effectively evaluate their outcome. Every RUP based project (after [Kruc03]) requires four phases that result in specific artifacts:

1) Inception (requirement analysis) is used to identify the requirements as well as the scope of the software solution that is going to be released. Tasks should determine the needs or conditions required to meet the expectations, taking into account the potential conflict of requirements of the various stakeholders, such as beneficiaries or users.
2) Elaboration (architecture and design identification) tries to identify an architecture that has a good chance of working. The architecture is often defined with diagrams, which explore the technical infrastructure, the major business entities and their relationships. The design is derived in a modeling session, in which issues are explored until the team is satisfied that they understand what needs to be delivered.
3) Construction (software implementation), where the main focus is on the development of components and other features of the system. This is the phase in which the majority of the coding takes place. In larger projects, several construction iterations may be developed in an effort to divide the use cases into manageable segments that produce demonstrable prototypes.
4) Transition (integration and tests). The primary objective here is to 'transit' the system from development into production, making it available to the end user and understood by him. The activities of this phase include training the end users and maintainers, and beta testing the system to validate it against the end users' expectations. The product is also checked if it satisfies the required quality level.

3.4.1 CRITICISM OF RUP

Critics say that RUP is a 'high ceremony methodology' because it demands all the requirements to be collected before starting the design phase. Once they are collected they need to be frozen before starting the development. However; it is very common that the requirements are not known in details or even a customer may require the features that are not needed at the end. Once the RUP process starts, all change requirements are recognized as additional cost. Also the process that once started, requires bureaucracy (every document must be approved in hierarchy of stakeholders), therefore it is considered as a slow and demanding method of software development.

3.5 AGILE METHODOLOGIES

An emergent behavior or emergent property can appear when a number of simple entities (agents) operate in an environment, forming more complex behaviors as a collective. This stream includes: neural networks, genetic programming, expert systems and many others AI activities.

With emergence as a key concept, it is also easier to understand what *agile* [Beck01] software development methodologies are proposing. If we take a look at a software as a result of work of group of programmers, where each one has a different background in field of software development and different psychological skills, it starts to become clear why it is so difficult to build the system related to the specific needs. Without consistent specification and prior educational task it is even harder. The agile methodology approaches this problem by focusing on building the ground for optimal cooperation between the stakeholders. The success of agile methodologies, that is currently observed, proves that even without specification and education, we can still build effective programs - what a surprise, with smaller budget and in a shorter time. Agile methods break tasks into small increments with minimal planning, and do not directly involve long-term planning. Agile Manifesto [Beck01] reads, in its entirety, as follows:

"*We are uncovering better ways of developing software by doing it and helping others do it. Through this work we have come to value:*

- *Individuals and interactions over processes and tools*
- *Working software over comprehensive documentation*
- *Customer collaboration over contract negotiation*
- *Responding to change over following a plan*

That is, while there is value in the items on the right, we value the items on the left more."

Agile methodologies, even if it is not clearly stated in manifesto, try to develop software products in emergent (self-organizing) way. Each agile programmer can be seen as a process that produces the part of computer system which in the end is a superposition of emergent work of the team. The core idea is the organization of **the environment** that will allow for emergent work e.g.:

- Programming is made by teams of competitive programmers, that handle the knowledge management inside the team
- The team produces programs as well as other programs that are to prove that the earlier mentioned ones are working
- There is an automated process that verifies the core properties of the system of programs that is going to emerge

It is worth notice that without a specification it is impossible to build the system in any methodology based on engineering, while agile methods emphasize face-to-face communication over written documents to overcome this limitation. This observation proves that agile methodologies are focused on psychological aspects rather than formal ones. One can say that the computer language is used to communicate with a computer, however nowadays, computer language is becoming more a communication language between stakeholders involved into software engineering process. Agile methodology these days, tends to be the standard for production of complex systems. This situation brought to life the task force that is trying to formalize agile methods and provide the sufficient toolchain, which can actively support stakeholders involved in the production process.

OASE have ambition to be useful in both software engineering and agile and therefore to create the bridge between those methodologies, due to the use of semantic technologies. Moreover, as it is proved by evaluation experiment, OASE can be a useful tool for research on the psychological and sociological aspects of the software development process.

3.6 QUALITY ASSURANCE

Software testing is the process of analyzing a software item to uncover as many defects as possible. There are two basic classes of software testing, black box testing and white box testing:

- Black box testing (also called functional testing) is a way of testing that ignores the internal mechanism of a system or component and focuses solely on the outputs generated in response to selected inputs and execution conditions.
- White box testing (also called structural testing or glass box testing) is a type of testing that takes into account the internal mechanism of a system or component.

Agile methodologies use white box testing approach called Test Driven Development (TDD) [Beck02]. In TDD there should be no piece of software written, if the test for it does not exist. While white box testing requires that tests are made on software in every possible depth, the black box testing is created to test the software from a customer's perspective. Even if software is well written, it may not be acceptable for the customer that needs something different from what she already specified. In agile development it is not a big problem as it preserves continuous communication between the team that is developing the software and the customer. In software engineering approach such communication happens sporadically, as the process is based on assumption that requirements are well written and understood. To overcome this limitation engineering approach uses the black box testing on two levels: internal and external. Internal test needs to be made by the software producer while external is made by a potential software consumer.

OASE adds here a possibility to test the design in the similar way to the TDD's (which does it for program runtime). The "design tester" specifies design constraint that needs to be kept by the design of the program in order to become a part of TDD. There is no such a role in the software development team as "design tester", so we can assume that the work of such stakeholder can be done by the software designer or software architect.

3.7 THE LANGUAGE OF PATTERNS

Christopher Alexander was an inventor of the idea of design patterns in urban architecture, and the idea of the language of patterns [Alex77]. A design pattern is a formal way of documenting a solution of a design problem in a particular field of expertise. In software engineering, a design pattern describes a particular, recurring, design problem that arises in the specific design contexts and also presents a well-

proved solution for the problem. In 1995, Gamma, Helm, Johnson and Vlissides published [Gamm95] the first catalogue of software design patterns which was the Alexander's idea applied in the field of software development.

The vocabulary of The Language of Patterns is made of design patterns. The syntax (and grammar) of the language is given by the web of applicable solutions that the design pattern can fit into. The semantics of the language is given by the standard of documentation of design patterns, that includes its interconnections. Usually it is specified informally in natural language. A pragmatic aspect of the language of patterns in terms of designers (the core users of the language), is to allow them to start from any part of the problem and work towards the unknown parts basing on rails formed by the language of patterns. A reason to believe that though the designer may at first not completely understand the design problems and that the resulting design will be usable, is based on the success-stories of the previous applications of the language.

The language of patterns had been adopted in the field of software development. Every technology and approach that is useful in software development has its own language of patterns. Those informal definitions of software design patterns functions are placed in a form of catalogues of good practices [Busc96] [Busc07a] [Busc07b] [Schm00] [Kirc04]. To allow computers for automatic validation of language of software design patterns it is required to formalize their semantics. There exist a large number of approaches to formal description of specific aspects of software design patterns [Taib07].

In the next chapter, we present the results of our research in this area. We show by examples, that OASE can be seen as the language of software patterns. Using OASE, the designer can quickly think of a one solution and then turn to a related, needed solutions, and specify them in a formal way (that can be processed by the validation algorithm), basing on the formal semantics of the OASE-English design pattern language that is expressible in description logic.

4. OASE

The aim of this chapter is to show the results of our research on formularization of Semiotics in the field of Software Development. The most important result presented here is Ontology-Aided Software Engineering (OASE) method.

4.1 THE MEANING TRIANGLE OF SOFTWARE ENTITIES

We analyze here the meaning triangle of software entities (classes, modules, functions, etc…), based on the standard semiotic triangle. Every software entity is represented by a specific, commonly used symbols (icons or words) and has a widespread meaning, which is formal in terms of program compilation, program runtime, software development, management process and software testing process as well (see Figure 20).

Computer languages differ from one another in terms of symbols used. The meaning triangles differ too, however all three of them: the object-oriented, model driven and service oriented methods, have one common and universal semantics of software entities that are generalized within UML/MDE frameworks. Every software entity is labeled with a name and forms an (virtual) object in the software world where it is used. There exist three kinds of symbols in software engineering (the situation remains unchanged, regarding to the semiotic principle): icons, indexes and labels. Icons (and iconic indexes e.g.: arrows) are used in graphical modeling languages like UML, while symbols (and symbolic indexes e.g.: references, variables) are used within programming languages.

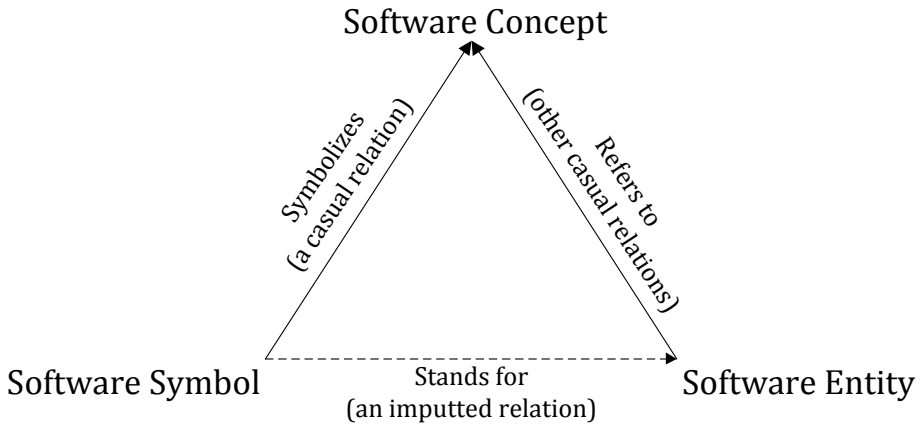


Figure 20. The Meaning Triangle of Software Entities

A well written source code of program should be equipped with meaningful comments that would allow other programmers to understand the code and transfer the knowledge within the team. Without documentation of source code it is difficult

to perform knowledge management activities in the team consisting of programmers. The value of comments is underestimated in software methodologies[37] nevertheless for pragmatic purposes there is often a need to equip the standard programming language entities (classes, methods, properties, etc.) with additional attributes. Those attributes form an input for additional tools that generate supporting code automatically. Such kind of code documentation is called code annotations and nowadays it becomes the core mechanism for software organization.

The code equipped with comments and code-annotations is a mixture of symbols and meanings from both: the natural and artificial languages. OASE (that is described later) standardizes this mixture by introduction of OASE-English as a language for OASE-Annotations, and therefore provides the way to document the source code in a formal, machine processable way. OASE-English is a semi-natural language with formal semantics, therefore it bridges the gap between natural and artificial languages.

4.2 ARTIFACTS IN SOFTWARE DEVELOPMENT

The artifacts that appear during software development project can be divided into four groups:

1) *Source code*: the direct requirement for system behavior, written in programming language.
2) *Design*: the indirect requirement on software entities, written in design languages e.g.: UML. It has a direct representation as a graph.
3) *Test cases*: the specification for acceptance of software system. Nowadays, they have a form of program source code that tests the specific functionalities of software system – dual to main source code, and informal specs.
4) *Supporting documents*: User requirement specification, project plan and many other documents that specify the system requirements.

The Pragmatic Software Circle (see Figure 21) is common for every software development scenario. It represents the cooperation between agents – programmers, testers and designers, and defines the communication channels between them as well. Software development is built over three basic steps that occur in cyclic manner: Programming, Testing and Refactoring. Transitions between those steps require the modification of corresponding software artifacts. It is worth notice that in such circle the communication is directed and therefore programmer cannot directly influence the design nor tester can modify the software code. It is also true for a designer, who cannot modify the test-cases; however the responsibilities of agents are strictly separated. Supporting documents are forming the rails for such cooperation as they must be realized by design as well as by test-cases (the source code should realize the design and fulfill the test-cases, so that it is not considered here as the one that has to fulfill the supporting documents too). The realize relationship

[37] In RUP the underestimation begins at the late stages of the project (when the deadline of a project approaches). In agile methodologies, documentation is an unimportant artifact as the face-to-face communication is a key factor that leads to success in agile methodology.

between design, test-cases and supporting documents means that the software must realize the requirements of both – the business and technological ones. Each communication channel in pragmatic software circle is a channel of communication between agents. For every type of agents-relation, there is a separate information transferred. Between a designer and programmer the design diagrams and design constraints are transferred, between programmer and tester it is the running software and between tester and designer, the test-results. Moreover, the system requirements and other organizational requirements written in supporting documents are transferred to designer and tester in a form of (informal or formal) specifications.

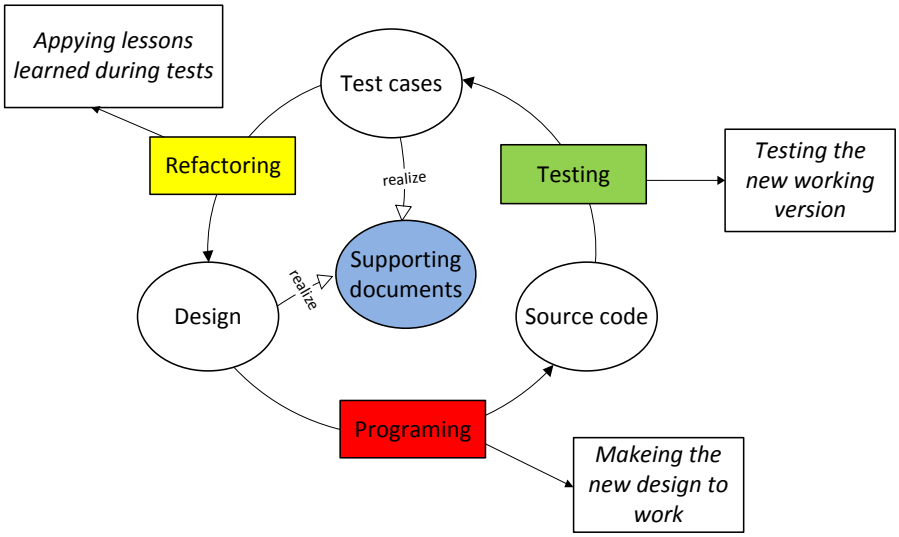


Figure 21. The Pragmatic Software Cycle

The common communication languages can noticeably reduce the cost of communication activities and allow for better understanding of the software system by all stakeholders that are involved in the process [Kapl08]; unfortunately we suffer from lack of standardization in this area.

To respond to this need, basing on semiotics, we propose to build the unified software development framework, that uses the CNL and DL as a common language of communication between the involved agents.

Recently it was discovered that even if the DL has a different semantics than object-oriented modeling languages have[38] , it is still possible to emulate crucial parts of object-oriented programming within DL [Koid05] [Bera03]. Moreover, models of software in UML are made of graphs of icons that are equipped with semantics; therefore software models can be treated as ontologies.

[38] DL is equipped with open-world assumption and it lacks defaults, while object-oriented programming uses closed-world assumption and defaults to describe a class-inheritance.

4.3 COMPUTABILITY AND COMPLEXITY OF SOFTWARE STRUCTURES

To discover the properties of computer programs we need to use the analysis of software-structures hidden in software-artifacts. Software property is verifiable if it is formally representable (has a representation in algebra or logic) and if its formal representation is decidable. It is known that many properties (e.g.: see the halting problem[39]) of software are not decidable in general; however it is possible to compute them in certain situations. If a problem is dependent on computability of a given property (that is not decidable in general), then we talk about a non-decidable problem. Even if some property is decidable, it needs to have a complexity that allows using it in pragmatic scenarios. It is known that only ≤ PTime complexity allows for doing so in any scenario; however some problems can have a large subset of problems that can be computed in a reasonable amount of time and space by using heuristics[40].

When developing the OASE, we assumed that the computability property of DL provides the means to separate the design from the runtime.

4.4 CLASSIFICATION OF ONTOLOGIES OF SOFTWARE ARTIFACTS

Object-oriented source code is created by using a hierarchical structure of design constructs. It forms a World Description (A-Box) of a particular object-oriented program. The structure of design constructs (that consists of general rules e.g.: polymorphism and encapsulation) can be seen as a model of knowledge about those entities and therefore it forms a Terminology (T-Box). Incorporating OASE-English (see next subchapters) being a language that is able to model object-oriented structures, enables us to use one and the same system for storing integrity constraints, as well as the project and system architecture, which in turn ensures the logical cohesion of artifacts created in different stages of software development.

The process of software development, if understood as knowledge engineering, is a way of developing some sort of software specifications (see Figure 22) that form ontologies. During the lifetime of software project, we can make a classification that distinguishes four basic ontologies:

1) *Requirements Specification Ontology*: Obtaining the client's needs is the basis for the whole process of constructing information systems and this stage influences the further way of project realization. The process of requirements specification and management is not easy. Each requirement is connected

[39] Given a description of a computer program, decide whether the program finishes running or continues to run forever.

[40] One of the well-known problems in Software Development is a problem of Compilation. This problem highly depends on the compiler of programming language and it is known that there exist languages that are non-decidable (e.g.: C++), while other are proven to be decidable (e.g.: Java, C#), There also exist languages that do not require compilation step at all (so called "dynamic-languages" e.g. JavaScript).

with many attributes [Wieg03], such as: completeness, correctness, feasibility, equivalence and verifiability. Determining the requirements as ontology, written in description logic, proposed here, facilitates constant monitoring of requirements attributes by maintaining their internal logical cohesion, which is no trifle matter if there are a lot of them. It is specified (informally or formally) within supporting documents.

2) *Architecture Ontology*: Software architecture [Bass03] [Elli96] is a high-level description of information system. By the purposeful omission of the implementation details, it describes basic ideas necessary for its realization. Architecture of information system consists of a high-level project and architectural style. High-level project implements functional requirements, while architectural style provides infrastructure on which nonfunctional requirements can be fulfilled. Architectural style is a part of metaontology. UML [Rumb05] provides a certain style, that can be seen as oriented to components (symbols) and connectors (indexes), which is a result of object-oriented methodologies (other architectural styles like stream programming [Abel96], and it also requires an application of other metaontologies). Architecture ontology is usually specified within design artifact; however parts of it appear also in supporting documents in informal way (in a form of non-functional requirements).
3) *Design Ontology*: Object-oriented programming can be understood as the way for a computational structures organization, similar to the way we organize physical things. An "object" models a selected autonomous part of the physical system, which can be influenced by actions modeled by "methods" [Abel96], thus causing a change in the system's state, which in turn is modeled as a sum of all states of individual objects.
4) *Program Structure Ontology*: Source code of a program can be interpreted as a knowledge base that describes the structure of a program. If this ontology reflects all important elements of programing language, then the machine-code can be generated from it. Source code can be analyzed. One way to do it is to use analysis of program static structure in order to find potential errors in the program. Another examination includes analysis of program dynamics in order to find run-time errors.

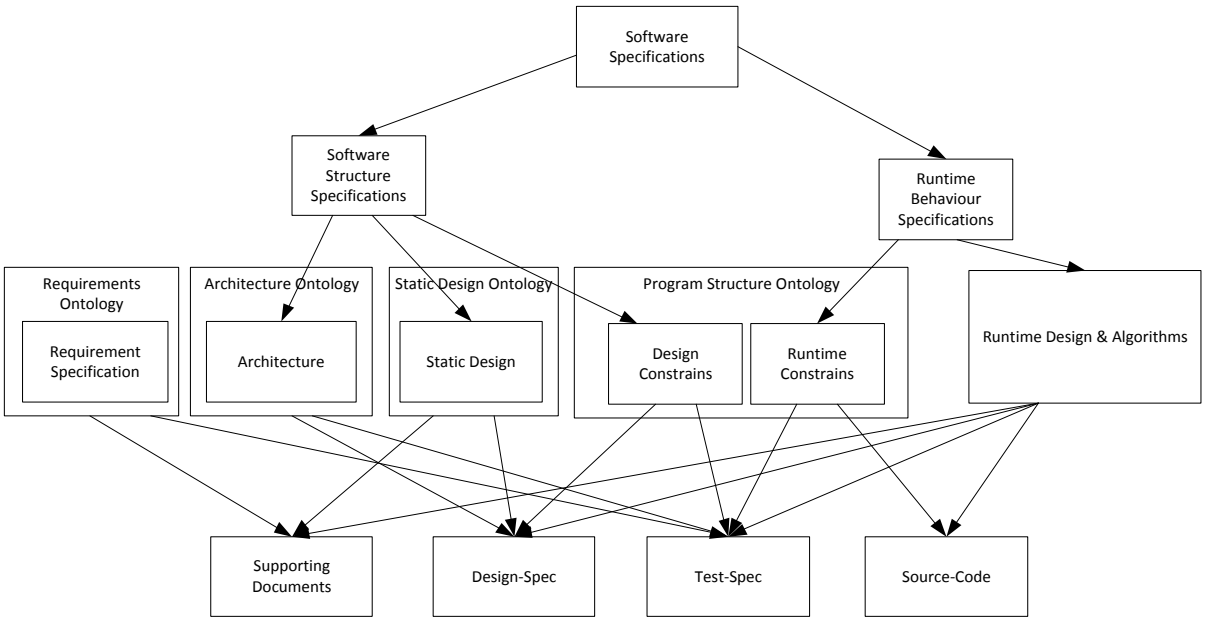


Figure 22. Software Specifications

4.5 OASE: FORMAL SEMIOTIC SYSTEM

The invented here method of software development is called **Ontology-Aided Software Engineering (OASE),** in reference to Computer-Aided Software Engineering (CASE). It is the main objective of this thesis.

OASE method realizes the total semiotic approach to software development by extending the existing methodologies with an ability to express the supporting knowledge in OASE-English (see next chapters). Software artifacts are the input of the overall process that results in a variety of explanations about the properties of current state of the software system. The Figure 23 is an overview of the OASE approach:

1) Software artifacts written with the support of OASE-English form an input of the OASE automated process and are transformed into OASE-English scripts via OASE-Transformations. The considered artifacts are:
    a. Source-Code - made by programmers
    b. Code-Annotations - made by designers (and programmers) in form of OASE-Annotations and OASE-Assertions
    c. UML-Diagrams – made by designers (with notes written in OASE-English)
    d. Other formal specifications in OASE-English – made by the customer, requirement-engineer or made by the management team.
2) Resulting OASE-English script is then processed by separate OASE-Validator that makes an intensive use of description logic reasoner. The reasoner takes advantages of the DL computability and guarantees that results can be provided in the limited computational time and space.

3) Explanations are returned from OASE-Validator to the stakeholders in the form of OASE-English. The acquired knowledge is aimed to be meaningful to them and can form an important input for decision-makers. They are meant to be usable within the improvement process of the considered program.

OASE is the languages of communication between all stakeholders and therefore is has both: iconic and symbolic representation. The semiotic framework needs to be equipped with all semiotic layers beside the syntax (icons and symbols), therefore it needs the semantics and pragmatics to be an integral part of it. Pragmatics then, needs to establish the connection between stakeholders and the framework, allowing for the "new quality of work", therefore it should be easily adapted by the existing software development environments and should provide additional benefits to the stakeholders. The iconic representation is considered in OASE because we made an observation, that software-structures have many viewpoints where icons are preferred over symbols. In "daily programmer's work" the symbols are preferred – this is a "source code producer" point of view. In "daily designer's work" the icons are preferred – this is a "diagram painter" point of view. OASE-Toolkit makes possible to convert UML (the iconic language) into OASE-English script.

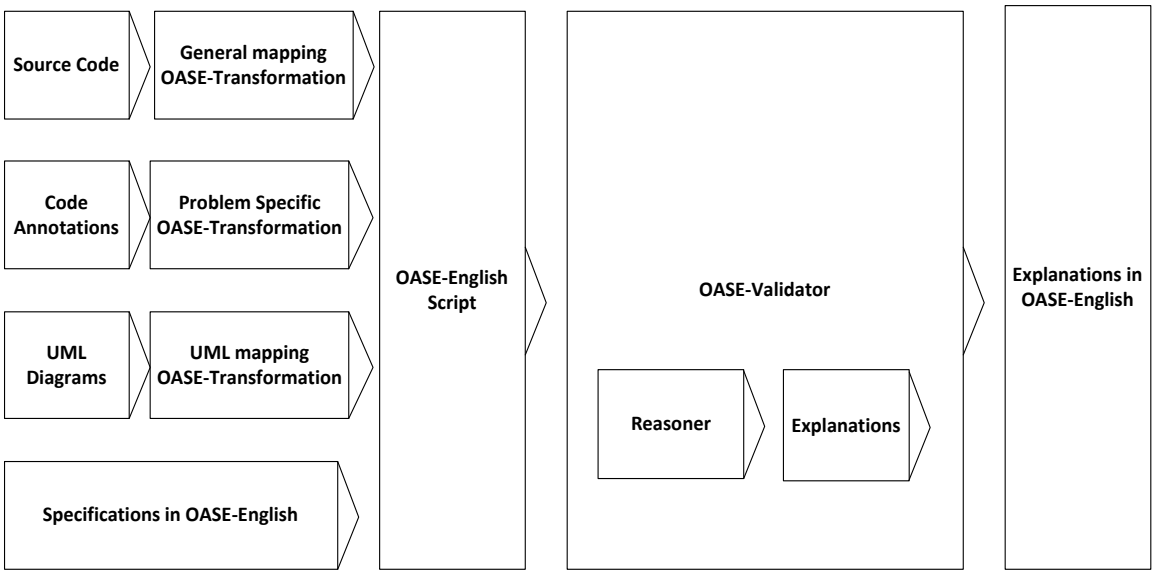


Figure 23. The Overview of OASE automated process

OASE-English is a verbalization of Description Logic. As DL is a subset of First Order Logic (FOL), for which the reasoning tasks are decidable, it is a perfect candidate to describe the static structures that exist within the software entities (moreover, it has a semantics that can be directly represented in Natural Languages). Moreover, DL is a natural candidate for a formal semantic framework of decidable software structures because:

a) DL focuses on ontologies (many software structures form ontology – see Figure 22), therefore it enables the usage of one and the same storage system, for requirements, project and system architecture.

b) DL is decidable by definition; moreover it has dialects that are tractable (have polynomial complexity e.g.: $\mathcal{EL}$++).

c) Its reasoning-tasks (performed by reasoner) makes possible to ensure logical cohesion of artifacts created on different stages of development, as well as between the different groups of people involved in the information project.

Software structures, if combined with knowledge (in a form of ontologies specified in DL) created by means of tools of reverse engineering and subjected to automatic inference, would result in the knowledge that is not explicitly specified but rather derived logically. It could be used for verification of design constraints or modifications of software ontologies themselves or the program, thus ensuring a cyclic continuation of the process and understanding of the problem by the analyst, designer and programmer. Description logic is here: - a semantic formal system, that can be computed by a machine in a limited time and space, - a knowledge representation language that is well understood and adopted by a large community of researchers, and - a software modeling formalism that is able to represent the fundaments of software design in terms of the decidable structure of software.

The pragmatic layer of OASE is covered with tools e.g.: predictive editor, which allows stakeholders to enter the correct OASE-English sentences after short training. Tools allow for a seamless integration of OASE and existing software development environments. Please note that predictive editing support is only needed in writing (not reading) OASE-English texts (and for people not familiar with the OASE-English syntax), therefore it is a usable tool for designers and programmers that deal with OASE-Annotations and want to edit them. Predictive editor is also important for the requirement engineers that are able to specify the requirement in the formal way by using OASE-English. Description logic, itself, is hidden behind the tool-chain as the tool-chains input and output are either in UML or in OASE-English.

OASE is not oriented on any particular software development (object-oriented) method, which makes it possible to use it commonly.

4.6 MOTIVATING EXAMPLES

To give some intuition that lies behind the OASE method some motivating examples are presented here.

4.6.1 SINGLETON DESIGN-PATTERN

The Singleton design-pattern can be described intuitively as a requirement made on a specific class that is forced to have the one and only instance during the whole life of the system. This restriction can be modeled in DL by using a single axiom:

$\exists \mathit{have\text{-}type\text{-}that\text{-}is}.\{\mathit{Class\text{-}Singleton}\} \sqsubseteq \{\mathit{The\text{-}Instance\text{-}Of\text{-}Singleton}\} \Leftrightarrow$

$\Leftrightarrow$ **Everything (that** has-type-that-is Class-Singleton**) is** The-Instance-Of-Singleton**.**

We can specify it by using UML Notes on UML class diagram, using DL syntax or OASE-English (see Figure 24).

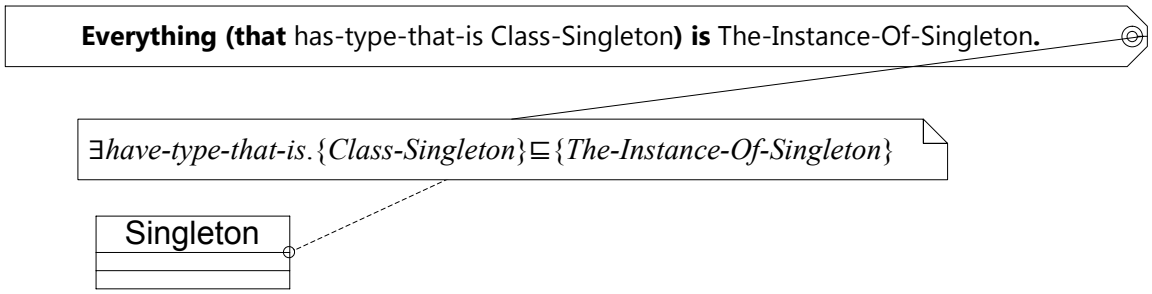


Figure 24. Singleton design pattern and its DL representation

Please note that the Class-Singleton is a name for an instance, however the expression ∃*have-type-that-is*.{*Class-Singleton*} represents a concept. In OASE we represent classes as instances (see chapter 4.11 for details about this mapping). The representation of a class by an instance may be a bit surprising, however as it will be presented in next chapters – such mapping has many advantages and allows for treating a class as a first order object without the loss of generality. Let's see what will happen if we specify two assertions on objects to be instances of the Class-Singleton using have-type-that-is relation, that connects object with its type:

1. *have-type-that-is*(*Object-X*, *Class-Singleton*) ⇔ Object-X has-type-that-is Class-Singleton.
2. *have-type-that-is*(*Object-Y*, *Class-Singleton*) ⇔ Object-Y has-type-that-is Class-Singleton.

The knowledge base is consistent only if all instances are equal (*Object-X*=*Object-Y*==*The-Instance-Of-Singleton*). It can be monitored continuously by an OASE-Validator.

4.6.2 PRESERVING CONSISTENCY BETWEEN ARTIFACTS

Artifacts generated at different stages of software development process are stored separately. To keep the logical consistency between them, it is required that artifacts that do have a formal specification, are continuously adapted to the rest of the artifacts. Requirement specification consists mainly of sentences in a form of "x SHALL y" and "x MUST y" [Wieg03]. OASE supports the process of requirement engineering with an adaptation of OASE-English as a formal language for requirements that "lookalike" the specifications in natural language. Such approach gives the possibility to continuously monitor the requirement attributes, stored as integrity constrains in the DL knowledge base, by preserving its logical consistency using reasoner. During the analysis phase, the requirements are assigned to specific use cases with the appropriate roles (e.g.: realize). Created architecture of the system is enabled to be analyzed in terms of its logic. This approach allows for the continuous monitoring of its attributes and preserves its consistency with other ontologies of software.

Let us now consider a requirement on the computer system about client's identification number. Let's assume that in this case we use US customer identification system. The social-security-number is a unique identifier of any citizen. In OASE-English this requirement can be formalized by the expression

Every man is-identified-by **a** social-security-number.

Additionally we may specify requirement for social-security-number to be a unique number and allow people to enter it:

Every social-security-number **is a** unique-identifier **(that** is-entered-by **a** man**).**

If we require also that unique identifiers are generated by the system and nothing that is generated by a system can be entered by a human:

Every unique-identifier **is a thing (that** is-generated-by **a** system**).**

Everything (that is-generated-by a system**) is not a thing (that** is-entered-by **a** man**).**

Then social-security-number cannot have any instance in such knowledge base; therefore social-security-number cannot be an identifier in our system, unless we resign from some restrictions that are put on it. This conclusion can be deducted by the OASE-Validator during the early design phase of the system, and therefore saves a lot of effort in the later stages of the software development process.

4.7 OASE-ENGLISH

OASE-English is a Controlled English that has a semantics defined by the description logic. The idea that lies behind the OASE-English resulted from the observation (made by us) that it is possible to use the English as a verbalization of $\mathcal{ALC}$ description using context free grammar (see Figure 25); therefore it can be supported via Predictive Editor that prohibits users from entering sentences that are not grammatically or morphologically correct [Kapl10b].

<*sentence*> ::= <*subject*>:S '**is**' <*object*>:O → $S \sqsubseteq O$

<*subject*> ::= '**every**' <*id*>:C → C
| '**everything**' → $\top$
| <subject>:A '**that-is**' <object>:B → $A \sqcap B$
| <*instance*>:I → $\{I\}$
| '**nothing**' → $\bot$

<*object*> ::= '**a**' <id>:C → C
| '**not**' <*id*>:C → $\neg C$
| '**something**' → $\top$
| <object>:A '**that-is**' <object>:B → $A \sqcap B$
| '**something**' <*that*>:E → E
| <*instance*>:I → $\{I\}$
| '**nothing**' → $\bot$
| <role>:R <object>:C → $\exists R.C$

<*role*> ::= <id>:R → R
| <*id*>:R '**by**' → R^-

<*instance*> ::= <upperl><lowerl>*('-'((<upperl><lowerl>*)|(<digt>+)))*

<id> ::= <lowerl>+('**-**'((<lowerl>+)|(<digit>+)))*

<upperl> ::= [**A**-**Z**]

<lowerl> ::= [**a**-**z**]

<digit> ::= [**0**-**9**]

Figure 25. Simple Grammar of CNL for $\mathcal{ALC}$ Description Logic

Predictive editor gives hints during the sentence writing, in the same way as the IDE is supporting programmer with entering the correct statement of the programming language. The ability to describe $\mathcal{ALC}$ dialect of DL in terms of controlled language that have the grammar expressive in LALR(1), motivated us to adopt it for $\mathcal{SROIQ}$ DL.

4.7.1 GRAMMAR AND SEMANTICS

The OASE-English compiler is composed of lexer, parser and semantic verifier. Lexer tokenizes OASE-English sentences and produces the stream of symbols that represents concepts, roles and instances on its output. Parser obtains input from the output of the lexer (that composes the <id>, <bigid> and <num> tokens).

OASE-English has LALR(1), a context-free grammar [Aho88] (see Appendix 1). Due to the limitations of LARL(1) there is a need to equip the OASE-English processor with an additional context-sensitive library, that can perform the morphological activities around the OASE-English. The library is based on the dictionary of irregular forms of English verbs and supports past-participle or present-simple forms of regular and irregular words.

OASE-English uses buzz-words to represent concepts, roles and instances. Buzz-word is a concatenation of few words composed with '-' sign e.g.: beautiful-girl, Pawel-Kaplanski, is-made-from). The morphology of buzz-words is applied if needed, for both: concept identifiers (if plural form of symbol is required) and for role names (if past-participate is required). There exist symbols that are reserved only for a special purpose. Those carefully selected keywords support the grammar of the language. Below is a list of buzz-word naming rules:

1) Each named individual (instance) identifier, is represented by a noun or a name in a singular form. It is written as a sequence of words starting with a capital letter and separated with 'dash' sign e.g.: Very-Beautiful-Girl, John-Dow.
2) Each concept identifier is represented by a noun in singular (or plural in the case of being a part of a number restriction) form (possibly prefixed with adjectives and other nouns). It is written as a sequence of words starting with a small letter and separated with 'dash' sign e.g.: giraffe, low-temperature, smart-guy, cats.
3) Each property (role, attribute) identifier is represented by a verb in past participle form, each starting with a small letter separated with 'dash' e.g.: is-part-of, has-age.
4) Software entities are represented as string bordered with square brackets e.g.: **[**Main.ServerClass**]**, **[**System.String**]** or **[**System.Object.ToString**]**, as they are treaded in special way within OASE.
5) Every name that does not fulfill previous requirements to be a valid symbol, needs to be prefixed with **the-thing-called** keyword, e.g.: **the-thing-called "**C++**"**, **the-thing-called "**:)**"** or **the-thing-called "**猫**"**. If there is a need to express the identifier that is a keyword in OASE-English, it is also required to express it in this form e.g.: **the-thing-called "**the-thing-called**"**.

6) Additionally, the OASE-English supports ontology namespaces. If naming conflict exists within a ontology, there is a need to attach prefix in the form of **[in-terms-of** <prefix>**]**. The prefix forms the namespace of symbols that allows for the disambiguation of homonym identifiers. Namespaces are defined here as symbols that represent context of other symbols e.g.: cloud **[in-terms-of** Weather-Ontology**]** or cloud **[in terms-of** Grid-Computing**]** are two different concepts that have nothing in common, except for the name. Namespaces are very important in terms of programming languages that use them to separate the semantics of symbols which are present in different libraries, however OASE separates ontology namespaces from namespaces that exists within the source code (second ones are directly represented in square brackets as a part of the software entities).

To understand the grammar of OASE-English let's consider some sentence patterns that have a direct representation in $\mathcal{SROIQ}$ DL:

1) **Every** <C> **is** <D>. , <I> **is** <D>. Those examples represent all cases where there is a need to specify the fact about the particular concept (represented by <C>, <D>) or instance (represented by <I>) (or expressions that evaluate the concept or instance in the form of subsumption e.g.: **Every** cat **is a** mammal., Pawel has **two** legs. or Mary **is** married **by** John., John knows **a** programming-language.). E.g.: **Every** tree **is a** plant. is equivalent to DL expression in the form of tree⊑plant. Concept can be subsumed by the complex expression that includes roles and attributes:
   a. The existential restriction e.g: **Every** branch is-part-of **a** tree. ⇔ $branch \sqsubseteq \exists be\text{-}part\text{-}of.tree$
   b. The universal restriction e.g: **Every** lion eats **nothing-but** herbivore. ⇔ $lion \sqsubseteq \forall eat.\ Herbivore$.

   Both (existential and universal) restrictions are complementary to each other so the user needs to understand that the only difference between those limitations lies in the usage of **nothing-but** keyword.
2) Restrictions can be arbitrarily complex if used with **(that** <…>**)** statement-pattern e.g.: **Every** giraffe eats **nothing-but thing (that is a** leaf **or is a** twig**).** ⇔ $giraffe \sqsubseteq \forall eat.(leaf \sqcup twig)$. Here, the union of concepts is used as a range of a restriction, however it is also possible to use the intersection e.g.: **Every** tasty-plant **is something (that is** eaten **by a** carnivore **and is** eaten **by an** herbivore**).** ⇔ $tasty\text{-}plant \sqsubseteq \exists eat^{-}.carnivore \sqcap \exists eat^{-}.herbivore$. To use the complementary part of the concept in the relation, it is helpful to make use of a **does-not** keyword e.g.: **Every** palm-tree **does-not have a** part **(that is a** branch**).** ⇔ $palm\text{-}tree \sqsubseteq \exists have.(part \sqcap \neg branch)$. **Every** herbivore **is-equivalent-of a thing (that** eats **nothing-but** plant **or** eats **nothing-but thing (that** is-part-of a plant**)).** ⇔ $herbivore \equiv \forall eat.plant \sqcup \forall eat.\exists be\text{-}part\text{-}of.plant$. To specify the instance of concept, the previously described simple class assertion is often enough e.g.: Sophie **is a** giraffe. ⇔ $\{Sophie\} \sqsubseteq giraffe$. However it is also possible to make complex specifications about the instances and their relationship.

3) A need to specify that concepts are mutually-exclusive e.g.:
Every man **and every** woman **are different.** ⇔ $man \sqsubseteq \neg woman$,
Every herbivore **and every** omnivore **are different.** ⇔ $herbivore \sqsubseteq \neg omnivore$.
4) Roles can have applied axioms that modify their semantics, like:
   a. transitivity e.g.: **If X** has-part **something that** has-part **Y then X** has-part **Y.** ⇔ $have\text{-}part \circ have\text{-}part \sqsubseteq have\text{-}part$.
   b. reflexivity e.g.: **Everything** is-part-of **itself.** ⇔$\top \sqsubseteq \exists be\text{-}part\text{-}of.\text{Self}$
   c. anty-reflexivity e.g.: **Nothing is a thing (that** is-proper-part-of **itself).** ⇔ $\bot \sqsubseteq \exists be\text{-}proper\text{-}part\text{-}of.\text{Self}$.

   All of them are in fact a kind of semantic sugar and can be though as a special case of general role inclusion and concept subsumption axioms.
5) Role inclusions are represented by **If…** expressions e.g.: **If X** is-proper-part-of **Y then X** is-part-of **Y.** ⇔ $be\text{-}proper\text{-}part\text{-}of \sqsubseteq be\text{-}part\text{-}of$. It is possible to enter any complex role expression when using **something that** e.g.: **If X** loves **something that** is-made-of **Y then X** loves **Y.** ⇔ $love \circ be\text{-}made\text{-}of \sqsubseteq love$ useful e.g.: in definition of inverse roles e.g.: **If X** is-type-of **Y then Y** has-type-that-is **X.**
6) Role equivalence is represented in the following manner e.g.: **X** is-close-to **Y and X** is-near-to **Y means-the-same.** ⇔$be\text{-}close\text{-}to \equiv be\text{-}near\text{-}to$
7) Disjoint roles are opposite to equivalent ones e.g.: **X** loves **Y and X** hates **Y are different.** ⇔ $love \sqsubseteq \neg hate$
8) It is possible to describe the role range or domain e.g.: **Everything** eats **nothing-but thing (that is an** animal **or is a** plant **or** is-part-of **an animal or** is-part-of **a plant).** ⇔$\top \sqsubseteq \forall eat.(animal \sqcup plant \sqcup \exists be\text{-}part\text{-}of.animal \sqcup \exists be\text{-}part\text{-}of.plant)$

OASE allows one to use requirement specifications that form a complementary part of the design structure specifications of the software system. It is important to state here that the OASE modalities differ in semantics from Saul Kripke modal logic. In Kripke modal logic, all worlds need to be taken into a consideration to perform reasoning. In OASE, we care only about specific worlds that the software system realizes. Therefore, in OASE we are talking about pseudo-modal expressions. Pseudo-modal expressions are valid OASE-English expressions that contain additional keyword (**must** or **should** or **can**) or its negation in the middle of it, e.g.: **Every** child **should** have parents**.** In OASE we assume three situations of alerts – outputs from computation of pseudo-modal expressions:

a) Inconsistency - the meaning of inconsistency is the same as in DL reasoning tasks – if the knowledge base is inconsistent, then it is not possible to make any further computation within it. This is a critical situation.
b) Error – means that the pseudo-modal expression does not fit into the state of the knowledge base, which from the pragmatic point of view is a critical situation and it requires a change of software's system design structure.
c) Warning - means that the pseudo-modal expression does not fit into the state of the knowledge base, but it is only a suggestion from the pragmatic point of

view and the situation should be solved somehow in the future (either by fixing the design structure or by modifying the requirements).

```
ALGORITHM Validation(world-description, instance-knowledge, integrity-constraints)
Tell the reasoner about world-description
Tell the reasoner about instance-knowledge
IF(knowledge base is not consistent)
THEN
  show inconsistency
  STOP
ENDIF
FOR(ic∈integrity-constraints)
  FOR(instance∈LeftHandSide(ic))
    IF(instance∉RightHandSide(ic))
      show error or warning depending on modality flag
      STOP
    END
END
```

Figure 26.The Integrity Constrain validation algorithm

The interpretation of **must** , **should** and **can** in OASE is then as follows (in terms of DL reasoning tasks):

1) <A> **is** <B> – means that it is true that all instances of <A> are instances of <B> – if there is a single instance model in the knowledge base that does not apply to this requirement, then the knowledge base is inconsistent and additional reasoning cannot be performed[41]. This case includes also <A> **is not** <C>: if we replace <B> with **not** <C>.
2) <A> **must be** <B> – means that for any single instance of <A> which at is not an instance of <B> the error is generated.
3) <A> **should be** <B> – means that for any single instance of <A> which is not an instance of <B> the warning is generated.
4) <A> **can be** <B> – means that if there is no single instance of <A> which is an instance of <B> then the warning is generated.
5) <A> **cannot be** <B> – means that for any single instance of <A> which is an instance of <B> the error is generated.
6) <A> **should not be** <B> – means that for any single instance of <A> which is an instance of <B> the warning is generated.
7) <A> **must not be** <B> – means that if there is no single instance of <A> which is not an instance of <B> then the warning is generated.

[41] If <A> has no instances, it means that <A> is a bottom concept and it does not produce the inconsistency.

Pseudo-modal expressions can be calculated by the reasoner, using a simple algorithm (see Figure 26). We adopted more efficient algorithm within the implementation of OASE-Validator.

EBNF for of OASE-English grammar is specified in details in Appendix 1.

4.8 OASE-TRANSFORMATIONS

StringTemplate is a domain-specific language, invented by T. J. Parr, for generating structured text from internal data structures. It is MDE model-transformation engine that we selected due to its simplicity and its graph->text orientation. OASE-Transformation is a StringTemplate that produces OASE-English script. OASE-Transformations are intensively used within OASE method, to provide the mapping between class descriptors (models of software structures - see chapter 3.2.1) and OASE-English. For more details about StringTemplate please refer to its detailed description presented in [Parr06].

4.9 SOFTWARE ICONS, INDEXES AND SYMBOLS IN OASE

In modern object-oriented languages (Java, C#) the class is considered as template for creation of objects. The modern languages allow for an inspection of design in the time of program execution (runtime). The mechanism that allows for such an inspection is called reflexion. Moreover, it allows to create a class in the same manner as an object. Old object-oriented languages separated object-oriented world into two parts – the abstract one (made of classes) and the virtual one (made of objects), now we use the only one (virtual), where everything, even the class is an object. The pragmatic observation of usefulness of this approach led us to a conclusion that the definition (and motivation) that lies behind the object-oriented paradigm must have changed over the years. While at the very beginning of the history of object-oriented languages, classes were mostly used as an abstract datatypes, nowadays classes become the object-templates used to create other ones. In other words, classes evolved from abstract objects into virtual ones; therefore the most appropriate ontological representation of classes in DL (in terms of ontology of software entities) is an instance (the instance of very general concept, that forms a creation pattern for other objects, but it is still the instance – not a concept).

The subtyping mechanism can be then described as a form of transitive relation, that moves properties and methods from base-class into the sub-class (– the partial ordering of classes). In short, this mapping can be described as: “class⇔instance, object⇔instance” leaving a place for higher level constructs to be mapped as concepts e.g.: “pattern⇔class”. In the following subchapter (see 4.12) this mapping is described in details.

4.10 CLASS DESCRIPTORS

In object-oriented paradigm, software is represented by a system of objects that cooperate with each other. The specification for object construction is called “a class”. In other words: all objects are instances of classes created during the object construction process.

The object-oriented paradigm assumes that object is a software entity that encapsulates its state and functionality for its own needs. State of the object is specified by the values that fills attributes (the data-placeholders in the instantiated class) and the functionality of an object is specified by functions that are assigned to it (the method-placeholders in the instantiated class). Therefore, the object forms a part-whole structure, where object is the whole and values and functions are parts of it. To “access by name” the part-whole relationship, *signatures* that identify a specific part of an object are used.

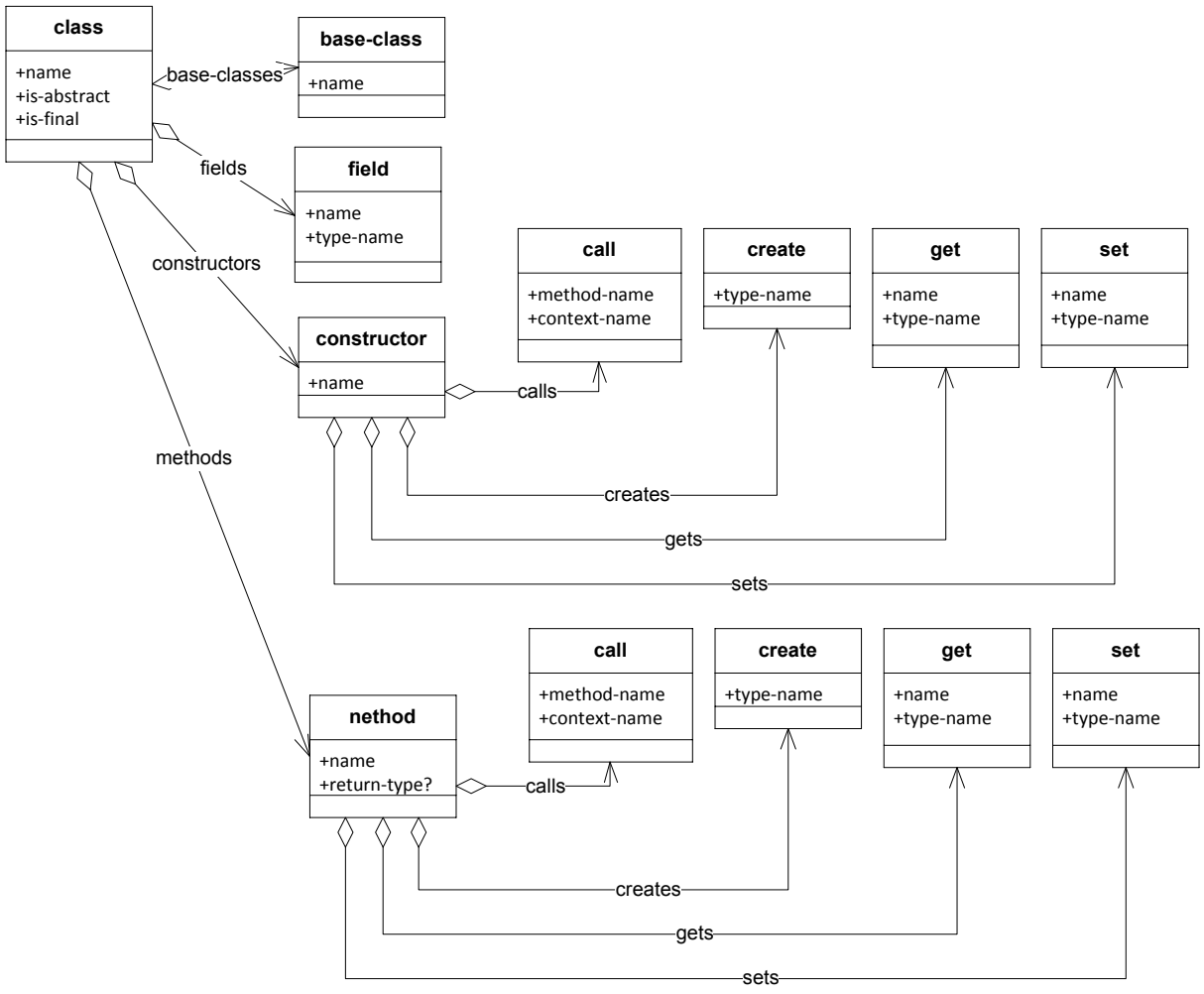


Figure 27. Simple structure of a class (in UML) is forming a composition tree of symbols.

The class-descriptor is a part-whole structure that represents the given class. It is made of class name, its base-classes, fields and methods (see Figure 27). The ability to represent every class in form of a class descriptor is a critical property of classes in both MDE and OASE. In OASE (following MDE) the design structure of object-oriented program forms a net of class descriptors. The net have direct representation in UML, where class-descriptors have representations in class symbols and the overall net is connected with arrows.

The mapping of net of class-descriptors into ontology we present in next chapters. We show two mappings: direct mapping – based on OMG MOF approach, and OASE-Mapping invented by us. Both of them transcribe class-descriptors into OASE-English.

4.11 DIRECT-MAPPING

To give a simple example of practical usage of OASE-Transformation let us create one that is related to Direct-Mapping and described in Figure 18 (see subchapter 3.2.1). It is based on the specific object-oriented upper ontology (see Figure 28). Direct mapping can be simply presented as: "class⇔concept, object⇔instance, attribute⇔role" and it is simpler than the OASE core ontology (discussed in 4.12) as OASE mapping is "pattern⇔concept, class⇔instance, object⇔instance, attribute⇔instance, association⇔role"), however the direct-mapping covers the general concepts of object-oriented entities and therefore it is worth to presenting that there exists a possibility of using the OASE to express it.

The Direct-Mapping OASE-Transformation deals with classes, types and records where the entire system structure of object-oriented system forms a net of symbols. The class-descriptor of a class has a form of a tree and is used as an input for the template that generates the script (see Figure 30).

Every abstract-class has-type **exactly one thing.**

Every record-type has-type **nothing-but none**.

No record-type **is a** method-type.

Figure 28. Upper ontology of Direct-Mapping

Let's consider the example class "manager" (see Figure 29) and the StringTemplate processor, which gets the class-descriptor as an input and iterates over it.

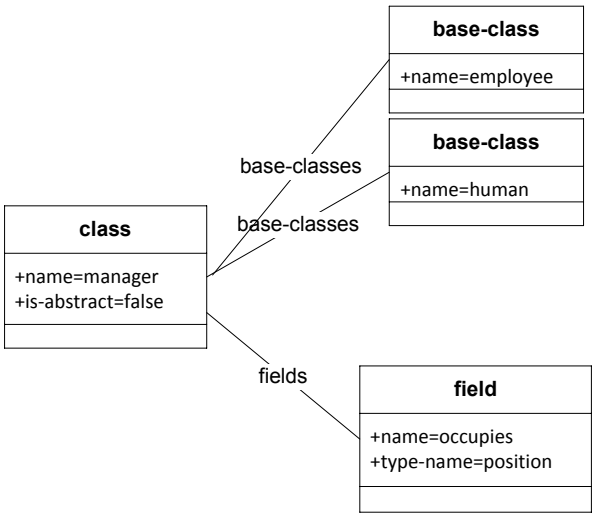


Figure 29. Example of Class Descriptor

The OASE-English script output that is a product of processing (see Figure 31) is an ontology written in OASE-English that together with upper-ontology (see Figure 28) allows for a deductive reasoning in such a representation of object-oriented program.

```
mapType(cls) ::= <<
   Every class-<cls.name> has-type nothing-but type-<cls.name>.
   Every type-<cls.name> is a record-type.
   <if(cls.is_abstract)>
      Every class-<cls.name> is an abstract-class.
   <endif>
   <cls.base_classes:{base_class |
      Every class-<base_class.name> is a class.
      Every class-<cls.name> is a class-<base_class.name>.
    }>
   <class.fields:{field |
      Every type-<cls.name> field-<field.name>s exactly one thing.
      Every type-<cls.name> field-<field.name>s nothing-but class-<field.type_name>.
   }>
>>
```

Figure 30. OASE-Transformation for Direct-Mapping

Every class-manager has-type **nothing-but** type-manager**.**

Every type-manager **is a** record-type**.**

Every class-employee **is a** class**.**

Every class-manager **is a** class-employee**.**

Every class-human **is a** class**.**

Every class-manager **is a** class-human**.**

Every type-manager occupies **exactly one thing.**

Every type-manager occupies **nothing-but** class-position**.**

Figure 31. Result of OASE-Transformation of Direct Mapping

The ability of deductive reasoning in object-oriented program allows the designer to understand the impact of change in terms of requirements, permits the programmer to trace the impact of change in terms of the design and finally allows the tester to test the impact of change to the required design (non-functional requirements).

4.12 THE OASE-METAMODEL

In OASE meta-ontology, classes are represented by instances of the concept called *class* and for each object there is assigned a specific instance that represents the class of the concept called *object*. Moreover; instances that represent objects created by a specific class are related to the class with *be-instance-of* role (see Figure 32).

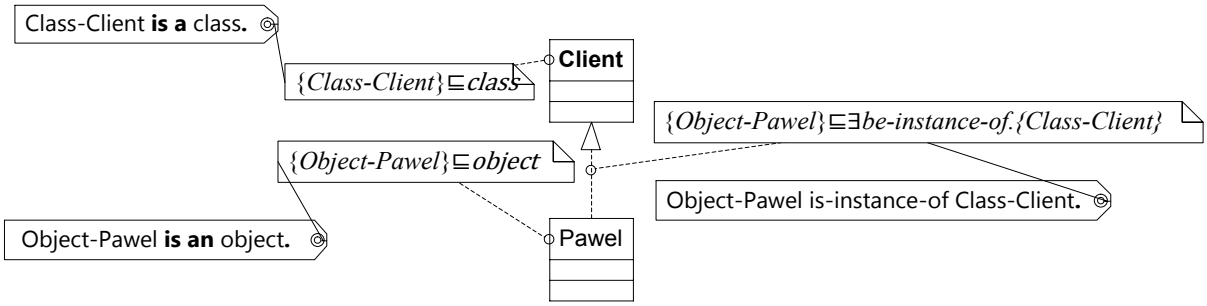


Figure 32. UML diagram of class Instantiation, its representation in DL and its meaning in OASE-English

Classes are related to each other with partial-ordering relation, represented in OASE with *be-subclass-of* role (see Figure 33). Subtyping mechanism (partial ordering over types) is the core idea behind the paradigm of object-oriented abstraction.

be-subclass-of∘*be-subclass-of*⊑*be-subclass-of* ⇔

⇔ **If X** is-subclass-of **something that** is-subclass-of **Y then X** is-subclass-of **Y.**

Given *be-subclass-of* relationship we can define its inverse called *be-superclass-of*:

be-subclass-of≡*be-superclass-of*$^{-}$ ⇔

⇔ **X** is-subclass-of **Y and Y** is-superclass-of **X means-the-same.**

Please note that *be-subclass-of* and *be-superclass-of* are DL roles. This is a great difference between OASE approach to Direct-Mapping (see chapter 4.11) and the approach in which the partial ordering of classes in hierarchy is represented by concept subsumption.

The "type of object" in object-oriented systems is understood as either explicit or implicit super-class of class that created the object, together with the class designed for the creation of the specific object. We can summarize above requirements (in OASE) with the following script (see also Figure 34):

1) **If X** is-instance-of **Y then Y** is-type-of **X.** ⇔ *be-instance-of*⊑*be-type-of*$^{-}$
2) **If X** is-instance-of **something that** is-subclass-of **Y then Y** is-type-of **X.** ⇔
   ⇔ *be-instance-of*∘*be-subclass-of*⊑*be-type-of*$^{-}$
3) **X** is-type-of **Y and Y** has-type-that-is **X means-the-same.** ⇔ *be-type-of*≡*have-type-that-is*$^{-}$
4) **X** is-instance-of **Y and Y** has-instance-that-is **X means-the-same.** ⇔
   ⇔ *be-instance-of*≡*have-instance-that-is*$^{-}$

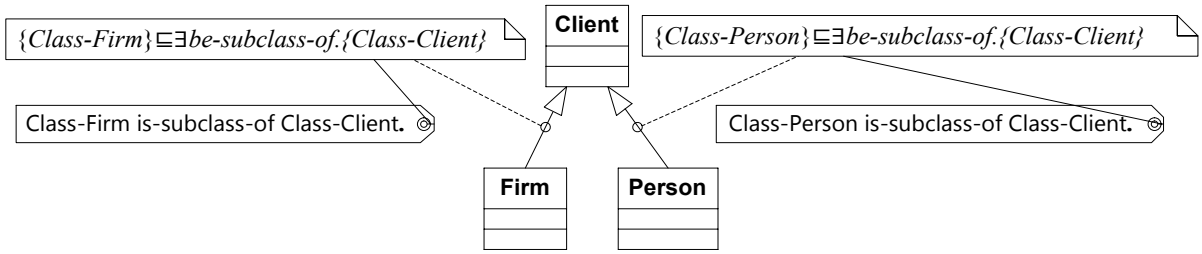


Figure 33. UML diagram of class inheritance and its representation in DL

With the given above OASE meta-ontology, we can formally describe the basic properties of objects and classes that have to be followed, e.g.: to specify that class *Person* is abstract (a class that cannot be materialized) we can chose direct DL representation in a form of: *{Class-Person}*⊑∀*have-instance-that-is*.⊥ and to specify that *Person* class is a root of a class hierarchy: *{Class-Person}*⊑∀*be-subclass-of*.⊥ . Moreover, we prevent the class from being inherited (such classes are called "final" in Java) with: *{Class-Person}*⊑∀*be-superclass-of*.⊥ (see Figure 36) statement.

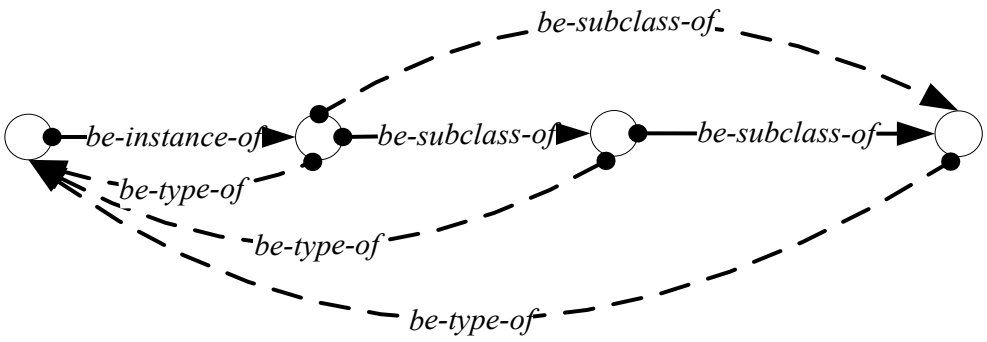


Figure 34. Explicit (solid) and implicit (dashed) relations in OASE upper-ontology.

4.12.1 THE MODEL OF PART-WHOLE

In OASE meta-ontology the *be-member-of* role as well as its inversion *have-member-that-is* are defined in the way that respects *be-subclass-of* role introduced previously; therefore with OASE part-whole model, it is possible to describe the situation in which an object of a specific class aggregates a limited number of objects of another class (see Figure 35).

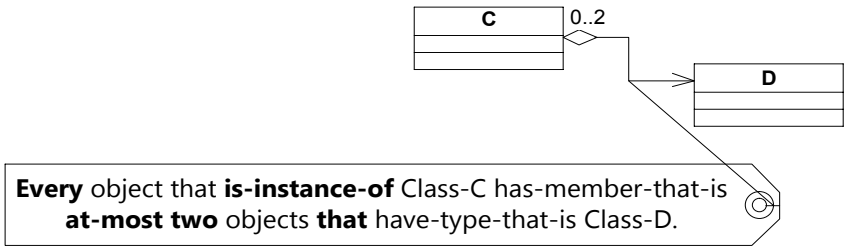


Figure 35. The aggregation and its DL representation

The limitation on expressivity of $\mathcal{SROIQ}$ forbids using number restrictions on the complex role [Horr06b] and consequently, in OASE part-whole model, is a need to introduce a separate transitive counterpart of *be-member-of* (which needs to stay a simple role in order to fit in the $\mathcal{SROIQ}$ limitations). Let's introduce *be-part-of* role that is useful in describing situations where the transitive behavior is more important than the number restriction. Summarizing: all above relations are represented in the following OASE-English script:

1) **X** is-member-of **Y and Y** has-member-that-is **X means-the-same.**
2) **If X** is-subclass-of **something that** has-member-that-is **Y then X** has-member-that-is **Y.**
3) **If X** has-member-that-is **Y then X** is-part-of **Y.**
4) **If X** has-member-that-is **something that** is-part-of **Y then X** is-part-of **Y.**

The *call* (transfer of code execution) relation between functions is another example of useful transitive role. On the other hand, during the method execution, a new

object is created in the OASE and it is represented by *create* relation. Every object is created as a product of construction process done by constructor (the function that explicitly creates the object based on the given class) therefore when the object construction occurs, the method calls the specific constructor. Those interconnections between objects are represented by the following OASE script:

1) **If X** calls **something that** calls **Y then X** calls **Y.**
2) **If X** creates **something that is** constructed **by Y then X** calls **Y.**

State of the object is specified by the set of values of its attributes. The functionality that object can provide is specified by the implementation of the method (functionality slots). Both, attributes and methods are parts of classes while attribute-values and method-implementations are parts of objects.

To "access by name" (i.e. when the specific function needs to change the state of the given attribute) the part-whole relationship in object-oriented languages, one has to use the signatures that identify a specific part of an object. For example, let's assume that the class *Client* has an attribute *Account*. In OASE, the identification of an attribute or a method is expressed with superimposition (a superimposition of a class C and signature S is a complex expression that involves both of them) of signature and class (here signature is *Account*), together with *identify* and *be-member-of* roles: $\exists identify^{-}.\{Signature\text{-}Account\} \sqcap \exists be\text{-}member\text{-}of.\{Attribute\text{-}Client\}$. The expression:

$\exists identify^{-}.\{Signature\text{-}Account\} \sqcap \exists be\text{-}member\text{-}of.\{Class\text{-}Client\} \equiv \{Attribute\text{-}Client\text{-}Account\} \Leftrightarrow$

Everything (that is identified **by** Signature-Account **and**
is-member-of Class-Client**) is-equivalent-of** Attribute-Client-Account**.**

states that the *Client-Account* attribute exists and expresses how to identify it uniquely. Having *Client-Account* attribute defined, one can put restrictions on the type of this attribute e.g.:

$\exists fill.\ \{Attribute\text{-}Client\text{-}Account) \sqsubseteq \exists have\text{-}type\text{-}that\text{-}is.\{Class\text{-}Account\} \Leftrightarrow$

$\Leftrightarrow$ **Everything that** fills Attribute-Client-Account has-type-that-is Class-Account**.**

If, by an analogy to attribute, we assume that the method is a placeholder for a function that can be performed by all objects that have type of given class, then expression:

$$\exists identify^{-}.\{Signature\text{-}Login\} \sqcap \exists be\text{-}member\text{-}of.\{Class\text{-}Client\} \equiv \{Method\text{-}Client\text{-}Login\}$$

uniquely identifies the method *Login* of a class *Client*. Functions that fill placeholders formed by methods are called method-implementations in object-oriented methodology. They are defined for the given parental classes and are assigned to the object during the construction process. Therefore to deal with the methods and its implementations lets introduce the *implement* relation e.g.: we specify that *Client-Login-Impl* function is an implementation of the *Client-Login* method (equivalent to $\exists identify^{-}.\{Login\} \sqcap \exists be\text{-}member\text{-}of.\{Client\}$) by using:

$$\{Function\text{-}Client\text{-}Login\text{-}Impl\} \sqsubseteq \exists implement.\{Method\text{-}Client\text{-}Login\}.$$

As every instance of *Client* class has a member of *Client-Login-Impl* we can specify that:

$$\exists be\text{-}instance\text{-}of.\{Class\text{-}Client\} \sqsubseteq \exists have\text{-}member\text{-}that\text{-}is.\{Function\text{-}Client\text{-}Login\text{-}Impl\}.$$

The polymorphism of methods and inheritance of method implementation differ in details within object-oriented languages. Especially when taken together into account, they create difficulties in describing them it in the DL. From the OASE point of view, both mechanisms are solved by the OASE-Validator that use the reflexion mechanism available in programming language itself, and therefore there is no necessity of additional support for the reasoning over their properties. In the OASE, the equivalence of functions (implementations of the methods) is done explicitly by the OAE supporting tools. The OASE tools specify which functions are the same and which are different.

4.12.2 CLASS HIERARCHIES

OASE Metamodel maps classes and objects into DL instances and arranges them in hierarchical order by using roles instead of subsumption between concepts. It leaves the room for higher-level object-oriented constructions to be mapped as concepts. One of a high-level object-oriented constructions is a class hierarchy. Hierarchy of classes is a set that consists of all the classes related with the be-subclass-of relationship, including the given class. To deal with hierarchies in OASE, we assume that each class (the instance that it represents) need to be explicitly hierarchized by some hierarchy (if a class is neither a super nor subclass of any other class, then its hierarchy hierarchizes this class only). Hierarchies in OASE are represented by instances of some general concept *hierarchy* e.g.: using DL assertion *hierarchize*(*Hierarchy-H, Class-X*). The *hierarchize* DL role has *a hierarchy* as a domain and the *class* as a range. A *hierarchize* DL role should follow the relationship between subclasses. Those rules can be formulated in the following statements:

1) **If X** hierarchizes **something that** is-subclass-of **Y then X** hierarchizes **Y.** $\Leftrightarrow$
$\Leftrightarrow$ $hierarchize \circ be\text{-}subclass\text{-}of \sqsubseteq hierarchize$

2) **If X is** hierarchized **by something that** is-subclass-of **Y then X** hierarchizes **Y.** ⇔
⇔ $hierarchize^{-} \circ be\text{-}subclass\text{-}of \sqsubseteq hierarchize$

If each instance that represents a class in the system is related to some instance that represents a hierarchy (possibly anonymous – if not specified directly) with a *hierarchize* role, then it is possible to automatically determine the concept that contains all of classes hierarchized by the same hierarchy as the given class e.g.: $hierarchy\text{-}of\text{-}class\text{-}x \equiv \exists hierarchize^{-}.\exists hierarchize.\{Class\text{-}X\}$.

In Figure 36 is presented the simple hierarchy of classes. The top class (class A) is here an abstract class and a root for the class hierarchy. The class hierarchy is connected via subclassing and is contained in h_c concept.

4.13 OASE-MAPPING

In Appendix 2 we present details of the OASE-Transformation which maps the structure of object-oriented program into OASE-English w.r.t. OASE-Metamodel presented in the previous subchapter. It is assumed that the input of the OASE-Transformation is a class-descriptor (see Figure 27) that represents the internal structure of classes within the object-oriented program (it is obtained either from the UML specification and/or from the source code structure taken directly by using mechanism of reflexion – introduced previously), therefore; OASE-Mapping can be considered as a transformation from either the UML specification or/and object-oriented source code into the OASE-English.

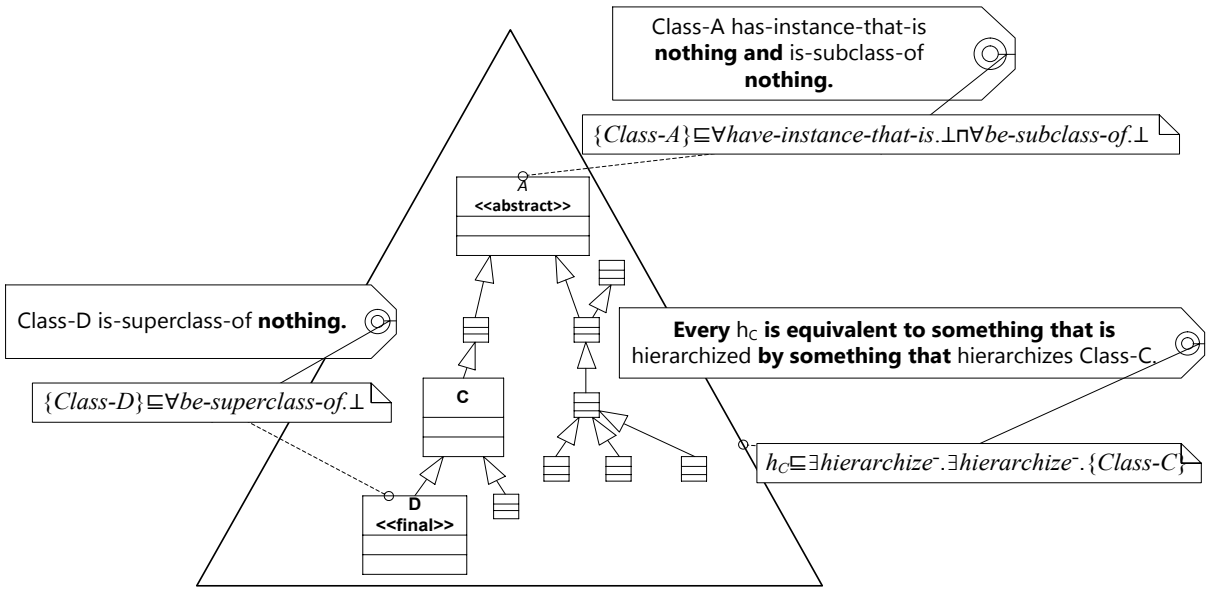


Figure 36. The class hierarchy for a given class C and its representation in DL

4.14 PROGRAMMING WITH OASE-ANNOTATIONS

OASE-Annotations [Kapl11b] support the pragmatic-layer (in terms of semiotics) of OASE and therefore they complete the OASE in terms of semiotic framework for Software Development.

Modern object-oriented programming languages (e.g.: Java, C #) are equipped with the capability of using annotations that comment on the entities of the program. Previously mentioned languages provide access to these annotations through the reflexion. OASE provides the means to annotate the source code with remarks in the form of OASE-English statements. The resulting code looks like a mixture of standard source code and English sentences. Once annotated with the code is therefore equipped with additional semantics, that allow to generate the formal specification of the entire system.

The casual collaboration between the designer and the programmer is unidirectional - what the former designs, the latter must implement. With the OASE-Annotation, the collaboration becomes bidirectional – the output of programmer's work can break the design, which will result in the inconsistency. This process is called by programmers "the verification of design by the implementation". Normally (in terms of casual collaboration between stakeholders), such a situation would result in downgrading of the design over implementation; however, when using OASE, it is possible to modify the design so that it still keeps the bidirectional consistency. The programmer and designer use the same semantic background – the description logic, which lies behind both: the annotated code and the UML models. Finally, explanations in OASE-English instruct both, the designer and programmer, about the cause of the problem that has occurred. OASE-Annotations allow for a specification of the design constraints on static structure within the source code, due to the fact that it is powerful enough to specify static structure of the code.

The usefulness of OASE-Annotations was verified by us in the experiment described in details in Appendix 5.

4.15 DEBUGGING WITH OASE-ASSERTIONS

OASE supports Design by Contracts paradigm, by allowing for take a usage of OASE-Assertions. OASE-Assertions can be seen as a form of documentation that is useful for verifying if an assumption made by the programmer (during the implementation of the program) remains valid (when the program is executed). OASE-Assertions implement the assertions in terms of checking for fulfillment of the contract that need to be preserved during program execution. They are verified in the debug-mode (in the final release of the software they are omitted). OASE-Assertions are discussed in Pipes & Filters case study described in chapter 4.17.2.

4.16 DISCUSSION OF OASE SEMIOTIC FRAMEWORK

As the aim of OASE is to become the semiotic framework, therefore below we discuss its three semiotic layers: Syntax, Semantics and Pragmatics.

4.16.1 OASE SYNTAX LAYER

The syntax of OASE provides the means to deal with basic software entities, in terms of icons (UML) or symbols (OASE-English). The icons that exist in UML diagrams of software static structure are preserved within the OASE.

The main advantage of OASE in the area of syntax of the software is an ability to describe the specification of design patterns.

The first general weakness of OASE syntax layer is the necessity of using buzz-words in OASE-English. Buzz-words are mix of symbols that represent concepts, roles and instances in ontologies; however they are not a part of natural language. The second general disadvantage lies in the core characteristic of OASE-English – it is a subset of English only. Even if English is a core language that lies behind every modern computer language, there is a need to adapt the OASE for other natural languages.

4.16.2 OASE SEMANTIC LAYER

Description logic (DL) forms a formal semantic layer of OASE. OASE allows to present existing UML diagrams as the static structure of software, however the limitations in semantic layer are caused by the DL itself. It is impossible to deal with a runtime software behavior with DL and therefore with OASE (because runtime behavior is non-decidable in general). This limitation allows for specifying and verifying only those statements that are in the expressive power of $\mathcal{SROIQ}$. Even if most of the structures that are essential (from the software development process point of view) need to be decidable, there is still a necessity to describe and perform reasoning over the runtime structures – that's when the OCL becomes useful. Although OCL is not intuitive, there exist approaches to build the semiotic framework over the OCL formalism. The expressive-power of OASE can be extended in the future with integration of a rule system. By now we support runtime structure by OASE-Assertions that allows to preserve the runtime constraints of the running program.

Future research needs to be made in order to permit for expressivity in e.g.: Adjectives, Full Modal Logic, Temporal Logic etc... – afterwards it is not clear if it will be possible to use LALR or any other context-free grammar anymore.

4.16.3 OASE PRAGMATIC LAYER

The pragmatic layer of OASE is a consequence of its usage by the stakeholders. Proposed methodology has a number of advantages for all involved groups of con-

tributors. OASE is based on the same natural-looking language and the logic is hidden. Users do not need any training in formal logic formalisms nor the support from computer specialties as long as they are able to use the predictive editor. Programmers are continuously checked by OASE-Validator whether the entered knowledge fulfills the Integrity Constraints. Designers are provided with the ability to explore the software, by using formal tools. They can also continuously adjust the Integrity Constraints while the implementation is still in progress.

Common limitation of OASE-English is the need for predictive editor, from the editor perspective. It is very difficult to create a correct OASE-English sentence without such support, but the LALR context free grammar of OASE-English allows one to build the predictive editor easily.

In comparison to Lepus3, the OASE is decidable and more focused on symbols than icons. The ability to represent the complex structures in the Controlled Natural Language is a valuable innovation, especially in the area dominated by the iconic languages. This can lead to a better understanding of the complex software structures by all stakeholders involved in the software development process. It also allows to employ the OASE-Validator as a part of continuous integration process – the core part of the agile software development methodology.

4.16.4 EVALUATION

Semiotic layers of OASE were evaluated within the survey (see Appendix 4 and the experiment (see Appendix 5). The experiment and survey were invented to check:

1) *If the syntax and semantic layers allow to use OASE in an understandable manner:* Evaluation proves that both semantics and syntax are understandable by English speaker. An emphasis was put on the pseudo-modal expressions. We found out that pseudo-modal expressions are ambiguous for the novice programmers and can lead to misuse.
2) *If the pragmatic layer provides usability in terms of software engineering:* The experiment proves that OASE improves the collaboration between designer and programmer, by reducing the amount of necessary communication between them. Instead of this communication, the OASE-Validator provides the programmer with meaningful explanations, leading him by hand via the design of the program. This is a very important effect that has a great impact on distributed workplaces, which are more and more popular nowadays.

4.17 CASE STUDIES

Next subchapters present the case studies of the practice of programming with OASE.

4.17.1 ARCHITECTURAL LAYERS

The layer separation paradigm manages usage relationship between the software entities. Architectural layers label each software entity and force the correct

ordering in terms of its bidirectional usage relationship. The most popular layered architecture is 3+1 architecture (3-vertical layers + 1 cross cutting layer) (see Figure 37).

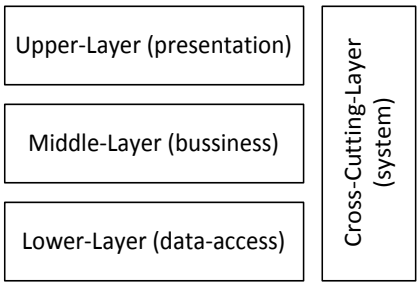


Figure 37. Layered Architecture

To take an advantage of Layered Architecture in OASE, the designer needs to label all software entities with exactly one Id of Layer (e.g.: see Figure 38) It is realized with newly introduced label role that connects the class with the corresponding Id of Layer, by simply specifying it literally.

Specification of layout of layers is understandable only when used together with a modal word (as it aims to express the requirement). Modal word enforces the treatment of following sentences as Integrity Constraints that need to be kept by classes in the system:

Everything that is marked **by** <upperLayerID> **can-not** use-directly **something that is** marked **by** <lowerLayerID>**.**

Everything that is marked **by** <middleLayerID> **can-not** use-directly **something that is** marked **by** <upperLayerID>**.**

Everything that is marked **by** <lowerLayerID> **can-not** use-directly something **(that is** marked **by** <middleLayerID> **or is** marked **by** <upperLayerID>**).**

To allow the OASE-Validator for automated checking of the layers ordering, all software entities need to be connected with the use-directly relationship. Fortunately it can be defined as an extension of OASE:

If X is implemented **by something that** calls **something that** implements **Y**
then X uses-directly **Y.**

If X is-type-of **something that** has-member-that-is **something that** has-type-that-is **Y then X** uses-directly **Y.**
If X is-type-of **something that is** constructed **by something that** creates **something that** has-type-that-is **Y then X** uses-directly **Y.**

If X reads **Y then X** uses-directly **Y.**
If X writes **Y then X** uses-directly **Y.**

Finally, using the verification algorithm (see Figure 26) one can always validate the system design against the layer ordering, and therefore ensure that according to the Integrity Constraints, classes in the system do not break the layered architecture.

```
[OASE.Entity(@"labeled by Upper-Layer")]
public class ApplicationClass
{
    public void doSomething()
    {
        //can use only Middle-Layer or Cross-Cutting-Layer
    }
}

[OASE.Entity(@"labeled by Middle-Layer")]
public class MiddlewareClass
{
```

Figure 38. Example of OASE-Annotation for Architectural Layers

We have made assessment of utilization of OASE-Annotation with Architectural Layers within the evaluation of the survey described in details in Appendix 4.

4.17.2 PIPES & FILTERS

The Pipes & Filters [Busc96] is a well-known Design Pattern [Gamm95], that is used to divide the task of a system into several sequential processing steps. Each processing step is implemented by a filter component that consumes and delivers data incrementally. The filters are connected sequentially by pipes. Filters are usually implemented as separate objects that use one common interface of a generic pipe and therefore filters can be freely configured, however it is highly desirable to prevent such a free-style by incorporating some design constraints. The solution requires an incorporation of specification language, which would allow the designer to exactly specify which pairs of filters are compatible with one other. OASE-Annotations together with OASE-Assertions, allow the programmer to build a Pipes & Filters design pattern validator, in a coherent way.

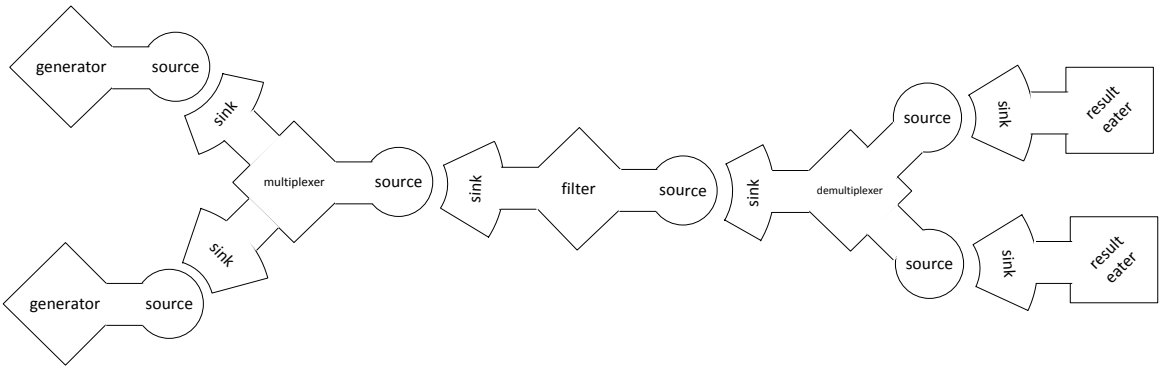


Figure 39. Pipes & Filters.

If we equip every method with the pre-condition in a form of OASE-Assertion and annotate the classes with supporting OASE-Annotations (see Figure 40), then it is possible for OASE-Validator to perform reasoning. The OASE-English script, which resulted from OASE-Transformation, is the formal specification of such Pipes&Filters system. What is more, the verification of Pipes & Filters can be done using OASE-Validator in runtime.

```
[module: OASE.Axiom("Pipe-A is-connectable-to Pipe-B.")]

public class Multiplexer
{
    [OASE.Architecture.PipeConnector("Pipe-B")]
    public IEnumerable<string> filter(IEnumerable<string> arg1, IEnumerable<string> arg2)
    {
        OASE.Debugging.Assert(arg1.GetPipeID() + " must be-connectable-to Pipe-A.");
        OASE.Debugging.Assert(arg2.GetPipeID() + " must be-connectable-to Pipe-A.");
        foreach (var a1 in arg1)
        {
            yield return a1 + "f";
        }
    }
}
```

Figure 40. OASE-Annotations in Pipes&Filters.

We have made an appraisal of utilization of OASE-Annotation and OASE-Assertions with Pipes & Filters within the evaluation of the survey described in Appendix 4.

4.18 OASE AS A DESIGN PATTERN LANGUAGE

Design pattern shows the promising way (in terms of pragmatics of software development process) of organizing the software entities. The design pattern can be treated in two ways: first - as a requirement put on software design and second - as a repetitive software structure that occurs unintentionally in software. The solution described by the design pattern, is specified by the roles of its constituent participants, their responsibilities and relationships, and the ways in which they collaborate. To approach the design pattern one is required to focus on each of these three areas:

1) The participating classes and objects
2) Relationships between the classes and objects
3) The overall collaboration of participants

Even if design pattern is not formally defined, the fulfillment of the above rules makes it possible to formalize it using formal methods. The software design pattern language [Alex77] [Busc07a], which can be used to describe each aspect of the software architecture, if formalized, can become a language that will allow for the requirement and discovery of essential software aspects. Common semiotic framework which lies behind the pattern language, functions as a background for the development of tools, that can deal with the design pattern language. DL and OASE-English together can provide such a framework.

4.18.1 ADAPTER

Adapter design pattern [Gamm95] translates one interface of a class into a compatible interface. It allows classes (that have incompatible interfaces) to work together (what would be impossible when providing its interface to clients while using the original interface). In other words: Adapter translates calls to its interface into calls to the original interface. Depending on the designer decision on adoptee class, it can be implemented via aggregation or inheritance: we call them class-adapter (when the adapter class inherits from the adoptee class) or object-adapter (when the adapter class contains the adoptee class) (see Figure 41) that takes the net of class-descriptors as an input.

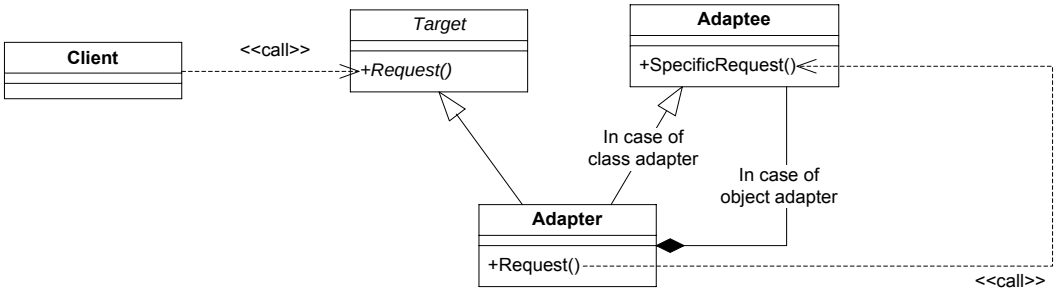


Figure 41. Adapter design pattern

In Appendix 3 the OASE-Transformation of Adapter design pattern is presented in details. We have made an assessment of utilization of OASE as a Design Pattern Language, in terms of Adapter Pattern within the evaluation of the survey described in details in Appendix 4.

5. OASE-TOOLS

This chapter presents the tools, we have developed, that support the OASE paradigm by:

- Ability to enhance the current software development tools with OASE-Annotations and OASE-Assertions
- Ability to use iconic representations of software structures using UML
- Ability to specify requirements and design in OASE-English using Predictive Editor

OASE-tools are to be used by two groups: the T-Box Engineers (software designers, requirement engineers) that specify the World Description of a software system and map its requirements onto Integrity Constraints and the A-Box Producers (programmers) that provide the knowledge about ontology assertions either manually or with an additional tool support that obtains assertions from the source code. Both participants do supportive work by using one of specialized predictive editors (OASE-Annotator, OASE-Diagrammer or standalone OASE-English predictive editor). Their work is continuously synchronized and validated by the OASE-Validator (see Figure 3). Moreover they can use additional custom tools (designed strictly for the given problem) which are based on Inferred-UI approach (described in the next chapter).

OASE-Tools can be downloaded from the OASE web-site: http://oase-tools.net .

5.1 OASE-VALIDATOR

OASE-Validator is a software component that is reused within entire OASE tool-chain. Given the OASE-English specification OASE-Validator returns the results of validation of pseudo-modal expressions contained within the knowledge base. The result of validation, that has a form of explanations specified in OASE-English, is finally returned from OASE-Validator to the user. The component consists of several subcomponents connected together (see Figure 42). The parser gets the output of the lexer and produces (with a support of the morphology component) the Abstract Syntax Tree (AST) of OASE-English sentence. The AST visitor transforms the AST and produces the DL representation of every sentence. The heart of OWL-Validator is a reasoner for $\mathcal{SROIQ}$ DL called HermiT [Shea08]. The explainer is a part of OWL-API [Bech03]. It constructs explanation mechanism about the inconsistency or broken integrity constraints. The Integrity Constraints Validator uses both: the reasoner and the explainer.

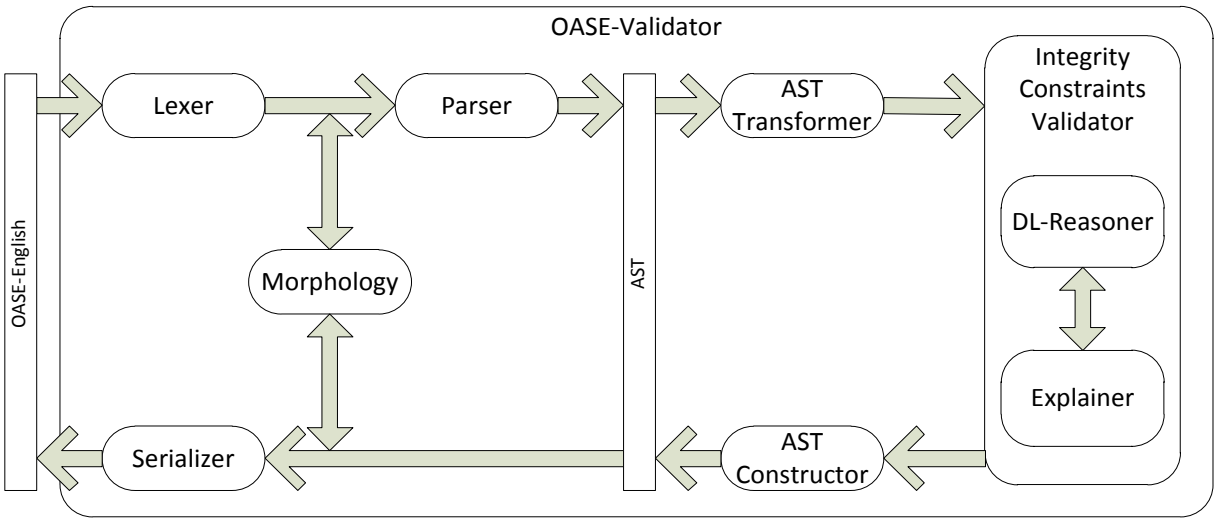


Figure 42. Internal structure of OASE-Validator

5.2 OASE-ENGLISH PREDICTOR

Predictive Editor for OASE-English [Kapl11a] is realized in the form of reusable UI component (called OASE-English Predictor) which is shared among all OASE editors (see Figure 43). The implementation is inspired by the predictive editors used in modern Integrated Development Environments (IDE), like Microsoft Visual Studio[42] that actively supports the programming process by providing the programmer with meaningful hints.

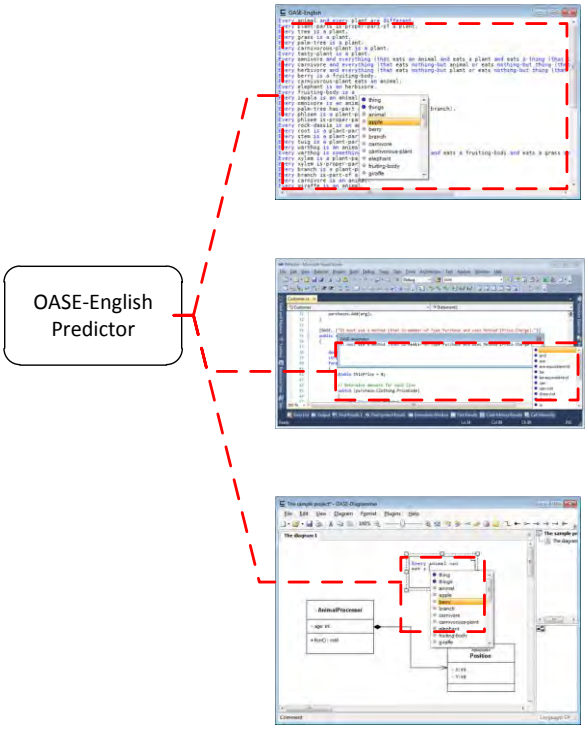


Figure 43 Reusability of OASE-English Predictor within the family of OASE-Editors

[42] http://www.microsoft.com/visualstudio

OASE-English Predictor allows one to create a variety of predictive editors that support the OASE-English. It is realized as a library, which manages a number of tokens that are the possible continuations of a given OASE-English sentence and presents them to the user. It is developed by basing on general principles of LALR(1) grammar, which allows to determine the possible tokens that can be placeholders of the new language production. OASE-Editor Predictor is a generic component. Based on this component there is provided the OASE-Editor standalone application (see Figure 44). The standalone editor is a valuable tool for all involved stakeholders as it provides the means for a direct modification of OASE ontologies by using predictive editor, however to provide designer and programmer with more intuitive (and adapted to their needs) tools, we have invented another two OASE-Editors: OASE-Annotator and OASE-Diagrammer (described in the following subchapters).

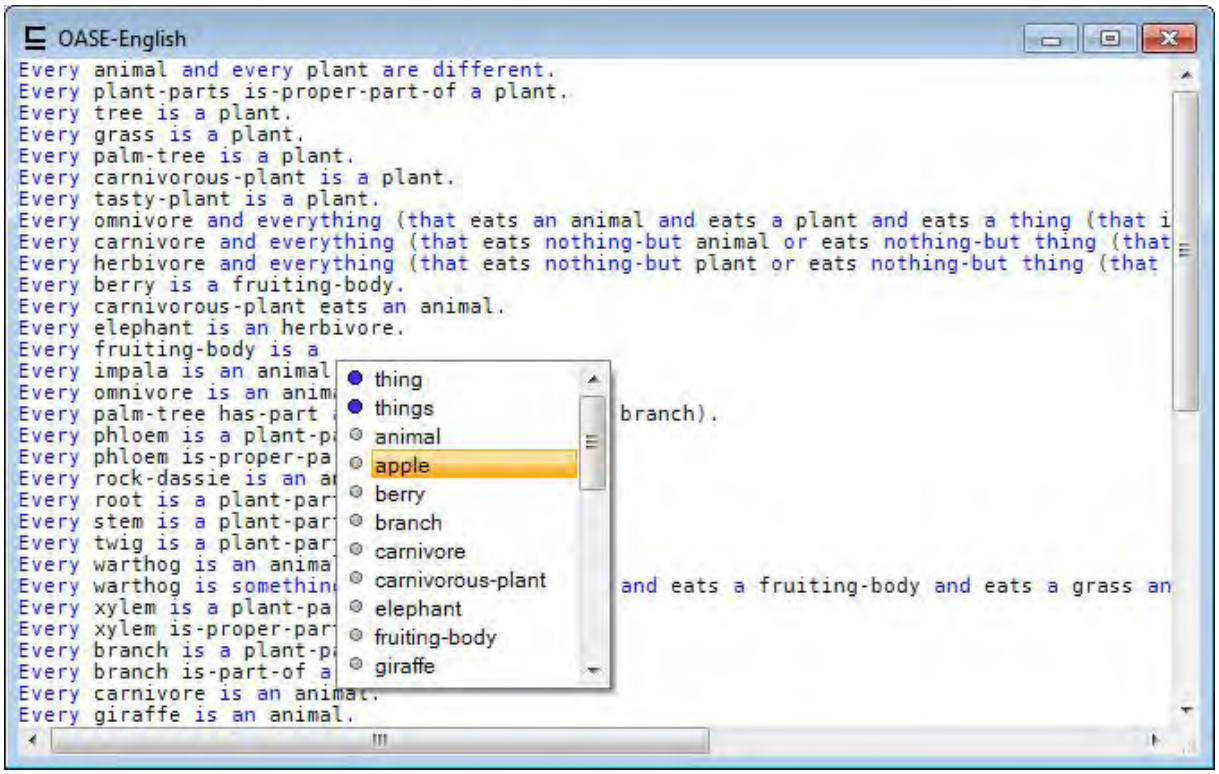


Figure 44. Standalone application of predictive editor for OASE-English based on OASE-English Predictor component

5.3 OASE-TRANSFORMATION PROCESSOR

The OASE-Transformation processor allows programmers and designers to deal with OASE without the need for any modification of their daily work habits. They still operate on objects in the form of its representation in either source code or UML diagrams as OASE-Transformation processor maps those two artifacts onto the OASE-English scripts. OASE-Transformation processor is based on StringTemplate [Parr06] Engine that produces scripts from Class-Descriptors w.r.t. given

OASE-Transformation (see Figure 45) and is actively used internally by the entire OASE toolkit.

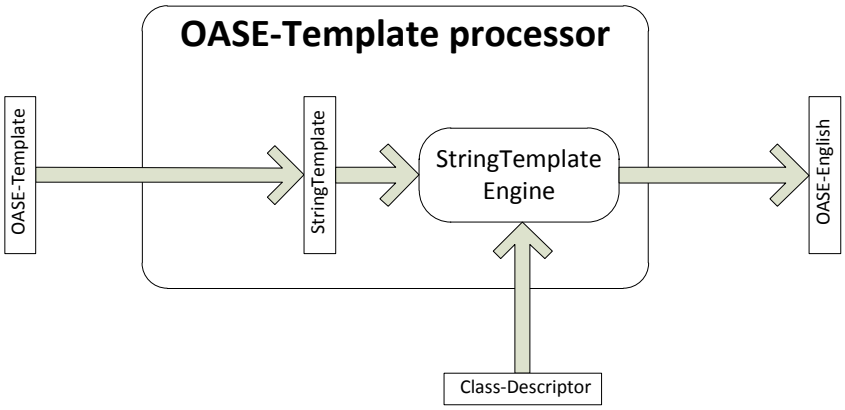


Figure 45. Architecture of OASE-Transformation processor

5.4 OASE-ANNOTATOR

OASE-Annotations and OASE-Assertions allow for the protection of the programmer from breaking the design-time or runtime assumptions and can be checked by the reasoning services (OWL-Processor) in terms of consistency and preservation of logical constraints. The OASE-Annotator supports editing of the OASE-Annotations. It is a MS Visual Studio IDE plugin (see Figure 46).

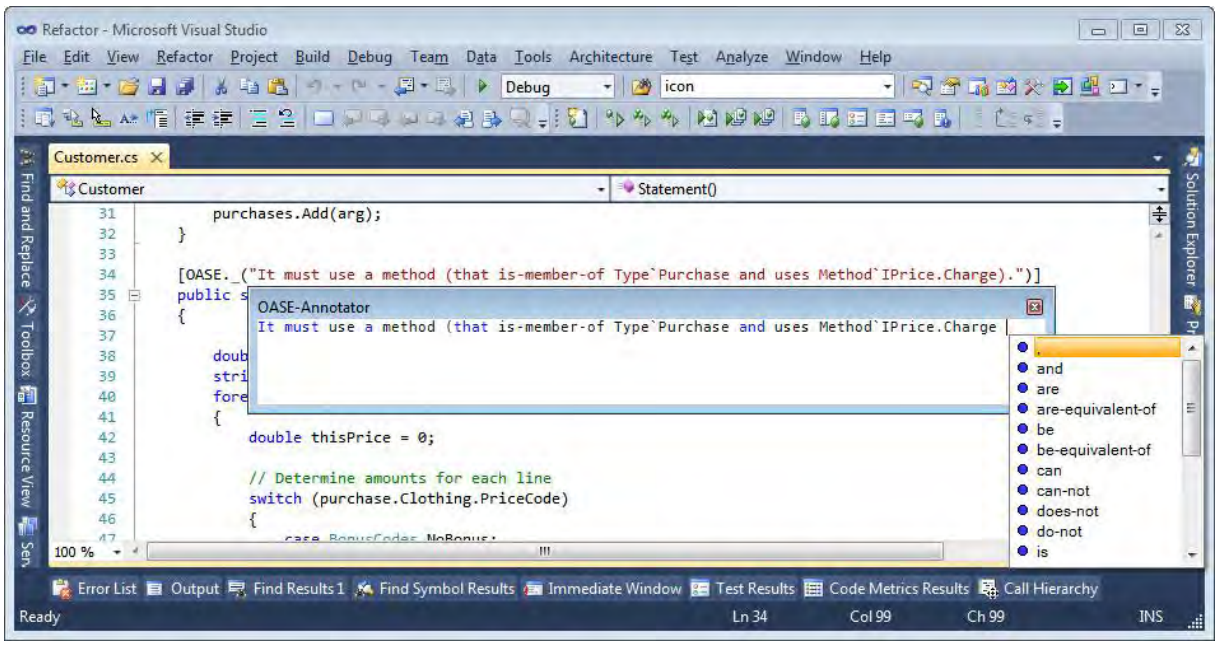


Figure 46. OASE-Annotator MS. Visual Studio plugin

When there is a need to edit the OASE-Annotation, the programmer places the caret on the annotation and then by pressing the combination of keys she invokes the OASE-Annotator. OASE-Annotator reuses the OASE-English Predictor

(see Figure 43) making it possible to take advantages of supporting hints during an edition of OASE-Annotation.

5.5 OASE-DIAGRAMMER

OASE-Diagrammer adds the ability to use the iconic language (UML), together with the OASE framework. OASE-Diagrammer is dual to OASE-Annotator. It allows to draw the UML representations of software entities and supports OASE-Annotations. OASE-Annotations can be placed here using UML Notes, which if attached correctly to the corresponding software entities, are equivalent to OASE-Annotations, entered by the programmer, that use OASE-Annotator described earlier. OASE-Diagrammer reuse the OASE-English Predictor (see Figure 43) therefore, during the edition of Notes, designer is supported with meaningful hints.

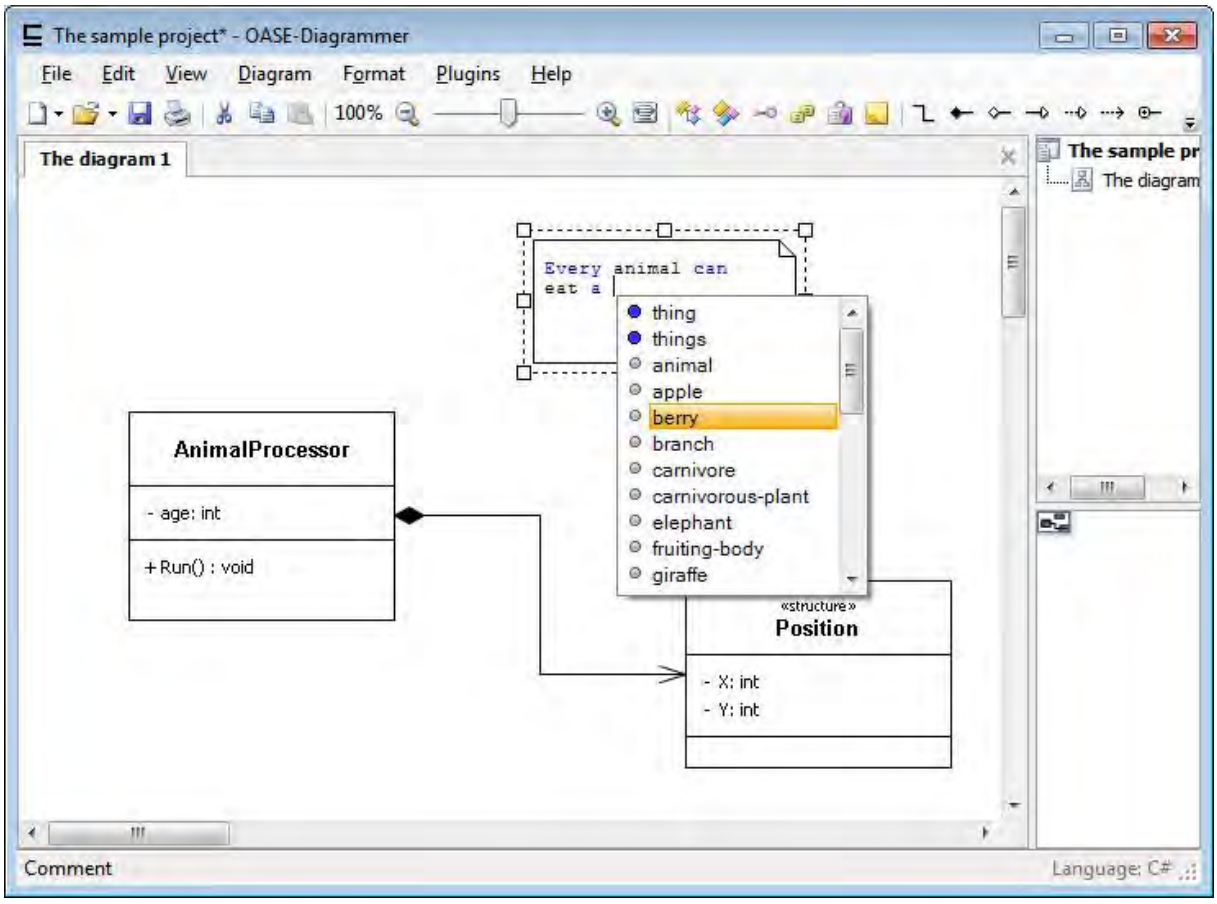


Figure 47. OASE-Diagrammer

6. OASE-TOOLS IN CUSTOM APPLICATIONS

Besides the support for software development, we have discovered that it is possible to use OASE-Tools, described in the previous chapter, in terms of components of practical software solutions. We have found two areas of interests that can be approached with the OASE-Tools. We call them: Inferred-UI and Self-Implemented Requirement. First aims to use the reasoner to generate MVC automatically. Second aims to use OASE-English predictive UI-Component together with the reasoning services, in order to provide the ability for the end-user to modify (by himself) the requirement she have earlier put on the software. They are presented in the following subchapters. The feasibility of the practical usage of both of them is proven by the implementation of Clinical Decision Support System described in details in Appendix 6.

6.1 INFERRED-UI

The Model-View-Controller (MVC) [Busc96] [Busc07b] architectural pattern is one of the most frequently used solutions in (among the others) internet services. It divides an application, concerning the three roles:

- A Model - that contains the core functionality and provides an access to the database.
- Views that display an information to a user.
- Controllers that control a user input.

Views and Controllers together form a User Interface (UI). A change-propagation mechanism ensures consistency between the UI and the Model (see Figure 48). The "naked objects" [Paws04] architectural pattern allows for automatic implementation of MVC by applying three principles:

1. Business logic is encapsulated by domain objects.

2. The user interface is a direct representation of the domain objects, with all user actions consisting, explicitly, of creating or retrieving domain objects and/or invoking methods on those objects.

3. The user interface is automatically created from the definition of the domain objects.

Inferred-UI discussed here, is an application of "naked objects" in the domain of ontology editors. It actively uses reasoning services. In other words: the Inferred-UI is a program that automatically generates the MVC-application, which fulfills a specification formed by a given ontology. The UI of the generated application allows a user to browse and modify the A-Box of its parental ontology. During the interactive activities that result in the A-Box modification, the generator adapts the current

state of the ontology to the MVC and updates its model. The final application arises as a product of the generator, which continuously reconstructs the application with a respect to the modified ontology.

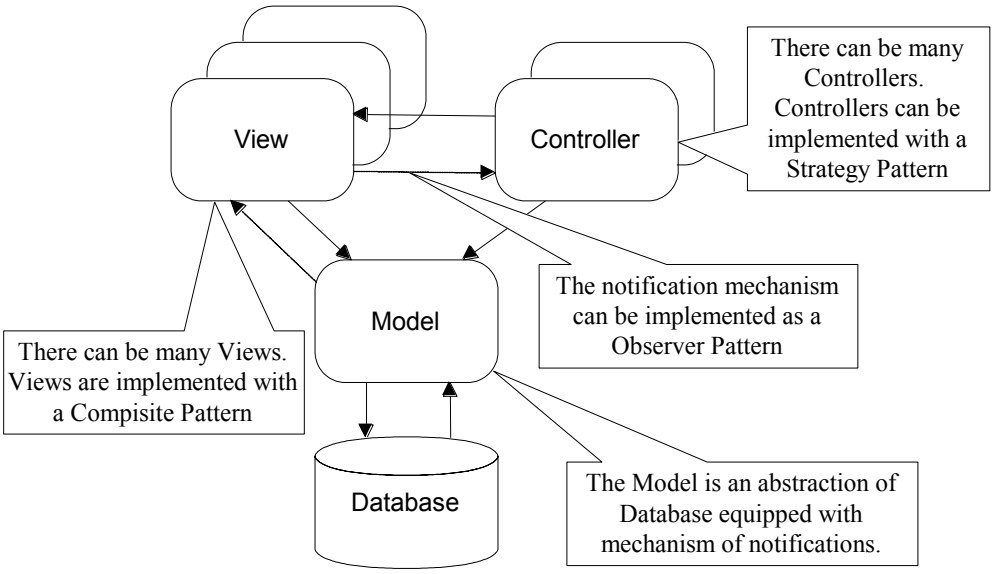


Figure 48. MVC architectural pattern

There are two main components of the Inferred-UI (see Figure 49): a generator and an application. The generator has a direct access to the knowledge base via the session object. The session therefore, maintains the ontology of interest. The reasoner manages the inferred knowledge and provides automated reasoning tasks. The heart of the system - the MVC Generator - uses the reasoner to build and/or update MVC Applications according to the knowledge inferred by the reasoner. The way in which the MVC Factory determines the whole UI, depends on the implementation and the UI framework, but a general algorithm can be described as well (see also Figure 50):

1) The algorithm assumes that the UI framework supports the MVC by providing a set of UI controls that can be bound to its models. In other words: each UI control is also an implementation of MVC. Supposing that the UI framework contains: panel control (control that can aggregate other UI controls), Combo Box control (control that allows selection), Text Box, Button, List etc. in order to build View/Controller MVC factory, the algorithm would go recursively from the top of the inferred ontology and place a Panel control for each subsumpion of concepts.
2) Each concept can then be examined whether its instances exist and those instances, if found, can be checked for the existence of relationships with other instances.
3) If such a relationship is discovered, then the algorithm can generate a Combo Box that allows to select any instance of the most specific concept (that the corresponding instance is an instance of).

4) The controller part of such an interface inserts or modifies the A-Box of the particular instance; both the concept-assertion and the role-assertion. The View and Controller in this scenario remain unchanged because DL is monotonic and new assertions do not have an impact on the overall ontology but add the new knowledge to the OMS.
5) The T-Box can be modified by other application (i.e. the application for experts) and such modification will invalidate the View and Controller and therefore will trigger the full UI generation process. Information derived from the reasoner, can be submitted back from the Inferred-UI to the expert, for a review or analysis to let him fully understand the semantic implications of asserted knowledge.

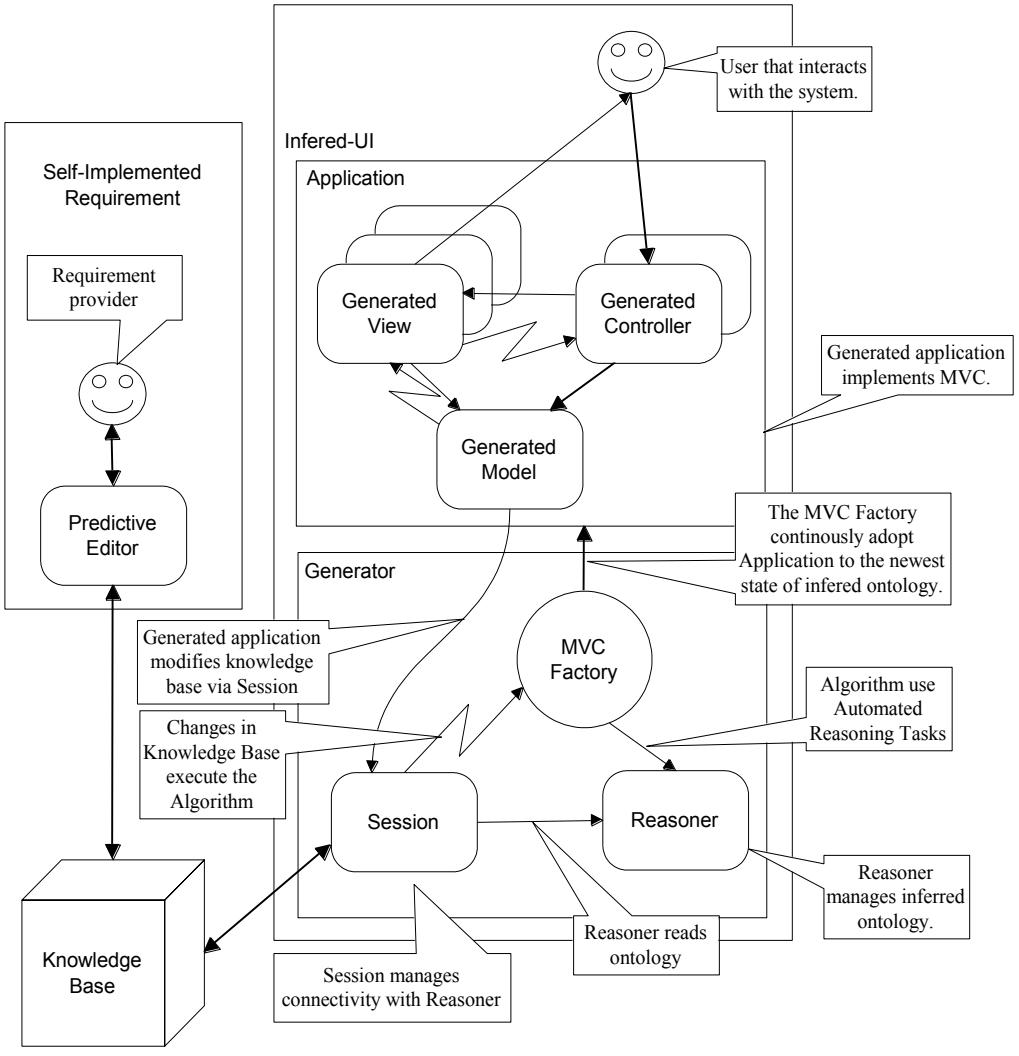


Figure 49. Architecture of Inferred-UI Pattern Application

Inferred-UI application uses DL reasoning services intensively and can activate other custom application functionalities. The reasoner is in this case a standard component of the application that uses Inferred-UI.

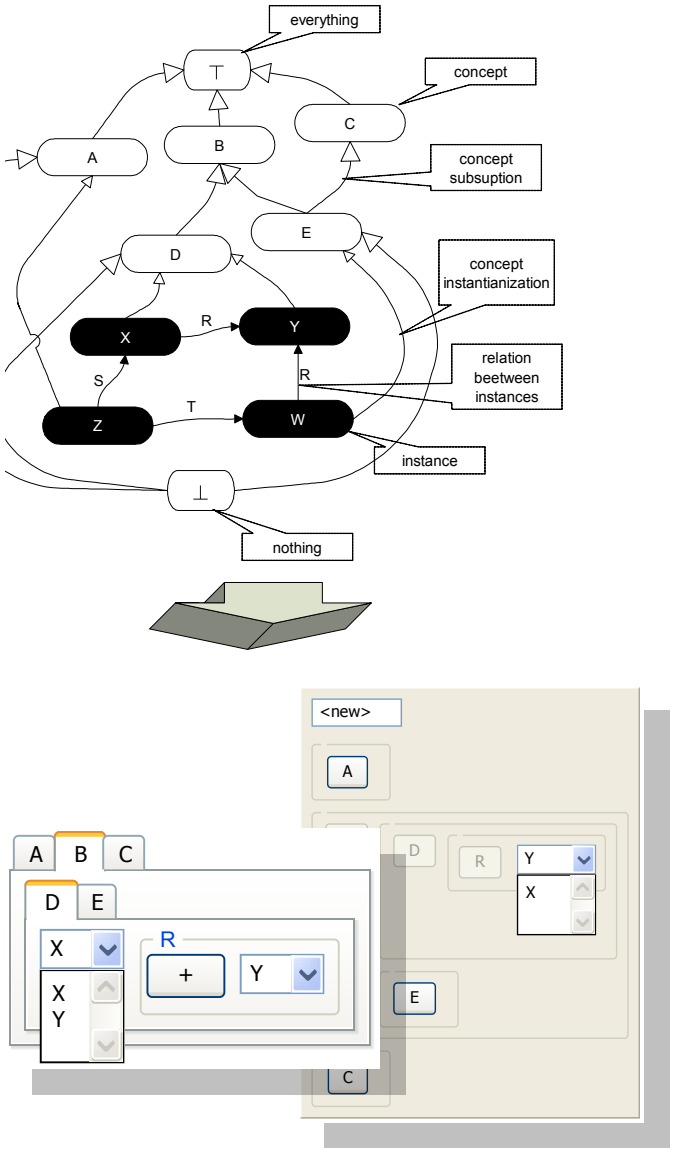


Figure 50. Ontology and generated View-Controller.

6.2 SELF-IMPLEMENTED REQUIREMENT

The ability to change and trace the requirements of the software system, typically results in the involvement of a designer, programmer and requirement-engineer. The possibility to build the system in the way that gives the end-user possibility of changing and validating the requirements “in-vivo” (of the running system) will reduce the overall cost of the software system. Self-Implemented Requirement is a software solution that follows this observation.

When combined with Inferred-UI, it is possible to build sophisticated application that exhibits to the end user a part of system requirements. Inferred-UI allows for a modification of the World-Description (A-Box) of the system directly. The ability of

changing the Terminology part (T-Box) of a knowledge base (see Figure 51) given to the end-user, can be implemented by using Self-Implemented requirement.

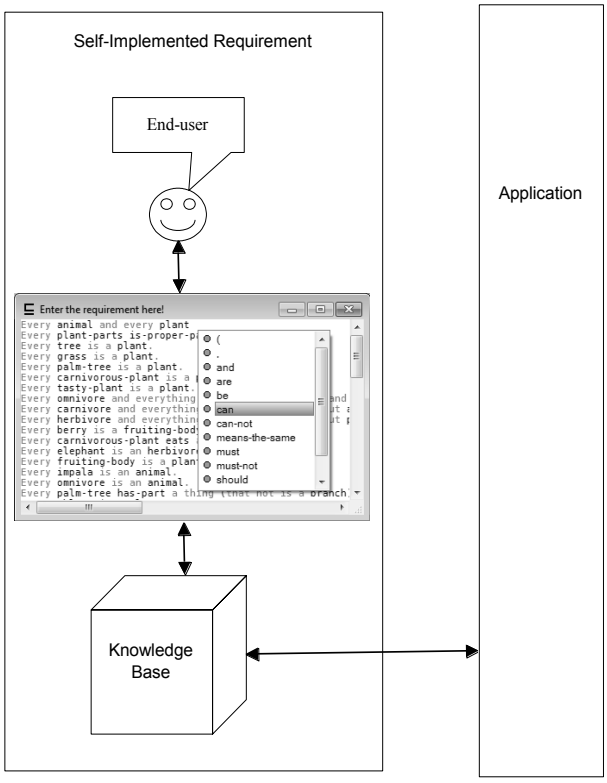


Figure 51. Self-Implemented Requirement

6.2.1 RELATED ONTOLOGY EDITORS

Protégé[43] allows editing ontology and inspecting the inferred knowledge [Muse10]. Both Protégé and Inferred-UI allow editing an A-Box via an automatically generated UI. However, the main difference between the Inferred-UI and Protégé lies in the means of user's interaction with the system. While Protégé generates a UI for an A-Box, basing on the asserted ontology, the Inferred UI Pattern does it by using the reasoner. User interactions force the reasoner to classify new facts and inferred (and only inferred) knowledge which is used to build a UI or display a message to a user.

[43] http://protege.stanford.edu/

7. SUMMARY

7.1 RESULTS OF THE THESIS

By this thesis, we tried to prove that the Knowledge Representation and Reasoning (KRR) is applicable in the area of software development. We focused on the modern offspring of KRR, namely Description Logic (DL), and we have shown that its expressiveness is sufficient to build the bridge between the world of formal specification and the particular sub-world of software development which we recognized as a world of static software structures. To complete the bridge we invented OASE-English – a Controlled Natural Language (CNL) that verbalizes the DL. Moreover, we found out that the software development process can be represented in terms of a formal semiotic system that fulfills the laws of semiotics and allows interpreting the semantics of signs in a formal way. OASE (Ontology-Aided Software Engineering) is the name for the proposed formal semiotic system that we have introduced.

A) We have created the Proposal for Natural Kernel Language in terms of Kernel Language requested by SEMAT [Jaco12], but that has a representation in natural language. Our Natural Kernel Language supports five principal applications:

1) ***Describing universals: practices and patterns that are the building blocks and the composition mechanisms for building methods out of these elements***. OASE allows for description of practices and patterns (we have evaluated its usability within the survey (see Appendix 4)) by allowing for the description of both of them in the OASE-English. We have shown that an object-oriented program forms a world description (A-Box) that is built on top of a specific terminology (T-Box). The terminology is a formal representation of object-oriented design ontology (that consists of general rules that rule the world of object-oriented programming e.g., polymorphism and encapsulation). The requirements (e.g., use of design patterns, architectural limitations, use of generic structures, etc.) can then be considered as Integrity Constraints in terms of OASE-English pseudo-modal expression, and therefore we can say that within the OASE method the architecture and design patterns are becoming clear in terms of both terminology and semantics. The other field of the usage of OASE-English is a human-machine interface between the software system and developers. The system can specify the errors that occur in the middle of programmers' work by using OASE-English to interact with the engineers who can fix the problems found by the system itself (with the full support of natural language). This task is supported by OASE-Annotations (see chapter 4.14) and OASE-Assertions (see chapter 4.15) which have a form of formal comments and contracts (respectively) written in OASE-English within the source code itself.

2) ***Simulating software systems.*** OASE allows for the simulation of software systems in terms of their static structure; therefore, we can say that OASE-English is a Kernel Language for the static structure of the software (see Chapter 4).
3) ***Closing the communication gap between stakeholders involved in software development process.*** By carrying out an experiment on a group of programmers (see Appendix 5), we have proved that this statement is suitable for OASE. They felt like OASE-Validator was leading them by the hand, or they were simply solving the puzzle-like problem. Moreover, we applied OASE-Tools in the pilot implementation of a clinical decision support system (CDSS). The properties that are useful for stakeholders involved in a software development process (e.g.: a human-machine interface in controlled natural language, automatic explanations, or decidability of a knowledge base) are also valuable in the medical treatment.
4) ***Method elements are useful outside the area of their origin.*** We have shown that OASE is applicable in other areas – solely outside the software development process, which we have proven with a feasibility study, we performed on the application of the Clinical Practice Guideline (see Appendix 6) for lung cancer staging. OASE-Tools can be used separately, within a wide range of applications, as ordinal yet powerful software components.
5) ***Allowing for addition or modification of practices, patterns and possibly composition techniques.*** This is true for OASE. OASE-English allows for building extensible domain descriptions – domain-specific ontologies (see Chapter 4).

B) OASE-English is understandable for people and can be automatically processed by machines. It can also be used in many areas of software development, where natural language is currently used, because of the pragmatic problems. We have proven this within the implementation of a CDSS, especially by providing the Self-Implemented Requirement (see Chapter 6.2) implementation as part of the CDSS.

C) The language is formal. It can be processed by the $\mathcal{SROIQ}$ Description Logic reasoners and therefore allows its users to take a benefit from the implicit knowledge. The reasoner aids the stakeholders in their daily work. We implemented OASE-Tools (see Chapter 0): the computer (by using DL reasoning services) automatically maintains the overall knowledge base and communicates to all the stakeholders if any inconsistencies are found. This is done via OASE-English that is embedded either into a programming language (by using annotations) or into a UML (in the form of UML notes).

7.2 CONTRIBUTION TO THE FIELD

The main contribution of this thesis may be summarized as follows:

1) *Review of current state of the art in the field of formal semiotic systems with special focus on computational semantics, and ontology engineering.* We take a closer look at the knowledge representation and reasoning with a special focus on description logic (DL), its properties and algorithms that are used to deal therewith. We also discuss an emerging area that bridges the computational semantics with software development, namely a semiotics of software artifacts.
2) *Chronological review of methods and tools used in the software development process.* Starting from a classification of programming languages and approaches that aim to formalize them, we discuss approaches that allow to deal with complex software systems. We discuss computability and complexity of software structures. Moreover, we discuss the differences between engineered and agile software methodologies. Finally, we discuss the language of software patterns as an example of a software-oriented semiotic system.
3) *Definition of the ontology aided software development process that is an extension of software engineering.* We call it Ontology-Aided Software Engineering (OASE) as it gives the possibility of dealing with artifacts that appear within the software development process in means of knowledge engineering and tools. OASE pretends to be a formal semiotic system focused on the field of object-oriented software development.
4) *Definition of OASE-English.* OASE-English is a verbalization of DL intended to deal with software design. We provide the mapping between OASE-English and Description Logic.
5) *Definition of OASE-Transformations which bridge the world of software design with the OASE.* We provide OASE-Transformations that convert the object-oriented source code into OASE-English script. Moreover, we present examples showing that OASE-Transformation can be used as a language for formal specification of design patterns.
6) *Development of general-purpose tools and components that support OASE-English-oriented activities*.
    a. OASE-Validator – a general purpose tool that provides communication with reasoning services in OASE-English. It takes speciation and returns to the user explanations of validation results.
    b. OASE-English Predictor – a general purpose predictive editor for OASE-English.
    c. OASE-Transformation Processor – a general purpose tool (based on StringTemplate engine) that transforms any enumerable input and produces an OASE-English script. It allows programmers and designers to deal with OASE without the need for any modification of their

daily work habits. They still operate on representations of objects via manipulation of either a source code or UML diagrams. OASE-Transformation processor maps those two artifacts onto OASE-English scripts.

7) *Development of a Clinical Decision Support System – a custom application of OASE-Tools.* We present two ideas: Inferred UI – a way to automatically generate a UI from ontology and a Self-Implemented requirement – a way to reduce the cost of change in terms of business requirements. We built a CDSS that implements these solutions. Therefore, we have proven that OASE-Tools are not only directed to support and extend the software engineering process but that they have a large spectrum of practical applications.
8) *Definition of OASE-Annotations – enrichment of programming that makes use of formal annotations verbalized in OASE-English.* OASE-Annotations are checked by the OASE-Validator – the tool that performs reasoning tasks.
9) *Definition of OASE-Assertions – enrichment of programming that makes use of formal assertions verbalized in OASE-English.* Verification of OASE-Assertions is performed in runtime by the OASE-Validator.
10) *Development of OASE-oriented tools*.
    a. OASE-Annotator – OASE-oriented, MS Visual Studio IDE plugin that allows programmers for manipulating OASE-Assertions and OASE-Annotations directly from IDE.
    b. OASE-Diagrammer – OASE-oriented tool that provides the ability to use the iconic language (UML), together with the OASE framework. It equips the designer with a UML tool that supports OASE-Annotations. OASE-Annotations are placed here in the form of UML Notes.
11) *Evaluation of OASE.* We carried out a survey and a validation experiment. The survey was prepared to acquire the necessary information about the OASE method and validate some crucial assumptions taken for OASE. The usability of OASE was validated within the experiment.
12) *Creating the Web-page [www.oase-tools.net] for OASE*. It is an entry point for the community interested in OASE.

7.3 FUTURE WORK

One can consider modern software-intensive systems as made of three kinds of participants: software, hardware and people. While communication between software and hardware is realized by a computer code, a programming language bridges software components with people. It is worth to make a detailed research on aspects of a dialog between a human and a machine when OASE-English is used. It is especially important to provide a new version of the language.

From the pragmatic perspective, the OASE-Tools demand some further development in terms of the full integration with the daily work of programmers and designers. Moreover, we expect to find more potential applications of OASE-Tools,

that can be used as standard software components. Special care needs to be taken of pseudo-modal expressions. We discovered that their meaning is ambiguous for programmers (see Appendix 4).

The computability limitations that are caused by the core properties of description logic constitute another direction of the future work that needs to be done. We expect that the usage of reasoners with polynomial complexity (like that for $\mathcal{EL}$++ DL) and set heuristic-based cartographic algorithms (see Chapter 2.7.3) can provide an efficient implementation of OASE-Validator for source codes of very large software systems. Nevertheless, some further studies in this area are need to be done.

Appendix 1. MAPPING BETWEEN OASE-ENGLISH AND DL

OASE-English grammar that allows describing the $\mathcal{SROIQ}$ DL statements in terms of natural language is presented below in EBNF form:

<*paragraph*> ::= {<*sentence*> '**.**'}

<*sentence*> ::= <*subject*>[<*modalWord*>] {'**equivalent-of**'} <*objectRoleExpression*>
| '**if**' '**X**' <*roleChain*> '**Y**' '**then**' '**X**' <*role*> '**Y**'
| '**if**' '**X**' <*roleChain*> '**Y**' '**then**' '**Y**' <*role*> '**X**'
| <*subject*> '**and**' <*subject*> '**means-the-same**'
| '**X**' <*role*> '**Y**' '**and**' '**X**' <*role*> '**Y**' '**means-the-same**'
| '**X**' <*role*> '**Y**' '**and**' '**Y**' <*role*> '**X**' '**means-the-same**'

<*subject*> ::= ('**every**'|'**no**') <*single*> | '**everything**' [<*that*>] | <*instance*>| '**nothing**'

<*modalWord*> ::= ['**must**'|'**should**']

<*objectRoleExpression*> ::= [{'**not**'}] (('**is**'|'**be**'|'**are**') <*object*>| <*role*> <*objectRestriction*>)

<*roleChain*> ::= <*role*> [{'**something**' '**that**' <*role*>}]

<*role*> ::= <id> | ('**is**'|'**be**'|'**are**') <id> '**by**'

<*instance*> ::= <bigid>

<*object*> ::= ['**a**'|'**an**'] <*single*> | '**something**' [<*that*>] | <*instance*> | '**nothing**'

<*objectRestriction*> ::= <*object*>
| ('**nothing-but**'|<*comparer*><*count*>) (<*single*>|<*instance*>|'**something**' <*that*>
| '**none**'
| '**itself**'

<*single*> ::= <id> [<*that*>] | '**thing**' | '**things**'

<*that*> ::= '**that**' <*objectRoleExpressionIntersectionUnion*>
| '**(**' '**that**' <*objectRoleExpressionIntersectionUnion*> '**)**'
| '**(**' '**that-is-one-of:**' <*instance*> {',' <*instance*>} '**)**'

<*objectRoleExpressionIntersection*> ::= <*objectRoleExpression*> [{'**and**' <*objectRoleExpression*>}]

<*objectRoleExpressionIntersectionUnion*>::=<*objectRoleExpressionIntersection*> [{'**or**' <*objectRoleExpressionIntersection*>}]

<*comparer*> ::= ['**at-most**'|'**at-least**'|'**less-than**'|'**more-than**'|'**different-than**']

<*count*> ::= ('**no**'| '**single**' |'**two**' |'**three**' |...|'**ten**') | <num>

<bigname> ::= <upperl><lowerl>*('-'((<upperl><lowerl>*)|(<digt>+)))*

<entityid> ::= '**[**' <anyid> '**]**'

<name> ::= <lowerl>+('-'((<lowerl>+)|(<digit>+)))*

<anyid> ::= (<upperl>|<lowerl>)(<upperl>|<lowerl>|'-')*

<terms> ::= '**[**' '**in-terms-of**' <anyid> '**]**'

<bigid> ::= (('**The-thing-called**' <anyid>)|<bigname>)<terms>?|<entityid>

<id> :: = <name><terms>?

<num> ::= <digit>+

<upperl> ::= [**A**-**Z**]

<lowerl> ::= [**a**-**z**]

<digit> ::= [**0**-**9**]

Appendix 2. OASE-TRANSFORMATIONS FOR OASE-MAPPING

The main StringTemplate which allows for a conversion between the Class-Descriptor and OASE-English is presented below:

```
group Mapping;

global() ::= <<
If X is-subtype-of something that is-subtype-of Y then X is-subtype-of Y.
X is-subtype-of Y and Y is-supertype-of X means-the-same.

If X is-instance-of Y then Y is-type-of X.
If X is-instance-of something that is-subtype-of Y then Y is-type-of X.
X is-type-of Y and Y has-type-that-is X means-the-same.
X is-instance-of Y and Y has-instance-that-is X means-the-same.

If X is-subtype-of something that has-member-that-is Y then X has-member-that-is Y.
X is-member-of Y and Y has-member-that-is X means-the-same.

If X has-member-that-is Y then X is-part-of Y.
If X has-member-that-is something that is-part-of Y then X is-part-of Y.

If X calls something that calls Y then X calls Y.
If X creates something that is constructed by Y then X calls Y.

If X is implemented by something that calls something that implements Y then X uses-directly Y.

If X is-type-of something that has-member-that-is something that has-type-that-is Y then X uses-directly Y.
If X is-type-of something that is constructed by something that creates something that has-type-that-is Y then X uses-directly Y.

If X is implemented by something that gets something that fills Y then X reads Y.
If X is implemented by something that gets something that has-type-that-is Y then X reads Y.
If X is implemented by something that calls something that gets something that fills Y then X reads Y.
If X is implemented by something that sets something that fills Y then X writes Y.
If X is implemented by something that calls something that sets something that fills Y then X writes Y.

If X reads Y then X uses-directly Y.
```

```
If X writes Y then X uses-directly Y.
If X uses-directly Y then X uses Y.
If X uses something that uses Y then X uses Y.

Every class and every attribute and every signature and every constructor and every method and
every function and every object are different.
Everything that is-removed-from The-Design-Of-The-Program is nothing.
>>

mapType(class) ::= <<

[<class.className>] is a class.
<class.baseFullNames:{baseFullName |
        [<baseFullName>] is a class.
        [<class.className>] is-subtype-of [<baseFullName>] .
}>

<class.fields:{field |
        [<class.className>.<field.name>] is an attribute.
        [<class.className>.<field.name>] is-member-of [<class.className>] .
        [<class.className>.<field.name>] is-placeholder-for [<field.typeDesc.className>] .

        [.<field.name>] is a signature.
        Everything (that is identified by [.<field.name>] and is-member-of [<class.className>])
is-equivalent-of [<class.className>.<field.name>] .

        Everything (that fills [<class.className>.<field.name>]) has-type-that-is
[<field.typeDesc.className>] .

        Everything (that is-instance-of [<class.className>]) has-member-that-is an object (that
fills [<class.className>.<field.name>]).
}>

<first(class.constructors):{constructor |
        [<class.className>.~ctor] is a constructor.
        Everything (that constructs object (that is-instance-of [<class.className>])) is-equivalent-
of [<class.className>.~ctor] .
}>

<class.constructors:{constructor |
        [<class.className>.~ctor.<constructor.id>.~impl] is a function.
        [<class.className>.~ctor.<constructor.id>.~impl] implements [<class.className>.~ctor]
.
        Everything (that is-instance-of [<class.className>]) has-member-that-is
[<class.className>.~ctor.<constructor.id>.~impl] .

        <constructor.parameters :{param |
                [<class.className>.~ctor.<constructor.id>.~impl] takes object (that has-type-
that-is [<param.typeDesc.className>]).
                [<class.className>.~ctor.<constructor.id>.~impl] gets an object (that has-type-
that-is [<param.typeDesc.className>]).
        }>
```

```
	<constructor.calls:{call |
		[<class.className>.~ctor.<constructor.id>.~impl] calls a function (that implements [<call.typeDesc.className>.<call.name>]).
	}>
	<constructor.creates:{create |
		[<class.className>.~ctor.<constructor.id>.~impl] creates an object (that has-type-that-is [<create.className>]).
	}>
	<constructor.gets:{get |
		[<class.className>.~ctor.<constructor.id>.~impl] gets an object (that fills [<get.typeDesc.className>.<get.name>]).
	}>
	<constructor.sets:{set |
		[<class.className>.~ctor.<constructor.id>.~impl] sets an object (that fills [<set.typeDesc.className>.<set.name>]).
	}>
}>
<class.methods:{method |
	[<class.className>.<method.name>] is a method.
	[<class.className>.<method.name>] is-member-of [<class.className>] .

	[.<method.name>] is a signature.
	Everything (that is identified by [.<method.name>] and is-member-of [<class.className>]) is-equivalent-of [<class.className>.<method.name>] .

	Everything (that implements [<class.className>.<method.name>]) returns nothing-but object
	(that has-type-that-is [<method.returnTypeDesc.className>]).

	<first(method.parameters) :{param |
		Everything (that implements [<class.className>.<method.name>]) takes nothing-but object (that is something
		(that has-type-that-is [<param.typeDesc.className>])
		}>
	<rest(method.parameters) :{param |
		or is something (that has-type-that-is [<param.typeDesc.className>])
		}>
	<first(method.parameters) :{param |
		).
		}>

	[<class.className>.<method.name>.<method.id>.~impl] is a function.
	[<class.className>.<method.name>.<method.id>.~impl] implements [<class.className>.<method.name>] .
	Everything (that is-instance-of [<class.className>]) has-member-that-is [<class.className>.<method.name>.<method.id>.~impl] .

	[<class.className>.<method.name>] returns an object (that has-type-that-is [<method.returnTypeDesc.className>]).

	<method.parameters :{param |
```

```
		[<class.className>.<method.name>.<method.id>.~impl] takes object (that has-type-that-is [<param.typeDesc.className>]).
		[<class.className>.<method.name>.<method.id>.~impl] gets an object (that has-type-that-is [<param.typeDesc.className>]).
	}>
	<method.calls:{call |
		[<class.className>.<method.name>.<method.id>.~impl] calls a function (that implements [<call.typeDesc.className>.<call.name>]).
	}>
	<method.creates:{create |
		[<class.className>.<method.name>.<method.id>.~impl] creates an object (that has-type-that-is [<create.className>]).
	}>
	<method.gets:{get |
		[<class.className>.<method.name>.<method.id>.~impl] gets an object (that fills [<get.typeDesc.className>.<get.name>]).
	}>
	<method.sets:{set |
		[<class.className>.<method.name>.<method.id>.~impl] sets an object (that fills [<set.typeDesc.className>.<set.name>]).
	}>
}>
<if(class.isAbstract)>
[<class.className>] has-instance-that-is none.
<endif>
<if(class.isFinal)>
[<class.className>] is-supertype-of none.
<endif>
>>
```

To understand in what way the StringTemplate processes the enumerable input (here it is a class-descriptor), the reader is recommended to do a further reading about it on the StringTemplate webpage[44].

[44] http://www.stringtemplate.org/

Appendix 3. OASE-Transformation For Adapter Design Pattern

In Figure 52 adapter design pattern is presented. It is realized by the net of class-descriptors for: client, target, adapter and adaptee. Those class-descriptors are connected with the generalization and calls (besides its name, each class, has a number of methods that calls or can be called by other methods). All class-descriptors have to be labeled with a unique patternID, as design patterns can interfere with each other (the same class can potentially have multiple labels with different patternIDs).

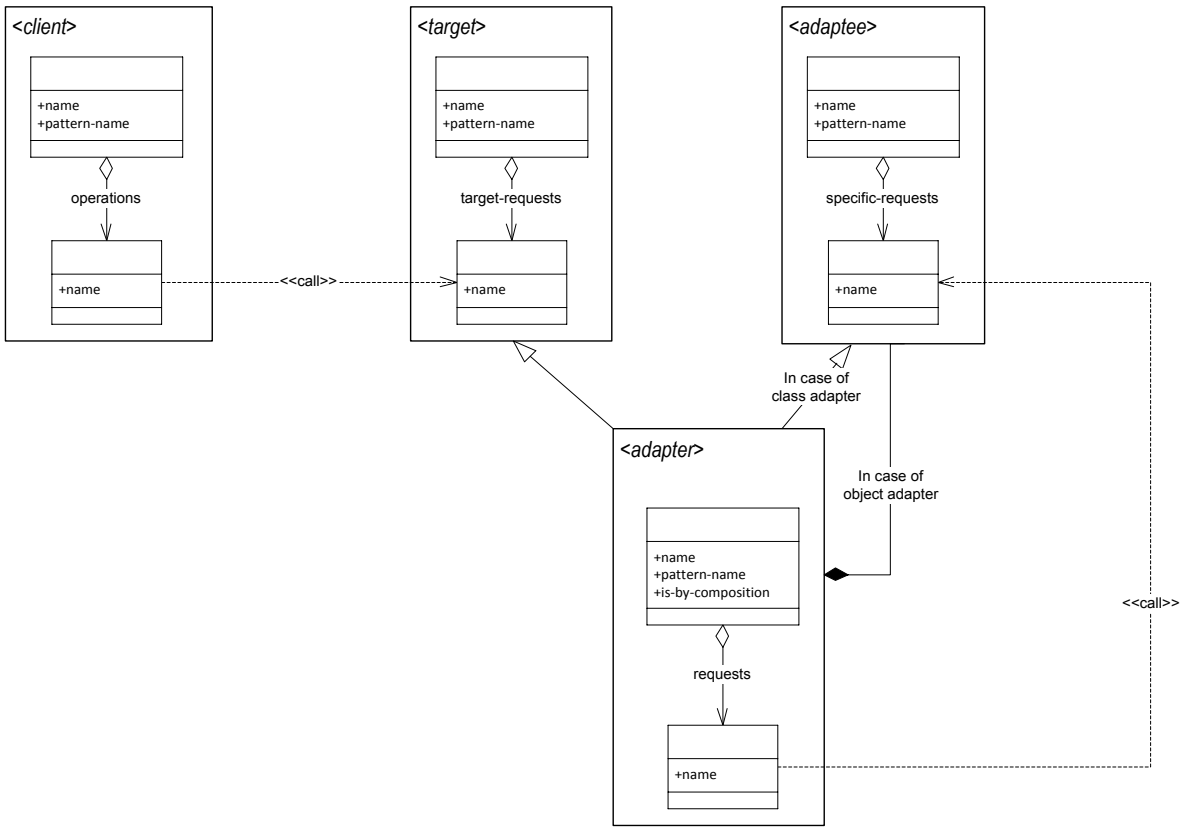


Figure 52. Adapter design pattern as a wood of symbols

The class descriptors allow to represent adapter design pattern as a set of four OASE-Transformations (one for each: adapter, target, client and adaptee). Each script directly correspond to the given class descriptor (see Figure 53). Those OASE-Transformations if combined with class-descriptors produce the ontology of adapter design pattern.

```
group GOF_Adapter;

adapter(patternID,className,requests) ::= <<

        [<className>] must be a class.
        [<className>] must be-subtype-of a target-of-<patternID>.

        One-and-only adapter-of-<patternID> is [<className>].

        <requests:{methodName |
                [<className>.<methodName>.~impl] must be a function.
                [<className>.<methodName>.~impl] is an adapter-request-of-<patternID>.
        }>

        Every adapter-request-of-<patternID> should call a function (that implements an
adaptee-specific-request-of-<patternID>).
>>

target(patternID,className,targetRequests) ::= <<

        [<className>] must be a class.
        [<className>] must have-instance-that-is none.

        One-and-only target-of-<patternID> is [<className>].

        <targetRequests:{methodName |
                [<className>.<methodName>] must be a method.
                [<className>.<methodName>] is an target-request-of-<patternID>.
        }>

>>

adaptee(patternID,className,specificRequests) ::= <<
```

```
        [<className>] must be a class.

        One-and-only adaptee-of-<patternID> is [<className>].

        <specificRequests:{methodName |
                [<className>.<methodName>] must be a method.
                [<className>.<methodName>] is an adaptee-specific-request-of-<patternID>.
        }>

>>

adapterClient(patternID,className,operations) ::= <<

        [<className>] must be a class.

        [<className>] is an adapter-client-of-<patternID>.

        <operations:{methodName |
                [<className>.<methodName>.~impl] must be a function.
                [<className>.<methodName>.~impl] is an client-operation-of-<patternID>.
        }>

        Every client-operation-of-<patternID> should call a function (that implements a target-
request-of-<patternID>).
>>
```

Figure 53. OASE-Transformations for Adapter Design Pattern

There are four OASE-Transformations. Each corresponds to one class descriptor and finally to one of the components of adapter design pattern. They are processed by the OASE kernel in the matter that takes advantage of reflexion and semantic annotations (see Figure 54)

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using System.Diagnostics;
using Antlr3.ST;
using System.IO;


namespace OASE.GOF
{
    [Ignore]
    static class AdapterLoader
    {
```

```
        public static StringTemplateGroup STG = new StringTemplateGroup(new StreamRead-
er(System.Reflection.Assembly.GetExecutingAssembly().GetManifestResourceStream("OASE.GOF.A
dapter.stg")));
    }

    [Ignore]
    public enum ClassCombinationKind { Unknown, Inheritance, Composition };

    [Ignore]
    [AttributeUsage(AttributeTargets.Class, Inherited = false)]
    public class Adapter : SemanticAttribute
    {
        [Ignore]
        [AttributeUsage(AttributeTargets.Method)]
        public class Request : TagAttribute
        {
            public string PatternID;
        }

        public string PatternID;

        public override string GetSemantic(object o, Mapping mapping)
        {

            var ST = AdapterLoader.STG.GetInstanceOf("adapter");
            var type = (o as System.Type);

            ST.SetAttribute("className", type.FullName);
            ST.SetAttribute("patternID", PatternID);

            var requests = new List<string>();
            var methods = type.GetMethods();
            int i = 0;
            foreach (var method in methods)
            {
                var reqs=from r in meth-
od.GetCustomAttributes(typeof(OASE.GOF.Adapter.Request), true) where (r as
OASE.GOF.Adapter.Request).PatternID==PatternID select r;
                if (reqs.Count() > 0)
                    requests.Add(method.Name+"."+i.ToString());
                i++;
            }

            ST.SetAttribute("requests", requests);
            var vvv = ST.ToString();
            return ST.ToString();
        }
    }


    [Ignore]
    [AttributeUsage(AttributeTargets.Interface, Inherited = false, AllowMultiple = true)]
    public class Target : SemanticAttribute
    {
        [Ignore]
        [AttributeUsage(AttributeTargets.Method,AllowMultiple = true)]
        public class Request : TagAttribute
        {
            public string PatternID;
        }

        public string PatternID;
        public override string GetSemantic(object o, Mapping mapping)
        {
            var ST = AdapterLoader.STG.GetInstanceOf("target");

            var type = (o as System.Type);

            ST.SetAttribute("className", type.FullName);
            ST.SetAttribute("patternID", PatternID);

            var requests = new List<string>();
            var methods = type.GetMethods();
            int i = 0;
            foreach (var method in methods)
            {
```

```
                var reqs = from r in meth-
od.GetCustomAttributes(typeof(OASE.GOF.Target.Request), true) where (r as
OASE.GOF.Target.Request).PatternID == PatternID select r;
                if (reqs.Count() > 0)
                    requests.Add(method.Name);
                i++;
            }

            ST.SetAttribute("targetRequests", requests);

            return ST.ToString();
        }
    }

    [Ignore]
    [AttributeUsage(AttributeTargets.Class, Inherited = false, AllowMultiple = true)]
    public class Adaptee : SemanticAttribute
    {
        [Ignore]
        [AttributeUsage(AttributeTargets.Method, AllowMultiple = true)]
        public class SpecificRequest : TagAttribute
        {
            public string PatternID;
        }

        public string PatternID;
        public override string GetSemantic(object o, Mapping mapping)
        {
            var ST = AdapterLoader.STG.GetInstanceOf("adaptee");
            var type = (o as System.Type);

            ST.SetAttribute("className", type.FullName);
            ST.SetAttribute("patternID", PatternID);

            var requests = new List<string>();
            var methods = type.GetMethods();
            int i = 0;
            foreach (var method in methods)
            {
                var reqs = from r in meth-
od.GetCustomAttributes(typeof(OASE.GOF.Adaptee.SpecificRequest), true) where (r as
OASE.GOF.Adaptee.SpecificRequest).PatternID == PatternID select r;
                if (reqs.Count() > 0)
                    requests.Add(method.Name);
                i++;
            }

            ST.SetAttribute("specificRequests", requests);

            return ST.ToString();
        }
    }

    [Ignore]
    [AttributeUsage(AttributeTargets.Class, Inherited = false, AllowMultiple = true)]
    public class AdapterClient : SemanticAttribute
    {
        [Ignore]
        [AttributeUsage(AttributeTargets.Method,AllowMultiple = true)]
        public class Operation : TagAttribute
        {
            public string PatternID;
        }

        public string PatternID;

        public override string GetSemantic(object o, Mapping mapping)
        {
            var ST = AdapterLoader.STG.GetInstanceOf("adapterClient");

            var type = (o as System.Type);

            ST.SetAttribute("className", type.FullName);
            ST.SetAttribute("patternID", PatternID);

            var requests = new List<string>();
            var methods = type.GetMethods();
```

```
            int i = 0;
            foreach (var method in methods)
            {
                var reqs = from r in meth-
od.GetCustomAttributes(typeof(OASE.GOF.AdapterClient.Operation), true) where (r as
OASE.GOF.AdapterClient.Operation).PatternID == PatternID select r;
                if (reqs.Count() > 0)
                    requests.Add(method.Name + "." + i.ToString());
                i++;
            }

            ST.SetAttribute("operations", requests);

            return ST.ToString();
        }
    }
}
```

Figure 54. The source code for adapter

Usability issues of this approach were evaluated within the survey (see Appendix 4).

Appendix 4. THE SURVEY

The survey was prepared to acquire the necessary information about the OASE method and to validate some crucial assumptions taken in OASE. It is divided into Info&Test and four main parts (1,2,3,4) in two versions (A,B). Participants (subjects of the survey) were given a combination of Info&Test and (1A or 1B), (2A or 2B), (3A or 3B) and (4A or 4B). Versions (A or B) were randomly selected.

Info&Test was prepared in order to collect the basic properties of the subject. This part included a brief description of OASE and a quick test of knowledge about C# language to provide simple measurement of programming skills owned by the subject.

Part 1 was prepared to examine the differentiation between "what is" and "what has to be done" in terms of software development process. We have prepared two versions. First version (1A) was to check what is a default meaning of modalities in OASE-English in the context of UML diagram, the purpose of the second one (1B) was to check the meaning of modalities in the context of C# source program.

The aim of the part 2 was to check the usefulness of OASE-Annotations in terms of layered architecture (see chapter 4.17.1). To examine the usefulness we have created two versions: 2A – without the output of OASE-Validator and 2B – with the output. Both versions were equipped with the same OASE-Annotations in the attached source code.

The aim of part 3 was to check the usefulness of OASE-Annotations as a design pattern language. We selected adapter design pattern (see chapter 4.18.1). To examine the usefulness we created two versions: 3A – without the output of OASE-Validator and 3B – with the output. Both versions were equipped with the same OASE-Annotations in the attached source code.

The aim of part 4 was to check the usefulness of OASE-Annotations in terms of design constraints put on Pipes&Fiters (see chapter 4.17.2). To examine the usefulness we have created two versions: 4A – without the output of OASE-Validator and 4B – with the output. Both versions were equipped with the same OASE-Annotations in the attached source code. Reader can find the full text of the survey at the end of this appendix (see pages 107-116).

EXECUTION OF THE SURVEY

Below we present the collected output of the survey that was taken on the group of students and professionals. They are ordered by the level of their skills – first are presented answers of the less skilled ones.

Case 1 – The Junior C++ Programmer

The programmer responded for the call and described himself as a student that has a basic knowledge about C++ without any knowledge about C#. The core programming test proven that he was a novice in object-oriented programming as he has not distinguished the subtyping from aggregation. His skills were too low for the rest of the survey; however he was able to solve the task (see Appendix 4).

Case 2 - The Junior C# programmer

The programmer responded for the call and described himself as a student that has good knowledge about C# programming language. Tests performed by him in Part 1 confirmed his skills. He was requested to solve the survey in the following case (1B,2A,3B,4A). He answered only query no. 1B. His skills were too to fill in the rest of the survey; however he was able to solve the task (see Appendix 4).

1B) Respondent selected all of the answers as "must".

Case 3 - The Junior C# programmer with basic UML skills

The programmer responded for the call and described himself as a student with basic knowledge about C# programming language. Tests performed by him in Part 1 confirmed his skills. He was requested to solve the survey in the following case (1B,2B,3A,4A).

1B) Respondent selected almost all responses as "is" but just one as "must". The one selected was: [Purchase] must have-member-that-is an attribute (that is-placeholder-for [Clothing])."

2B) "Error is caused by the fact that GfxDriver class creates an object that is assigned to other than the "Drivers" or "Cross-Cutting" layer." This is a correct answer

3A) Respondent answered that: "The problem lies in the implementation of Drive method of the Adapter (Class CDrivableCessna172), where the recursive call is attempted to itself, which leads to stack overflow." This is a correct answer.

4A) Respondent answered that: "In the first line of execute() method there is forced connection between Pipe-B and Pipe-A and Pipe-D.I assume that this is correct due to the fact that it is consistent with the axiom. Execute() method also attempts to create a connection between Pipe-B and Pipe-D. This is a situation similar to the previous one, but with the exception that the validator should exhibit an error here because the "sink" is checked against SinkOfText class condition (assert) connection, and the only possible, defined by a combination of the Pipe-B is a Pipe-A." This answer is very complex and shows that the participant had a problem with understanding the particular situation.

Case 4 - The Senior C++ programmer

The programmer responded for the call and described himself as a professional C++ programmer that has basic knowledge about C# programming language. Tests performed by him in Part 1 confirmed his skills. He was requested to solve the survey in the following case (1A,2A,3B,4B).

1A) Respondent selected as a "must" all responses to questions about modalities in the second round of software development regarding UML diagram. He thought that the diagram that appears in the iterative way expresses an obligation for the programmer.

2A) Respondent answered that: "GfxDriver (Drivers-Level) should not contain/call TextBoxController (Application level)", therefore he made correct answer without the support of OASE-Annotator explanations.

3B) Respondent answered that:"Drive method from Adapter class (CDrivableCesna172) should call Fly() method from Adaptee class (CCesna172). Recurrent call for Drive() method". It is a correct answer.

4B) Respondent answered that: "Pipe-D is not connectable to Pipe-B". It is a correct answer.

Case 5 -The Senior C++ and C# programmer with UML skills

The programmer responded for the call and described himself as a professional in C++ that has good knowledge about C# programming language. Tests performed by him in Part 1 confirmed his skills. He was requested to solve the survey in the following case (1A,2A,3B,4B).

1A) Respondent selected all almost responses as "must" but one as "is". The one selected was: "[IPrice] is-superclass-of [Price4BuyTwoGetOneFree]." He argued that when speaking about class hierarchies, you refer to things that are true by definitions (even if this is a second cycle and the diagram specifies changes that need to be made. In other words, even if he had selected "must" for all other responses the "is" represents the semantics of class subtyping better.

2A) Respondent answered that: "GfxDriver class calls directly TextBoxController object, which leads to flow control in both directions between layers (upper and lower) instead of event-driven approach. And secondly, in this case, Driver-Layer object (GfxDriver) communicates directly with Application-Layer object, bypassing the Middleware-Layer". It is a correct answer.

3B) Respondent answered that: "CDrivableCesna172 object is not going to flyanywhere, because its method Drive() calls itself (infinite recursion) instead of calling CCesna172::fly() method." It is a correct answer. Unfortunately, he had noticed it at the very beginning, while reading the code, therefore he made correct answer without the support of OASE-Annotator explanations.

4B) Subject answered that: “SinkOfText:sink()” asserts that its argument must be connectable to Pipe-B. In the second line of Execute() method SourceOfText:source() returns stream attributed as Pipe-D and there is no axiom stating that Pipe-D is connectable to Pipe-B”. It is a correct answer.

INTERPRETATION OF RESULTS OF THE SURVEY

In Part 1 we have found out that the differentiation between “what is” and “what has to be done” in terms of software development process exists. The differentiation exists in two areas: the stakeholders role within the software development process (if he was a designer or the programmer), and on the phase of the development process (if it was the initial or continuous phase of the development process). We expected to find out which modal word is the best to be used in OASE-Annotations in both UML-notes and source code comments. Participants that were in the designer shoes were convinced that the diagrams are specifying what has to be done in the future (the “must” answers), however participants that were in the programmer shoes, were describing the situation either as it already “is” or it “must” be done. The differentiations between those two points of view made us think that the modality expressed in OASE-Annotations is ambiguous for the programmers, and can lead to misuse of “must” and “is” keyword. This shows that there is a need to introduce the programmers with the semantics of pseudo-modal expressions before they start their work with OASE.

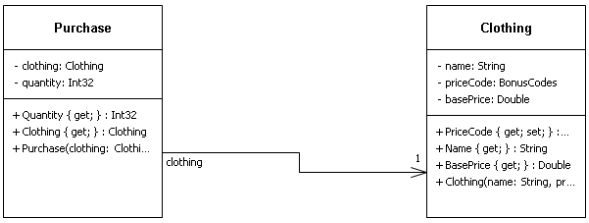
Parts 2 and 3 were solved correctly regardless whether they were equipped with hints from OASE-Validator or not, but the Part 4 has proved that with the aid of OASE-Validator explanations it is easier to find out what really is the source of the problem . One of the programmers was unable to understand what is happening in the Pipes&Filers design, while the others, who were able to take a use of the OASE-Validator explanations, were able to understand it clearly.

FULL TEXT OF THE SURVEY

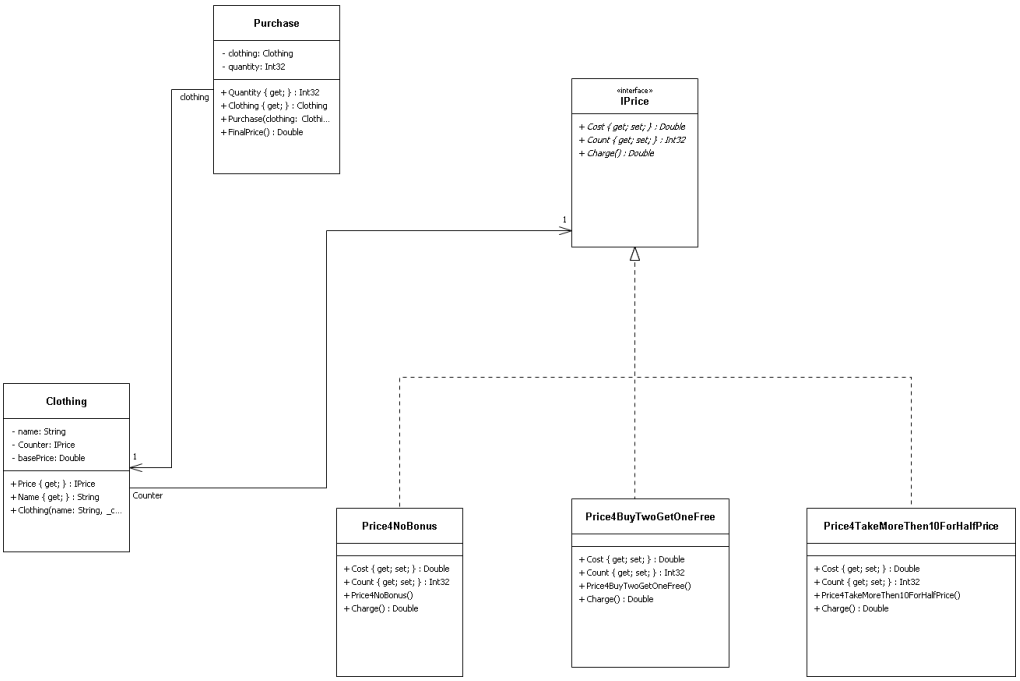
I) The modalities

Version A

Imagine that you are involved with the group of designers in the development process of some program. The first iteration of software development process resulted in the following design diagram that was implemented as a prototype of working system:



After the first iteration the group of designers decided that there is a need for refactoring of the produced code. They proposed that the design of the program is now:



Keeping in mind that you are now in the second iteration of the software develpement process, what statements suit best the new design model in terms of work that is going to be done by the programmers?

I) The modalities

Version B

Imagine that (together with a group of programmers) you are involved in the development process of some program. The first iteration of software development process resulted in the following implementation of working system:

```
public class Purchase
{
    private Clothing clothing;
   /**/
}

public class Clothing
{
   /**/
}
```

After the first iteration the refactoring resulted in another version of code:

```
public class Purchase
{
    private Clothing clothing;
   /**/
}

public class Clothing
{
    private IPrice Counter;
}

public interface IPrice
{
    double Cost { get; set; }
    int Count { get; set; }
    double Charge();
}

public class Price4BuyTwoGetOneFree : IPrice
{
    public double Cost { get; set; }
    public int Count { get; set; }
    public double Charge()
    {
        return (Count - (Count / 3)) * Cost;
    }
}

class Price4NoBonus : IPrice
{
    public double Cost { get; set; }
    public int Count { get; set; }
    public double Charge()
    {
        return Cost * Count;
    }
}
```

```
class Price4TakeMoreThen10ForHalfPrice : IPrice
{
    public double Cost { get; set; }
    public int Count { get; set; }
    public double Charge()
    {
        double thisPrice = 0;
        thisPrice = Count * Cost;
        if (Count > 10)
        {
            thisPrice = thisPrice / 2.0;
        }
        return thisPrice;
    }
}
```

Keeping in mind that you are now in the second iteration of the software development process, what statements suit best to the new version of the program?

Common

1) O[Clothing] has-member-that-is an attribute (that is-placeholder-for [IPrice]).
2) O [Clothing] must have-member-that-is an attribute (that is-placeholder-for [IPrice]).
3) O [Clothing] should have-member-that-is an attribute (that is-placeholder-for [IPrice]).
4) O [Clothing] can have-member-that-is an attribute (that is-placeholder-for [IPrice]).

A2)

1) O [Purchase] has-member-that-is an attribute (that is-placeholder-for [Clothing]).
2) O [Purchase] must have-member-that-is an attribute (that is-placeholder-for [Clothing]).
3) O [Purchase] should have-member-that-is an attribute (that is-placeholder-for [Clothing]).
4) O [Purchase] can have-member-that-is an attribute (that is-placeholder-for [Clothing]).

A3)

1) O [IPrice] has-member-that-is [IPrice.Charge].
2) O [IPrice] must have-member-that-is [IPrice.Charge].
3) O [IPrice] should have-member-that-is [IPrice.Charge].
4) O [IPrice] can have-member-that-is [IPrice.Charge].

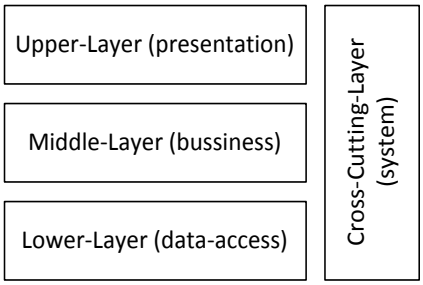
A4)

1) O [IPrice] is-superclass-of [Price4BuyTwoGetOneFree].
2) O [IPrice] must be-superclass-of [Price4BuyTwoGetOneFree].
3) O [IPrice] should be-superclass-of [Price4BuyTwoGetOneFree].
4) O [IPrice] can be-superclass-of [Price4BuyTwoGetOneFree].

II) Layered Architecture

Common

The layer separation paradigm manages usage of relationships between software entities. It uses the architectural layer concept as a mark for each software entity and requires the ordered usage of labeled entities. The most common layered architecture is 3+1 architecture (3-vertical layers + 1 cross cutting layer).



Layered Architecture

To take advantage of Layered Architecture, the designer (or system architect) needs to give a mark to every software entity with exactly one Id of Layer.

You are given the following source code marked with OASE annotations:

```
[module: OASE.Architecture.LayerOrdering(
        UpperLayerID = "Application-Layer",
        MiddleLayerID = "Middleware-Layer",
        LowerLayerID = "Drivers-Layer",
        CrossCuttingLayerID = "System-Layer"
)]

[OASE.Architecture.Layer(LayerID = "Application-Layer")]
public class TextBoxController
{
    EditorModel model = new EditorModel();
    Utilities utils = new Utilities();
    TextBoxView view = new TextBoxView();
    public void a(){
        model.m();
        utils.s();
        view.x();
    }
}

[OASE.Architecture.Layer(LayerID = "Applicationlayer")]
public class TextBoxView
{
    EditorModel model = new EditorModel();
    TextBoxController ctrl = new TextBoxController();
    public void x()
    {
        model.m();
        ctrl.a();
        /*...*/
    }
}

[OASE.Architecture.Layer(LayerID = "Middleware-Layer")]
public class EditorModel
{
    GfxDriver gfx = new GfxDriver();
    Utilities utils = new Utilities();
    public void m()
    {
        gfx.d();
        utils.s();
```

```
            /*...*/
        }
    }

    [OASE.Architecture.Layer(LayerID = "Drivers-Layer")]
    public class GfxDriver
    {
        Utilities utils = new Utilities();
        TextBoxController ctrl = new TextBoxController();
        public void d()
        {
            utils.s();
            ctrl.a();
            /*...*/
        }
    }

    [OASE.Architecture.Layer(LayerID = "System-Layer")]
    public class Utilities
    {
        public void s()
        {
            /*...*/
        }
    }
```

Version A

What do you think is wrong with the implementation?

Click here to enter text.

Version B

detected problems within 3+1 Layered Architecture.

1. Due to the problems with design of [TextBoxView] the following design-constraint failed:
Everything (that is used by something (that is marked by Application-Layer)) must be something (that is marked by Middleware-Layer or is marked by System-Layer or is marked by Application-Layer).

2. Due to the problems with design of [TextBoxController] the following design-constraint failed:
Everything (that is used by something (that is marked by Drivers-Layer)) must be something (that is marked by Middleware-Layer or is marked by System-Layer or is marked by Drivers-Layer).

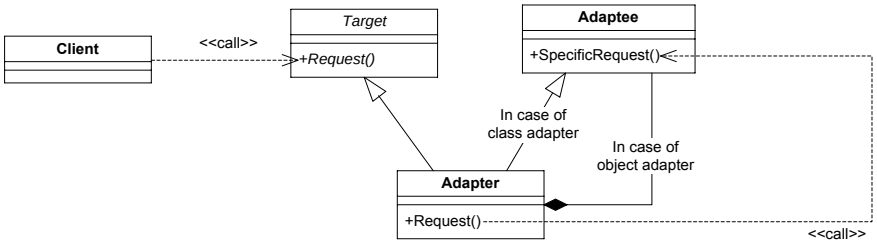
What in your opinion are the reasons of the above errors?

Click here to enter text.

III) Adapter

Common

One of the most common design patterns is Adapter. Adapter design pattern translates one interface for a class into a compatible interface. Adapter allows classes that normally could not cope together (because of incompatible interfaces), to work together by providing special interface (Target) to the client. Adapter translates calls to the new interface into calls to the original interface. Depending on the designer decision on Adoptee class it can be implemented via aggregation or inheritance: we call it a class-adapter (when the adapter class inherits from the adaptee class) or object-adapters (when the adapter class contains the adaptee class)



Adapter design pattern involves four classes and therefore all of them have to be labeled with a unique patternID. Design patterns can interfere with each other so the same class can potentially have many labels with different patternIDs.

In this query we are dealing with the following vehicles:

Cesna 172

Subaru Impreza

You are given the following source code marked with OASE annotations:

```
using System;

[OASE.GOF.Target(PatternID = "A1")]
public interface IDrivable
{
    [OASE.GOF.Target.Request(PatternID = "A1")]
    void Drive();
}

public class CSubaruImpreza : IDrivable
{
```

```
        public void Drive()
        {
            Console.WriteLine("Vroom Vroom, we're off in our Subaru Imreza...");
        }
    }

    [OASE.GOF.Adaptee(PatternID = "A1")]
    public class CCessna172
    {
        [OASE.GOF.Adaptee.SpecificRequest(PatternID = "A1")]
        public void Fly()
        {
            Console.WriteLine("Static runup OK, we're off in our Cesna 172...");
        }
    }


    [OASE.GOF.Adapter(PatternID = "A1")]
    public class CDrivableCessna172 : CCessna172, IDrivable
    {
        [OASE.GOF.Adapter.Request(PatternID = "A1")]
        public void Drive()
        {
            Drive();
        }
    }

    [OASE.GOF.AdapterClient(PatternID = "A1")]
    public class CDriver
    {
        [OASE.GOF.AdapterClient.Operation(PatternID = "A1")]
        public void Drive(IDrivable thing)
        {
            thing.Drive();
        }
    }


    class Program
    {
        static void Main(string[] args)
        {
                var car_driver = new CDriver();
                car_driver.Drive(new CDrivableCessna172());
                car_driver.Drive(new CSubaruImpreza());
        }
    }
```

Version A

What do you think is wrong with the implementation?

Click here to enter text.

Version B

And the following warning is produced by the OASE processor that describes the detected problem within Adapter-Pattern implementation.

1. Due to the problems with design of [CDrivableCessna172.Drive] the following design-constraint failed:
Everything (that is an adapter-request and is labeled by A1) should call a function (that implements an adaptee-specific-request (that is labeled by A1)).

What are the reasons of the above warning?

Click here to enter text.

IV) Pipes & Filters

Common

The Pipes & Filters is a well-known Design Pattern, that is used to divide the task of a system into several sequential processing steps. Each processing step is implemented by a filter component that consumes and delivers data incrementally. The filters are connected sequentially by pipes. Filters are usually implemented as separate objects that use one common interface of a generic pipe and therefore filters can be freely configured, however it is highly desirable to prevent such a free-style by incorporating some design constraints. The solution requires some kind of specification language to be incorporated, which would allow the designer to specify exactly which pairs of filters are compatible with each other. OASE-English as a Semantic Annotation language allows the programmer to build a Pipe and Filters design pattern validator, with formal semantic background. The validator is executed in runtime when the new connection between pipes is detected.

You are given the following source code marked with OASE annotations:

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using OASE.Architecture;

[module: OASE.Axiom("Pipe-A is-connectable-to Pipe-B.")]


public class IdentityFilter
{
    [OASE.Architecture.PipeConnector("Pipe-A")]
    public IEnumerable<string> filter(IEnumerable<string> arg)
    {
        foreach (var a in arg)
        {
            yield return a + "f";
        }
    }
}

public class Multiplexer
{
    [OASE.Architecture.PipeConnector("Pipe-B")]
    public  IEnumerable<string>  filter(IEnumerable<string>  arg1,  IEnumerable<string>
arg2)
    {
        OASE.Debugging.Assert(arg1.GetPipeID() + " must be-connectable-to Pipe-A.");
        OASE.Debugging.Assert(arg2.GetPipeID() + " must be-connectable-to Pipe-A.");
        foreach (var a1 in arg1)
        {
            yield return a1 + "f";
        }
    }
}

public class SourceOfText
{
    [OASE.Architecture.PipeConnector("Pipe-D")]
    public IEnumerable<string> source()
    {
        for (int i = 0; i < 10; i++)
        {
            yield return "aaaa";
        }
    }
}
```

```
public static class PFApplication
{
    static IdentityFilter identityFilter = new IdentityFilter();
    static SourceOfText sourceOfText = new SourceOfText();
    static SinkOfText sinkOfText = new SinkOfText();

    public static void Execute()
    {
        sinkOfText.sink(identityFilter.filter(sourceOfText.source()));
        sinkOfText.sink(sourceOfText.source());
    }
}
```

Version A

```
public class SinkOfText
{
    public void sink(IEnumerable<string> arg)
    {
      OASE.Debugging.Assert(arg.GetPipeID() + " must be-connectable-to Pipe-B.");
        foreach (var a in arg)
        {
            Console.WriteLine(a);
        }
    }
}
```

What is wrong here?

Click here to enter text.

Version B

```
public class SinkOfText
{
    public void sink(IEnumerable<string> arg)
    {
       OASE.Debugging.Assert(arg.GetPipeID() + " must be-connectable-to Pipe-
B.");
        foreach (var a in arg)
        {
            Console.WriteLine(a);
        }
    }
}
```

OASE-Assert (marked on red) was broken and raised an runtime exception. Why? What is wrong here?

Click here to enter text.

Appendix 5. 9Validation Experiment

Refactoring task with OASE-Annotations

The aim of this case study was to check the usability of OASE as an effective tool that allows for effective interactions between designer and programmer (in terms of the required refactoring that needs to be made on existing source code). The task was inspired by the example taken from Martin Fowler book [Fowl99], transformed from Java into C# with some modifications made by applying OASE-Annotations.

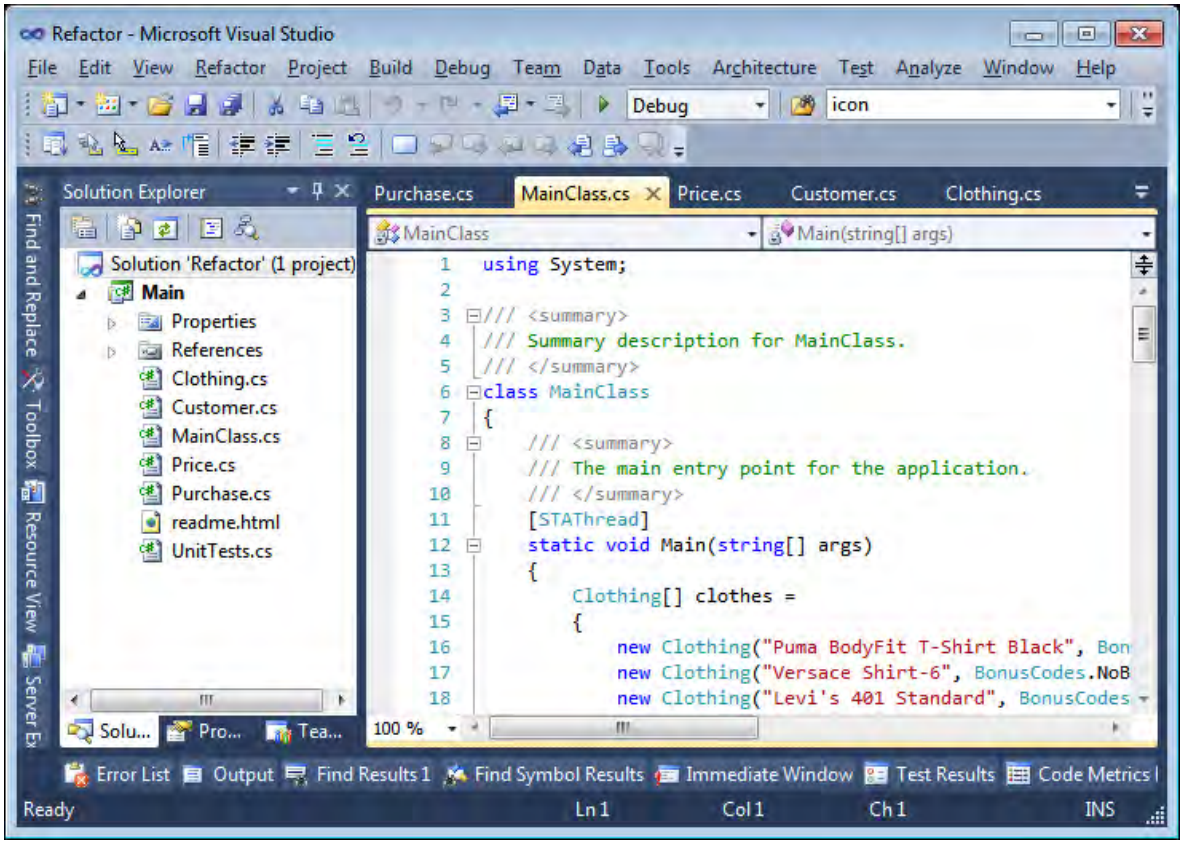


Figure 55. Validation experiment source code loaded into Visual Studio

The program to be refactored implements the functionality of the internet shop. Source code of the shop consists of few files and classes, like: 1) The class Clothing models clothing, 2) The class Purchase models a single purchase of clothing, 3) The class Customer models customer-services and other constructs.

The subject of the test is asked to refactor the “Customer.Statement” method which in the original form uses the "switch" expression over "PriceCode". The sub-

ject should eliminate the “PriceCode” in the way that “Customer.Statement” method uses the hierarchy of Prices instead. Each class derived from Price class should finally realize specific case from the refactored "switch" expression.

The original program included OASE-Annotations that formed Integrity Constraints that had to be preserved. In addition, it included the Unitary Tests to provide the way of checking the functionality during the refactoring job (see the source code below).

While the programmer works with a debugger, OASE-Annotations are continuously checked by the OASE-Validator each time she runs the program. This is a kind of dialogue between programmer and program via OASE-Validator. OASE-Validator explains what (and why) is (still) wrong in the program (w.r.t. Integrity Constraints specified within OASE-Annotations). Without the support of OASE-Validator, OASE-Annotations would be only a way for an unambiguous code-documentation.

The respondent was provided with a source code that she was requested to load into the Visual Studio programming environment (see Figure 55).

Reader can find the full text of the task as well as the source code of the task at the end of this appendix (see pages 122-131).

EXECUTION OF THE EXPERIMENT

The target population of the programmers was selected basing on the prepared survey (see Appendix 4). The following presents the brief description of each programmer-case.

Case 1 – The Junior C++ Programmer

The programmer responded for the call and described himself as a student that has a basic knowledge about C++ without any knowledge about C# (he admitted that he did not know anything about the memory management in terms of differences between C++ and C# in the field). The core programming test proved that he was a novice in the object-oriented programming. He did not distinguished the subtyping from aggregation. However, he was able to solve the task in unlimited time (it took around 8h) without any additional help. He executed the validator more than 10 times. The solution was fully-acceptable. In addition, he (by himself) learned about object-oriented methodology and made the following conclusion:

1) The removal of the BonusCodes class, together with the OASE-Annotation was for him ridiculous because he felt that he cannot do such operation, as he was requested to do only the refactoring. He assumed that the OASE-Annotation is a part of final design and any modification in the field is prohibited.
2) As interface and class are different keywords in C#, it was hard to understand for him that within the OASE both of them are represented in the same manner, however he was able to finish the task.

3) When asked, if the OASE-Annotations and if they were helpful to finish the task, he responded that the task was to remove the errors produced by OASE-Validator. It makes us wondering if he was thinking about the task in terms of solving a puzzle-like problem.

Case 2 - The Junior C# programmer

The programmer responded for the call and described himself as a student that has a good knowledge about C# programming language. He was able to resolve the task in 1 hour without any additional help. He executed the OASE-Validator 7 times. The solution was fully-acceptable. In addition, he made the following conclusion:

1) He found out that the usage of namespaces generates a problem as long as the specification is in a form of: "It must be-supertype-of [Price4NoBonus]." He needed some time to realize that the implementation of Price4NoBonus class must be placed in the default namespace. This is considered as a bug in the OASE-Toolkit and is resolved in the new version.
2) He said that he has solved it only by reading the OASE-Annotation and without the need for any other support - in this case he was also (like the Case 1 programmer) thinking about the task in terms of a puzzle-like problem.

Case 3 - The Junior C# programmer with basic UML skills

The programmer responded for the call and described himself as a student with a basic knowledge about C# programming language. He was able to resolve the task in 2 hours. The solution was fully-acceptable. He executed OASE-Validator 5 times. In addition, he made the following conclusion:

1) From the programmer's standpoint, OASE is certainly a great help. If the annotations are written in 100% correctly, the programmer will neither have to search over the code in order to find out what to do next, nor debug the entire program step by step. He is told what structures require additional source code editing.
2) From the designer's/architect's point of view OASE-Annotations will allow to communicate the required work clearly. The programmer also has (due to the OASE-Validator support) a guarantee that the programmer's job will be well done, as the OASE-Validator ensures it.
3) The potential disadvantage of OASE is the responsibility of the software designer to formulate the OASE-Annotation correctly, if not, then the result of the OASE aided process will be ineffective as well.

Case 4 - The Senior C++ programmer

The programmer responded for the call and described himself as a professional C++ programmer that has a basic knowledge about C# programming language. He was able to resolve the task in less than 1 hour without any additional help. The solution

was fully-acceptable. He executed OASE-Validator 4 times. In addition, he made the following conclusion:

1) Once he understood how the OASE-Validator works, he rapidly resolved the task by the continuous checking of what to do after each build. He said that: "It felt like the OASE-Validator leaded me by the hand. I did not even needed to plunge into what and how this program was supposed to do. Nevertheless I made it."
2) He was glad to see the idea of OASE. As he has knowledge about software design, he said that OASE is a revolutionary method, that allows to force the design to the programmer.

Case 5 - The Senior C++ and C# programmer with UML skills

The programmer responded for the call and described himself as a professional C++ that has good knowledge about C# programming language. He was able to resolve the task in 30 minutes. He executed OASE-Validator 2 times. He found out that the survey (see Appendix 4) contained the design diagram of the task, however he was not looking at it. The solution was fully acceptable. In addition he made the following conclusion:

1) Once he understood how OASE-Validator works he rapidly resolved the task. Only one iteration of OASE-Validator was needed to support him. The one iteration was about the annotation [BonusCode] must be-removed-from The-Design-Of-The-Program" – so simply he forgot to remove the class within the refactoring task. It made us think that the selected task was too easy for the senior programmers with UML skills.
2) He said that OASE-Annotations were understandable enough to resolve the task even without the need for additional support of OASE-Validator.
3) He said that OASE looks very promising and that he would like to use it if had been in commercial phase.

INTERPRETATION OF RESULTS OF THE EXPERIMENT

Experiment was performed on the group of programmers that were novices in the OASE. There was no future communication regarding the task. All participants were able to solve the given task. This proves that OASE-Annotations composed with OASE-Validator (in terms of the required refactoring that needs to be made on existing source code) were at least as valuable as personal interactions between the task inventor and the programmer would be.

Analysis of the experiment results (see Figure 56) uncovers the interesting potential in the correlation between the programmer skills and the usefulness of OASE in this particular scenarios (here – we deal with a refactoring task). The higher skills the programmer has, the shorter time and lower amount of needed OASE-Validator runs are required. Moreover, if our conclusion is correct, we can provide another useful application of OASE-Validator that is the programming-skills validation in terms of knowledge about the high-level design structure implementation. Once we

have executed the experiment on the candidate that tries to get a job, the recruiter can verify her skills, taking into consideration that there exists a correlation between the time of the experiment execution, number of OASE-Validator runs and his programming skills.

OASE limits the need for direct-communication. Validation experiment allows us to argue that OASE can be helpful in cost prone development environments due to the necessity of personal communication (e.g. distributed development environments, large teams, etc.).

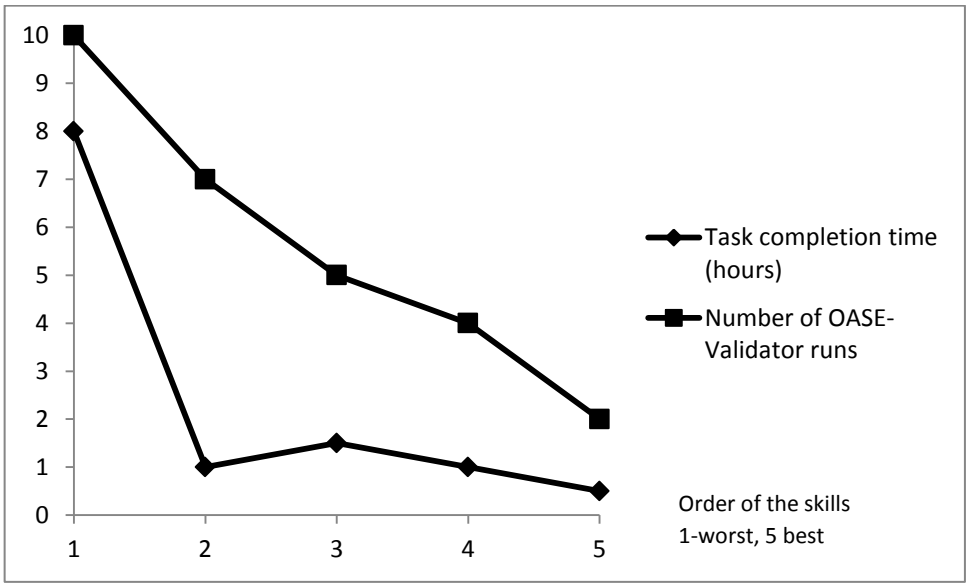
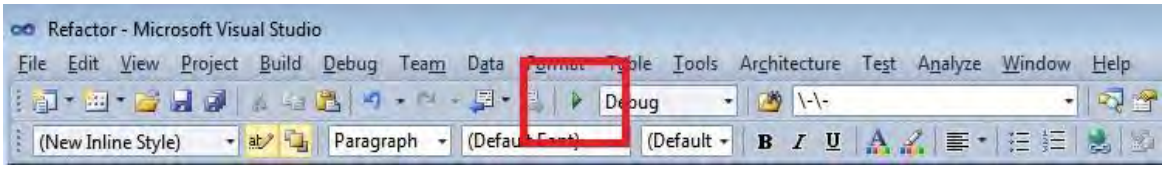


Figure 56. Analysis of the experiment results.

FULL TEXT OF THE TASK AND ITS SOURCE CODE

Task

Please try to run the program by clicking Run Button on the toolbar (see below) (or simply hit [F5] key).



To preserve the functionality the unitary tests (UT) are checked first. If some UT is broken you will be informed in the following manner:

```
UnitTest exception:
Assertion Failed (Puma BodyFit T-Shirt Black!=Puma BodyFit T-Shirt Blackx) at @C
ustomer.Statement when counting Name
   at UnitTests.AssertEqual[X](X a, X b, String msg) in C:\ROOT\Phd\!!2\exampleS
r\Refactor_Out\UnitTests.cs:line 164
   at UnitTests.TestCustomer() in C:\ROOT\Phd\!!2\exampleSr\Refactor_Out\UnitTes
ts.cs:line 142
   at UnitTests.Check() in C:\ROOT\Phd\!!2\exampleSr\Refactor_Out\UnitTests.cs:l
ine 41
```

If such a situation occurs then it mean that the functionality is not preserved.

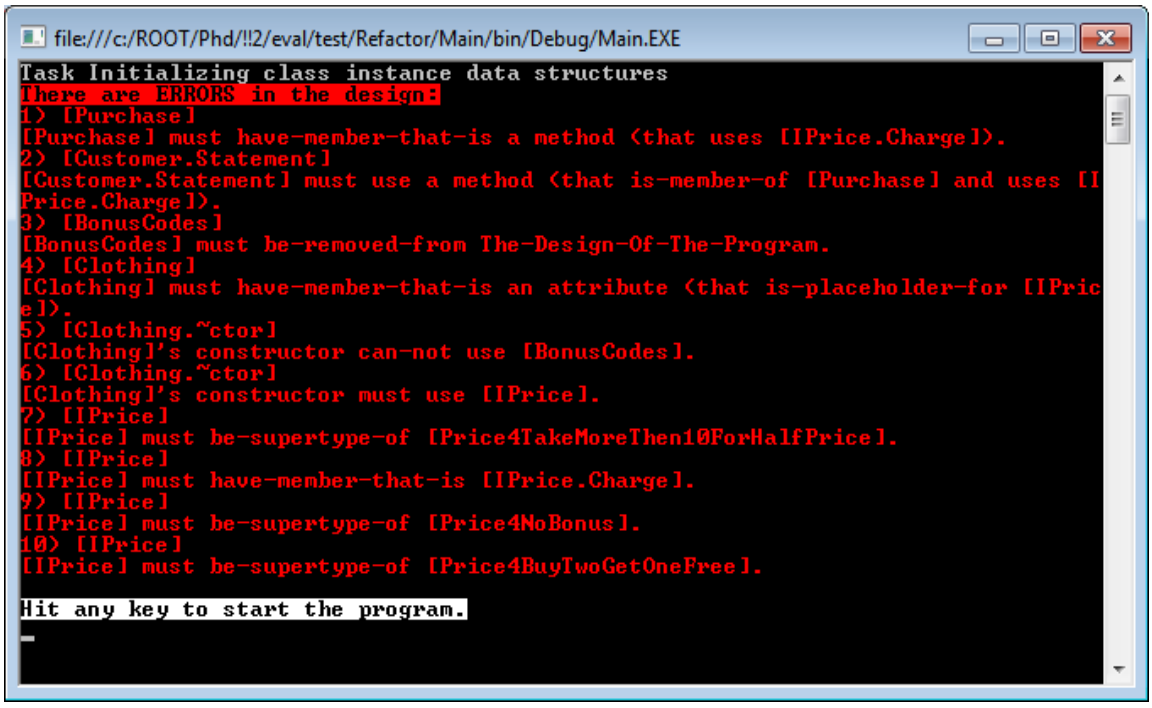
After UT, the program will load its design into OASE-Validator.

```
Loading the design into Reasoner ...
```

After loading the design is checked agains the broken design constrains.

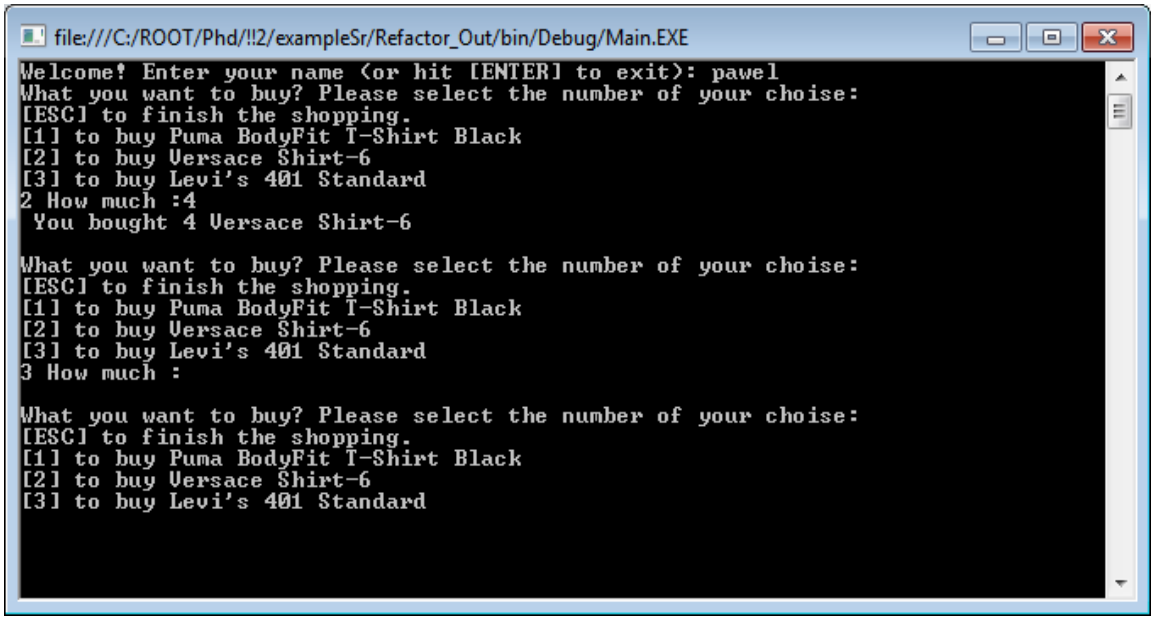
```
Checking: 70%
```

And finally all design errors that still exists in the source code are presented to the programmer:



Take a look at the errors; do you understand what they mean?

Next, after pressing any key the program starts to execute its "Main" function:



This demo program realizes shopping system. Right now it is fully functional and consist of few files and classes like: 1) The class Clothing models clothing, 2) The class Purchase models a single purchase of clothing, 3) The class Customer models a customer-services and other constructs. Please take a while to understand how it works.

Please take a look at the OASE OASE-Annotations e.g.:

```
14
15  /// <summary>
16  /// Clothing is just a simple data class.                    Class Annotation
17  /// </summary>
18  [OASE._("It must have-member-that-is an attribute (that is-placeholder-for [IPrice]).")]
19  public class Clothing
20  {
21      /* Fields */
22
23      // Data members
24      private string name;
25
26      private BonusCodes priceCode;
27
28      private double basePrice;
29
30      /* Constructor */
31
32      [OASE._("It can-not use [BonusCodes].")]
33      [OASE._("It must use [IPrice].")]
34      public Clothing(string name, BonusCodes priceCode, double basePrice)
35      {                                                        Constructor
36          this.name = name;                                    Annotation
37          this.priceCode = priceCode;
38          this.basePrice = basePrice;
39      }
40
41      /* Properties */
42
43      public BonusCodes PriceCode
44      {
```

Do you understand what OASE-Annotations are all about? They are to protect the design and are checked by OASE-Validator. When you modify the source code you can run it and the OASE-Validator check the Semantic Annotations against the design.

The Task:

You are requested to refactor the Customer.Statement method. Right now it is computing the statement using "switch" expresion over "PriceCode". You should provide the way to eliminate the need for PriceCode (PriceCode should be removed from the final version). The Customer.Statement method should instead use the hierarchy of Prices placed in Price.cs file. Each price in the file should realize specific case from the refactored "switch" expression. You should start from designing the overall Price hierarchy in Price.cs file. Next you should move the functionality from Customer.Statement "switch" expression into the newly created hierarchy. Please remember that the Customer.Statement should use directly Purchase class, which should use Clothing.Price member to obtain the correct Price object.

At the end there should be no error in the design (you should eliminate all 10 design errors that appear when you run the program) while UT should be preserved.

Good luck!

Source code

File: Customer.cs

```
using System;
using System.Collections.Generic;


/// <summary>
/// Customer represents a customer of the store.
/// </summary>
public class Customer
{
    private string name;

    private List<Purchase> purchases = new List<Purchase>();

    /* Constructor */
    public Customer(string name)
    {
        this.name = name;
    }

    /* Properties */

    public string Name
    {
        get { return name; }
    }

    /* Methods */

    public void Buy(Purchase arg)
    {
        purchases.Add(arg);
    }

    [OASE._("It must use a method (that is-member-of [Purchase] and uses
[IPrice.Charge]).")]
    public string Statement()
    {

        double totalPrice = 0;
        string result = "Purchase record for " + name + "\n";
        foreach (var purchase in purchases)
        {
            double thisPrice = 0;

            // Determine amounts for each line
            switch (purchase.Clothing.PriceCode)
            {
                case BonusCodes.NoBonus:
                    thisPrice += purchase.Quantity * purchase.Clothing.BasePrice;
                    break;

                case BonusCodes.BuyTwoGetOneFree:
                    thisPrice += (purchase.Quantity - (purchase.Quantity / 3)) * pur-
chase.Clothing.BasePrice;
                    break;

                case BonusCodes.TakeMoreThen10ForHalfPrice:
                    thisPrice = purchase.Quantity * purchase.Clothing.BasePrice;
                    if (purchase.Quantity > 10)
                    {
                        thisPrice = thisPrice / 2.0;
                    }
                    break;
            }
            // Show figures for this purchase
            result += "\t" + purchase.Clothing.Name + "\t" + thisPrice.ToString() + "\n";
```

```
            totalPrice += thisPrice;
        }

        // Add footer lines
        result += "Amount owed is " + totalPrice.ToString() + "\n";
        return result;
    }
}
```

File: Clothing.cs

```
using System;


/// <summary>
/// Price codes (bonuses)
/// </summary>
[OASE._("It must be-removed-from The-Design-Of-The-Program.")]
public enum BonusCodes
{
    NoBonus, //normal price
    BuyTwoGetOneFree, //buy two and get one free
    TakeMoreThen10ForHalfPrice // buy big boxex (more than 10 for 1/2 price)
}

/// <summary>
/// Clothing is just a simple data class.
/// </summary>
[OASE._("It must have-member-that-is an attribute (that is-placeholder-for [IPrice]).")]
public class Clothing
{
    /* Fields */

    // Data members
    private string name;

    private BonusCodes priceCode;

    private double basePrice;

    /* Constructor */

    [OASE._("It can-not use [BonusCodes].")]
    [OASE._("It must use [IPrice].")]
    public Clothing(string name, BonusCodes priceCode, double basePrice)
    {
        this.name = name;
        this.priceCode = priceCode;
        this.basePrice = basePrice;
    }

    /* Properties */

    public BonusCodes PriceCode
    {
        get { return priceCode; }
        set { priceCode = value; }
    }

    public string Name
    {
        get { return name; }
    }

    public double BasePrice
    {
        get { return basePrice; }
    }
}
```

File: Purchase.CS

```
using System;

/// <summary>
/// Purchase represents a customer buying clothing.
/// </summary>
[OASE._("It must have-member-that-is a method that uses [IPrice.Charge].")]
public class Purchase
{
    /* Fields */

    // Data members
    private Clothing clothing;
    private int quantity;

    /* Constructor */

    public Purchase(Clothing clothing, int quantity)
    {
        this.clothing = clothing;
        this.quantity = quantity;
    }

    /* Properties */

    public int Quantity
    {
        get { return quantity; }
    }

    public Clothing Clothing
    {
        get { return clothing; }
    }
}
```

File: Price.CS

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;


[OASE._("It must have-member-that-is [IPrice.Charge]. ")]
[OASE._("It must be-superclass-of [Price4NoBonus]. ")]
[OASE._("It must be-superclass-of [Price4BuyTwoGetOneFree]. ")]
[OASE._("It must be-superclass-of [Price4TakeMoreThen10ForHalfPrice]. ")]
public interface IPrice
{
}
```

File: UnitTest.CS

```
using System;
using System.Diagnostics;

[OASE.Ignore]
public class UnitTests : IDisposable
{
    public void Dispose()
    {
    }


    /* Fields */

    // Clothings
```

```
    Clothing m_tShirt;
    Clothing m_redVersaceShirt;
    Clothing m_blueJeans;

    // Purchases
    Purchase m_Purchase1;
    Purchase m_Purchase2;
    Purchase m_Purchase3;

    // Customers
    Customer m_MickeyMouse;
    Customer m_DonaldDuck;
    Customer m_MinnieMouse;

    /* Methods */

    public UnitTests()
    {
    }

    public void Check()
    {
        try
        {
            Init();
            TestClothing();
            TestCustomer();
            TestPurchase();
        }
        catch (Exception ex)
        {
            Console.ForegroundColor = ConsoleColor.Black;
            Console.BackgroundColor = ConsoleColor.Red;
            Console.WriteLine("UnitTest exception:");
            Console.ForegroundColor = ConsoleColor.Red;
            Console.BackgroundColor = ConsoleColor.Black;
            Console.WriteLine(ex.Message);
            Console.WriteLine(ex.StackTrace);
            Console.ResetColor();
        }
    }

    public void Init()
    {
        // Create Clothings

        m_tShirt = new Clothing("Puma BodyFit T-Shirt Black", Bonus-
Codes.TakeMoreThen10ForHalfPrice, 123.45);
        m_redVersaceShirt = new Clothing("Versace Shirt-6", BonusCodes.NoBonus, 4567.12);
        m_blueJeans = new Clothing("Levi's 401 Standard", BonusCodes.BuyTwoGetOneFree,
12.34);

        // Create Purchases
        m_Purchase1 = new Purchase(m_tShirt, 5);
        m_Purchase2 = new Purchase(m_redVersaceShirt, 12);
        m_Purchase3 = new Purchase(m_blueJeans, 4);

        // Create customers
        m_MickeyMouse = new Customer("Mickey Mouse");
        m_DonaldDuck = new Customer("Donald Duck");
        m_MinnieMouse = new Customer("Minnie Mouse");
    }

    public void TestClothing()
    {
        // Test Name property
        AssertEqual("Puma BodyFit T-Shirt Black" , m_tShirt.Name,"@Cloting.Name");
        AssertEqual("Versace Shirt-6" , m_redVersaceShirt.Name, "@Cloting.Name");
        AssertEqual("Levi's 401 Standard" , m_blueJeans.Name, "@Cloting.Name");
    }

    public void TestPurchase()
    {
        // Test Clothing property
        AssertEqual(m_tShirt , m_Purchase1.Clothing,"@Purchase.Clothing");
        AssertEqual(m_redVersaceShirt , m_Purchase2.Clothing, "@Purchase.Clothing");
        AssertEqual(m_blueJeans , m_Purchase3.Clothing, "@Purchase.Clothing");
```

```
        // Test Quantity property
        AssertEqual(5 , m_Purchase1.Quantity, "@Purchase.Quantity");
        AssertEqual(12 , m_Purchase2.Quantity, "@Purchase.Quantity");
        AssertEqual(4 , m_Purchase3.Quantity, "@Purchase.Quantity");
    }

    public void TestCustomer()
    {
        // Test Name property
        AssertEqual("Mickey Mouse" , m_MickeyMouse.Name, "@Customer.Name");
        AssertEqual("Donald Duck" , m_DonaldDuck.Name, "@Customer.Name");
        AssertEqual("Minnie Mouse" , m_MinnieMouse.Name, "@Customer.Name");

        // Test Buy() method - set up for test
        m_MickeyMouse.Buy(m_Purchase1);
        m_MickeyMouse.Buy(m_Purchase2);
        m_MickeyMouse.Buy(m_Purchase3);


        // Test the Statement() method
        string theResult = m_MickeyMouse.Statement();

        // Parse the result
        char[] delimiters = "\n\t".ToCharArray();
        string[] results = theResult.Split(delimiters);

        AssertEqual("Puma BodyFit T-Shirt Black", results[2], "@Customer.Statement when
counting Name");
        AssertEqual(617.25 , Convert.ToDouble(results[3]), "@Customer.Statement when
counting price");
        AssertEqual("Versace Shirt-6", results[5], "@Customer.Statement when counting
Name");
        AssertEqual(54805.44, Convert.ToDouble(results[6]), "@Customer.Statement when
counting price");
        AssertEqual("Levi's 401 Standard", results[8], "@Customer.Statement when counting
Name");
        AssertEqual(37.02 , Convert.ToDouble(results[9]), "@Customer.Statement when count-
ing price");
        AssertEqual(results[10], "Amount owed is " + (55459.71D).ToString(),
"@Customer.Statement when counting amount owed");
    }

    [OASE.Ignore]
    class AssertionExeption : Exception
    {
        public AssertionExeption(string msg, string a, string b)
            : base("Assertion Failed (" + a + "!=" + b + ") at " + msg) { }
    }

    void AssertEqual<X>(X a, X b,string msg)
    {
        if (!(a.Equals(b)))
        {
            throw new AssertionExeption(msg,a.ToString(),b.ToString());
        }
    }
}
```

File: MainClass.CS

```
using System;

/// <summary>
/// Summary description for MainClass.
/// </summary>
class MainClass
{
    /// <summary>
    /// The main entry point for the application.
    /// </summary>
    [STAThread]
    static void Main(string[] args)
    {
```

```
        Clothing[] clothes =
        {
            new Clothing("Puma BodyFit T-Shirt Black", Bonus-
Codes.TakeMoreThen10ForHalfPrice, 123.45),
            new Clothing("Versace Shirt-6", BonusCodes.NoBonus, 4567.12),
            new Clothing("Levi's 401 Standard", BonusCodes.BuyTwoGetOneFree, 12.34)
        };

        while (true)
        {
            Console.Write("Welcome! Enter your name (or hit [ENTER] to exit): ");
            var name = Console.ReadLine();
            if (name == "")
                break;
            var customer = new Customer(name);
            while (true)
            {
                Console.WriteLine("What you want to buy? Please select the number of your
choise:");
                Console.WriteLine("[ESC] to finish the shopping.");
                for (int i = 0; i < clothes.Length; i++)
                {
                    Console.WriteLine("[" + (i + 1).ToString() + "] to buy " +
clothes[i].Name);
                }
                var rk = Console.ReadKey();
                if (rk.Key == ConsoleKey.Escape)
                    break;
                else
                {
                    var rks = rk.KeyChar.ToString();
                    int rki;
                    if (int.TryParse(rks, out rki))
                    {
                        if (rki >= 1 && rki <= clothes.Length)
                        {
                            Console.Write(" How much :");
                            var cnts = Console.ReadLine();

                            int cnt;
                            if (int.TryParse(cnts, out cnt))
                            {
                                if (cnt > 0)
                                {
                                    Console.WriteLine(" You bought " + cnt.ToString() + "
" + clothes[rki - 1].Name);
                                    customer.Buy(new Purchase(clothes[rki - 1], cnt));
                                }
                            }
                        }
                    }
                }
                Console.WriteLine();
            }
            Console.WriteLine();
            Console.WriteLine(customer.Statement());
            Console.WriteLine("Press [ESC] to exit or any other key to try again.");
            if (Console.ReadKey().Key == ConsoleKey.Escape)
                return;
            Console.WriteLine();
        }
    }


#if DEBUG
    [OASE.Ignore]
    class Tester
    {
        public Tester()
        {
            //check Unit Tests
            using (var ut = new UnitTests())
            {
                ut.Check();
            }

            //check Design
```

```
            using (var oase = new OASE.ConsoleChecker(new OASE.OASEMapping()))
            {
                var assembly = System.Reflection.Assembly.GetExecutingAssembly();
                oase.LoadAssembly(assembly);
                oase.Check();
            }
        }
    }
    static Tester ____ = new Tester();
#endif

}
```

Appendix 6. CDSS

The Inferred-UI approach and Self-Implemented Requirement were implemented in the form of Clinical Decision Support System (CDSS) [Kapl10a]. The CDSS focuses on oncology and implements the Clinical Practice Guideline. Moreover, it supports the diagnosis of a lung cancer staging. Clinical practice guidelines are systematically developing statements designed to assist medical practitioners and patients with decisions about appropriate health-care for the specific clinical circumstances [Stah04]. The automation of a decision support occurs when the computer can make a use of patients' clinical data, follow its own algorithm, and present the information relevant to the current clinical situation [Cast08].

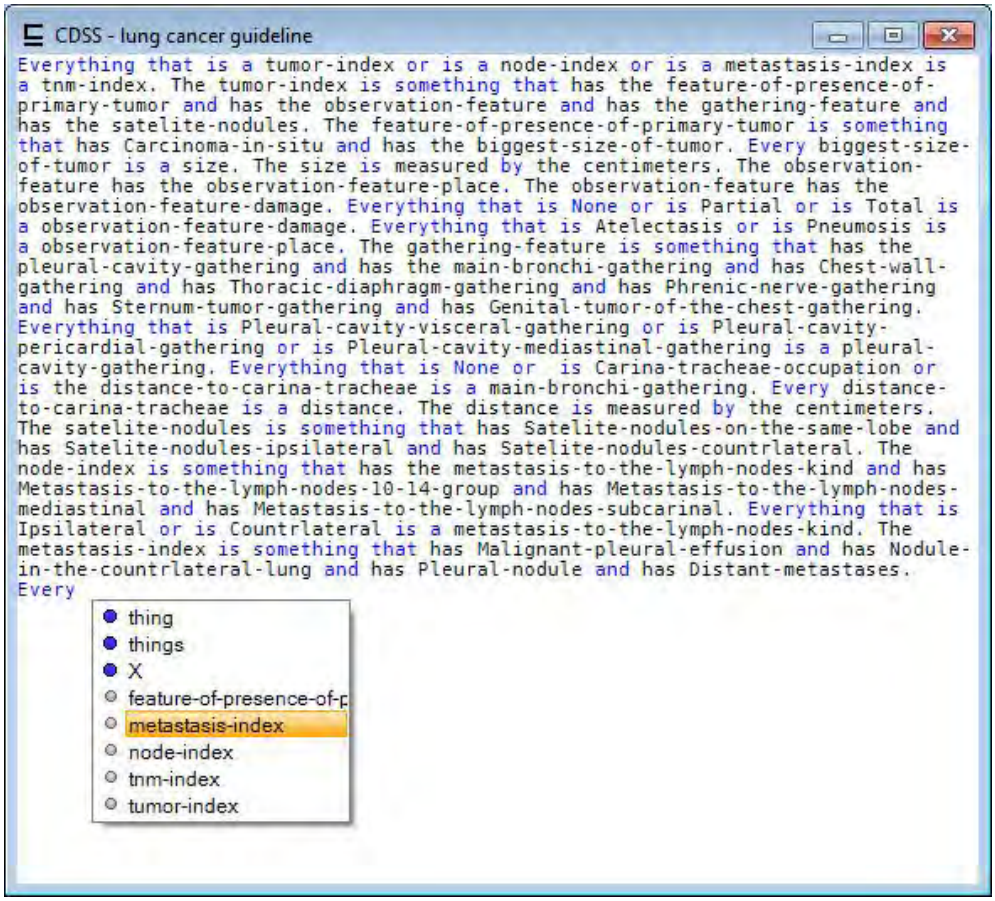


Figure 57. Example domain specific expert knowledge in OASE-English

The prototype has been implemented on top of the OASE-Toolkit software stack and proved that the approach is feasible. First, the medical-knowledge taken directly from the clinical-guideline was transcribed into OASE-English using OASE-English predictive editor (see Figure 57). In standard approaches to CDSS which is based on decision trees - generating and modifying the knowledge base requires the IT pro-

fessional and the programmer support. In our approach, the lung cancer experts can instantly create and modify the knowledge base of CDSS in (controlled) natural language.

The approach was selected to support lung cancer therapists to make clinical decisions by the direct computation of recommended treatment options and their justifications in fast and efficient manner. The generated UI (Figure 58), which is used to recommend patients adequate therapies, helps to collect the data by using the dialog-boxes that in daily work are more useful (from a pragmatic point of view) than the natural language.

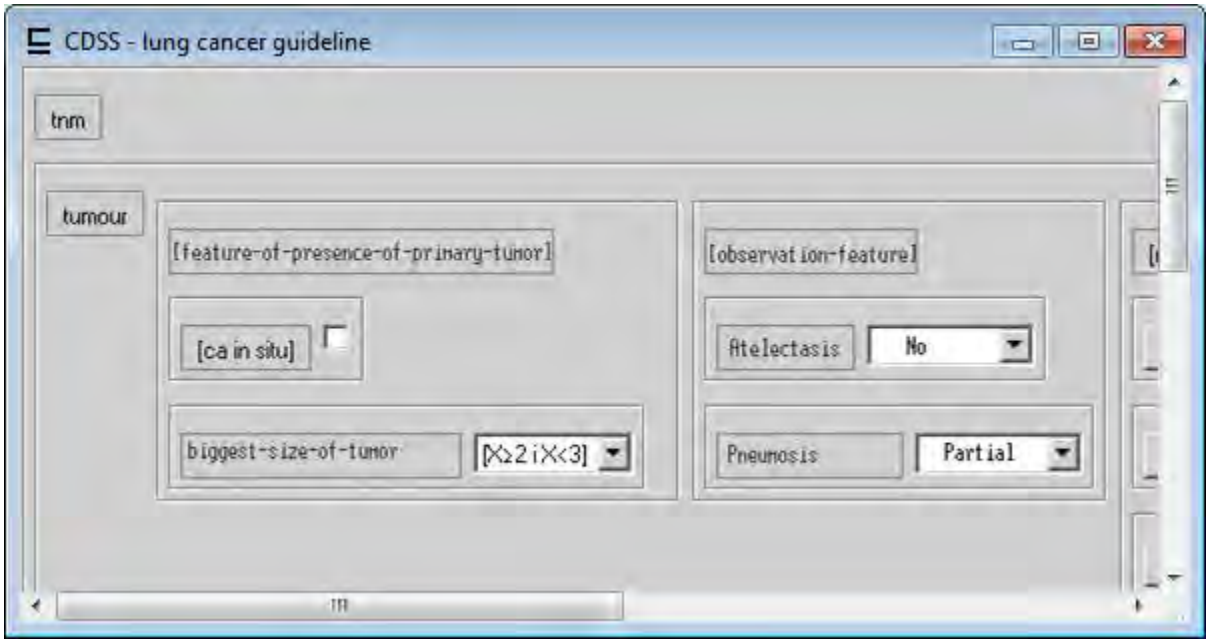


Figure 58. Example Inferred-UI application

In the solution provided by us, the knowledge base contained overall knowledge about:

1) Diagnosis (via transcription of clinical practice guideline into OASE-English)
2) Therapeutic options (via specification of the options in OASE-English)
3) Required information that needs to be entered by the therapist (via specification of the Integrity Constraints in OASE-English)

Knowledge base can be accessed by both:

1) Self-Implemented requirement – this option is remarkably functional for experts that can directly modify the content of the knowledge base without the need of any additional support from IT professionals
2) Inferred-UI – accessible to the therapists that need to quickly take use of the application, therefore the dialog-based UI is recommended in their field.

Even if both applications were separated, they were indirectly connected by the common knowledge base (see Figure 59).

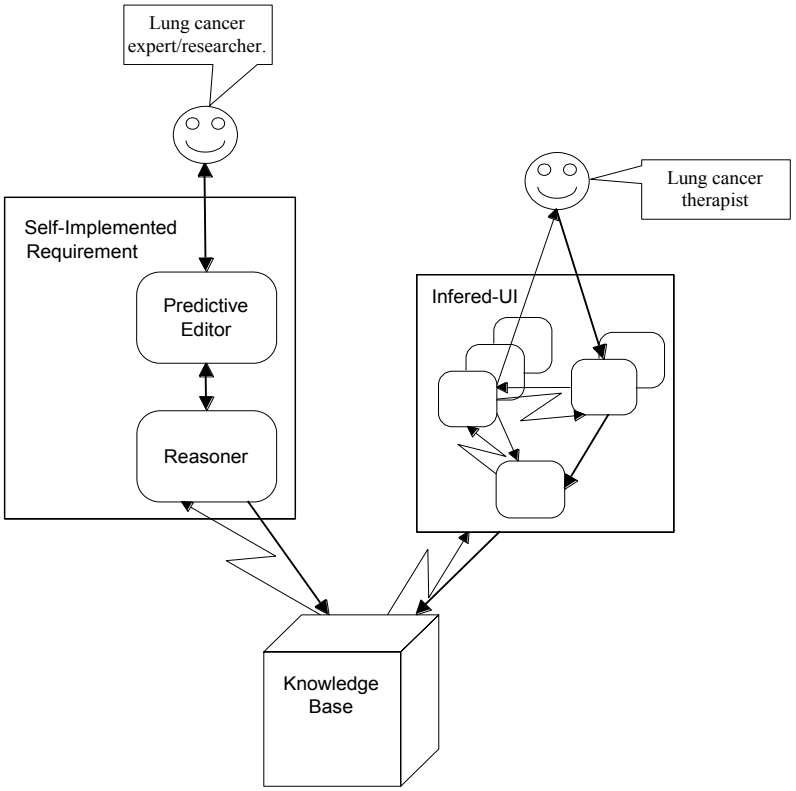


Figure 59. Architecture of CDSS

The CDSS presented here can be freely downloaded from the project website (see Appendix 7).

Appendix 7. THE WEB PAGE

The address of the website that supports the community interested in is: www.oase-tools.net. It is a good starting point for one that would like to make a future growth in OASE driven formal methods within the area of software development. The website will contains all the source codes and results described in appendixes of this thesis. It will be possible to take an advantage of using OASE-Tools by downloading them directly from the website; moreover it will be a source of knowledge about the OASE. The crucial knowledge about the purpose and usage of OASE is presented here, giving the opportunity to extend it for interested user. The website is made on WikiMedia solution. It allows one to add new articles, comments and/or upload the software solutions that take advantage from OASE-Tools.

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Inżynieria Oprogramowania Wspomagana Ontologicznie

Paweł Kapłański

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Streszczenie

WPROWADZENIE

Niniejsza praca doktorska łączy dziedziny takie jak: sztuczna inteligencja (AI), systemy formalnej reprezentacji wiedzy i wnioskowania (ang. *Knowledge Representation and Reasoning* - KRR), komputerowe wspomaganie wytwarzania oprogramowania (ang. *Computer-Aided Software Engineering* - CASE), oraz inżynierii oprogramowania opartej o modelowanie (ang. *Model-Driven Engineering* - MDE).

W szczególności, rozważamy tutaj logikę opisową (będącą podstawą matematyczną standardu W3C o nazwie OWL2). Formalizm ten pozwala na zapis statycznej struktury programu komputerowego, którą to jest rozstrzygalna (wnioskowanie o cechach tej struktury jest rozstrzygalne). Pokazujemy, że struktury statyczne są powszechne w inżynierii oprogramowania (np. diagramy klas UML, struktura wzorców projektowych, niektóre wymagania) oraz wskazujemy jak można poszerzyć obszar zastosowań logiki opisowej do zapisu kontraktów, których spójność jest badana w czasie wykonania programu.

Praca ta pokazuje również, w jaki sposób można połączyć świat specyfikacji formalnych ze światem języków programowania poprzez zastosowanie kontrolowanego języka naturalnego (ang. *Controlled Natural Language* - CNL) będącego werbalizacją logiki opisowej.

Celem niniejszej pracy doktorskiej jest wykazanie, że:

1) Można zdefiniować język, który pozwoli na zapis formalny (możliwy do przetwarzania automatycznego) struktur występujące w obiektowych metodach wytwarzania oprogramowania, który ma właściwości języka naturalnego. Możliwość tą upatrujemy w zastosowania kontrolowanego języka naturalnego, jako werbalizacji logiki opisowej.

2) Język ten może być stosowany w obszarach związanych z wytwarzaniem oprogramowania obecnie ściśle zarezerwowanych dla języka naturalnego.

3) Język ten jest użyteczny w procesie wspomagania produkcji oprogramowania.

STRUKTURA PRACY

Praca rozpoczyna się wprowadzeniem (rozdział 1). W rozdziale numer 2 zajmujemy się zagadnieniem inżynierii wiedzy z szczególnym naciskiem na ontologie, ich semiotykę oraz semantykę. Prezentujemy tu obecny stan wiedzy dotyczącej semiotyki formalnej z szczególnym naciskiem na logikę opisową - formalizm pozwalający na zapis użytecznych, rozstrzygalnych ontologii. Prezentujemy algorytmy pozwalające na wnioskowanie w logice opisowej. Dyskutujemy tu również semiotykę artefaktów pojawiających się w procesie wytwarzania oprogramowania.

W rozdziale numer 3 czytelnik znajdzie przegląd metod wytwarzania oprogramowania. Rozpoczynamy od przedstawienia historii oraz użyteczności poszczególnych rodzin języków programowania. Rozpatrujemy istniejące metody formalnego przedstawienia programów komputerowych. Wskazujemy różnice pomiędzy metodami zwinnymi a metodami inżynieryjnymi. W końcu, dyskutujemy koncepcję języka wzorców, która zainspirowana została pracami architekta Christophera Alexandra [Alex77].

W rozdziale 4 opisujemy, wynalezioną przez nas metodę o nazwie: "Inżynieria Oprogramowania Wspomagana Ontologicznie" (ang. *Ontology-Aided Software Engineering* - OASE). W metodzie tej, program komputerowy, jego projekt oraz wymagania przed nim stawiane, traktujemy jako ontologie. Dzięki takiemu przedstawieniu artefaktów algorytmy wnioskujące w logice (ang. *reasoners*) mogą aktywnie wspierać inżyniera zajmującego się rozwojem oprogramowania. Uogólniając, prezentujemy podejście do procesu wytwarzania oprogramowania w kategoriach semiotyki formalnej. W tym rozdziale rozważamy również zagadnienia związane z rozstrzygalnością oraz złożonością struktur występujących w programach komputerowych. Przedstawiamy również przykładowe problemy, które zmotywowały nas do rozpoczęcia badań nad metodą OASE. Wprowadzamy tutaj język OASE-English – kontrolowany język angielski, który pozostając werbalizacją logiki opisowej, został zaprojektowany specjalnie dla metody OASE, oraz przedstawiamy zarówno jego gramatykę jak i semantykę. Ponadto prezentujemy transformacje łączące świat wytwarzania oprogramowania z metodą OASE. Nazwaliśmy je OASE-Transformations. Prezentujemy koncept adnotacji oraz asercji semantycznych (odpowiednio: OASE-Annotations, OASE-Assertions). Adnotacje semantyczne wzbogacają język programowania, natomiast asercje semantyczne pomagają w znajdywaniu błędów w programach oraz mogą być traktowane, jak kontrakty (w rozumieniu programowania opartego o kontrakty). Na końcu tego

rozdziału, przedstawiamy OASE jako metodę pozwalającą na zapisanie, w sposób formalny, wzorców projektowych i przez co umożliwiającą zautomatyzowane wnioskowanie na temat poprawności ich użycia.

W rozdziale numer 5 prezentujemy narzędzia wspierające pracę z metodą OASE. Opisujemy ich strukturę wewnętrzną, sposób działania oraz przedstawiamy ich praktyczne zastosowania.

W rozdziale 6 przedstawiamy rozwiązania bazujące na ww. narzędziach takie jak: „Wywnioskowany interfejs użytkownika" (ang. *Inferred UI*) – sposób automatycznego generowania interfejsu użytkownika z ontologii, oraz „Wymaganie samoimplementujące się" (ang. *Self-Implemented Requirement*) – sposób na ograniczenie kosztów związanych ze zmieniającymi się wymaganiami użytkownika. Rozwiązania te dowodzą użyteczności ww. narzędzi również poza polem ich bezpośredniego zastosowania.

Podsumowanie oraz rezultaty pracy przedstawiono w rozdziale 7.

W pracy znajduje się siedem załączników. W załączniku pierwszym opisano w sposób szczegółowy mapowanie pomiędzy językiem kontrolowanym OASE-English a konstruktami logiki opisowej. Drugi załącznik prezentuje transformację OASE-Transformation, używaną do konwertowania kodu źródłowego programów napisanych w obiektowym języku programowania, do postaci skryptu w języku OASE-English. Załącznik numer 3 prezentuje transformację OASE-Transformation wzorca projektowego Adapter do skryptu w języku OASE-English. Załącznik numer 4 opisuje rezultaty ankiety, którą przeprowadzono na grupie projektantów i programistów mającej wskazać obecne ograniczenia i drogi dalszego rozwoju metody OASE. Załącznik numer 5 prezentuje wyniki eksperymentu walidacyjnego przeprowadzonego na tej samej grupie projektantów i programistów. Eksperyment ten miał za zadanie wykazanie użyteczność metody OASE. W załączniku numer 6 prezentujemy opis systemu wspierającego podejmowanie decyzji klinicznych (CDSS), który został zaimplementowany przez w ramach badań nad użytecznością narzędzi wspierających metodę OASE. Załącznik nr 7 prezentuje stronę internetową OASE (www.oase-tools.net), która w zamierzeniu ma stać się punktem wyjścia dla użytkowników zainteresowanych metodą OASE.

REZULTATY PRACY

Stworzona przez nas metoda pozwala na:

1) *Opisywanie praktyk i wzorców (uniwersaliów) wchodzących w skład procesu wytwarzania oprogramowania oraz na komponowanie ich w nowe praktyki i wzorce.* OASE pozwala na opisywanie uniwersaliów występujących w procesie wytwarzania oprogramowania (użyteczność metody OASE oceniono w bada-

niu ankietowym oraz w eksperymencie walidacyjnym). OASE pozwala na zapis uniwersaliów w kontrolowanym języku angielskim OASE-English. Pokazaliśmy, że program zapisany w obiektowym języku programowania tworzy Opis Świata w rozumieniu systemów zarządzania wiedzą. Ww. Opis Świata (ang. *World Description*) jest zbudowany na bazie określonej Terminologii będącej reprezentacją praw rządzących światem obiektowych języków programowania (takich jak np. polimorfizm, dziedziczenie, itp.) Wymagania stawiane przed programem (np. wymóg korzystania z pewnych wzorców projektowych, ograniczenia architektoniczne wprowadzone przez projektanta itp.) są reprezentowane tutaj, jako Ograniczniki Wiedzy (ang. *Integrity Constrains*), które mają reprezentację w bazie wiedzy w postaci wyrażeń pseudomodalnych. W kontekście OASE, architektura systemu, system oraz wzorce projektowe stają się równoprawne zarówno ze względu na semantykę jak i używaną przez użytkowników tej metody terminologię. Pozwala to na jednolite korzystanie z nich przez wszystkie osoby zaangażowane w rozwój oprogramowania. OASE pozwala również na automatyczne śledzenie postępów prac prowadzonych przez programistów, dzięki narzędziu walidacyjnemu, wcześniej zapisanych w postaci adnotacji i asercji, wymogów dotyczących tworzonego oprogramowania. Walidator udostępnia programiście wyjaśnienia w języku angielskim (ściśle w OASE-English), które prowadzą go niejako za rękę i dają jasne wskazówki, co do zakresu dalszych, wymaganych prac.

2) *Symulacja oprogramowania.* OASE pozwala na symulację struktury statycznej oprogramowania obiektowego poprzez umożliwienie wnioskowania w modelu formalnym tej struktury.
3) *Zamknięcie luki komunikacyjnej pomiędzy podmiotami zaangażowanymi w proces tworzenia oprogramowania.* To, że OASE zamyka lukę komunikacyjną udowadnia w pewien sposób przeprowadzony przez nas eksperyment wykonany na grupie programistów. W przeprowadzanych z nimi wywiadach opisują oni swoje osobiste doświadczenia z metodą OASE jako: „prowadzenie za rękę", czy „rozwiązywanie problemu typu puzzle". Co więcej, komponenty wspierające OASE (o nazwie OASE-Tools) udowodniły swoją przydatność w realizacji systemu wspomagania decyzji klinicznej (ang. Clinical Decision Support System – CDSS) – a co za tym idzie wykazaliśmy, że narzędzia OASE-Tools można wykorzystywać tak jak zwykłe (choć potężne) komponenty programów komputerowych.
4) *Elementy metody są użyteczne w innych dziedzinach niż wytwarzanie oprogramowania*. Stworzyliśmy rozwiązanie bazujące na komponentach OASE-Tools realizujące System Wspomagania Decyzji Klinicznych (CDSS), z szczególnym uwzględnieniem wiedzy dotyczącej raka płuca. Dzięki stworzeniu ww. Systemu wykazaliśmy, że komponenty wchodzące w skład metody OASE mają

zastosowanie również poza samą metodą. W przypadku CDSS pozwalają one na reużycie kanału komunikacyjnego wspieranego przez język OASE-English (stworzonego dla ludzi zajmujących się rozwijaniem oprogramowania) również przez terapeutów – lekarzy.

5) *Możliwość rozszerzania oraz modyfikacji metody*. Język OASE-English pozwala na pokrycie ekspresywności baz wiedzy w logice opisowej typu $\mathcal{SROIQ}$. Dzięki temu, możliwe jest rozszerzanie proponowanych przez nas praktyk i wzorców.

Stworzony przez nas język OASE-English jest zrozumiały dla ludzi, a jednocześnie może być przetwarzany automatycznie. Język ten może być stosowany w dziedzinach związanych z rozwojem oprogramowania, zarezerwowanych obecnie dla języka naturalnego. Udowodniliśmy to poprzez realizację systemu CDSS, który implementował wynalezione przez nas rozwiązania o nazwie „Wywnioskowany interfejs użytkownika" oraz „Wymaganie samo-implementujące się".

Stworzony język jest formalny a co za tym idzie może być przetwarzany przez algorytmy dowodzenia w logice opisowej. Dzięki temu, narzędzia wspierające OASE pozwalają na stworzenie procesu wytwarzania oprogramowania, w którym to komputer (przy użyciu algorytmów wnioskowania) utrzymuje automatycznie spójność bazy wiedzy, a wszelkie niespójności komunikowane są zainteresowanymi stronom w podzbiorze języka naturalnego. Komunikacja odbywa się w języku OASE-English, który jest wbudowany w język programowania (poprzez adnotacje) lub w języku UML (poprzez notatki języka UML).

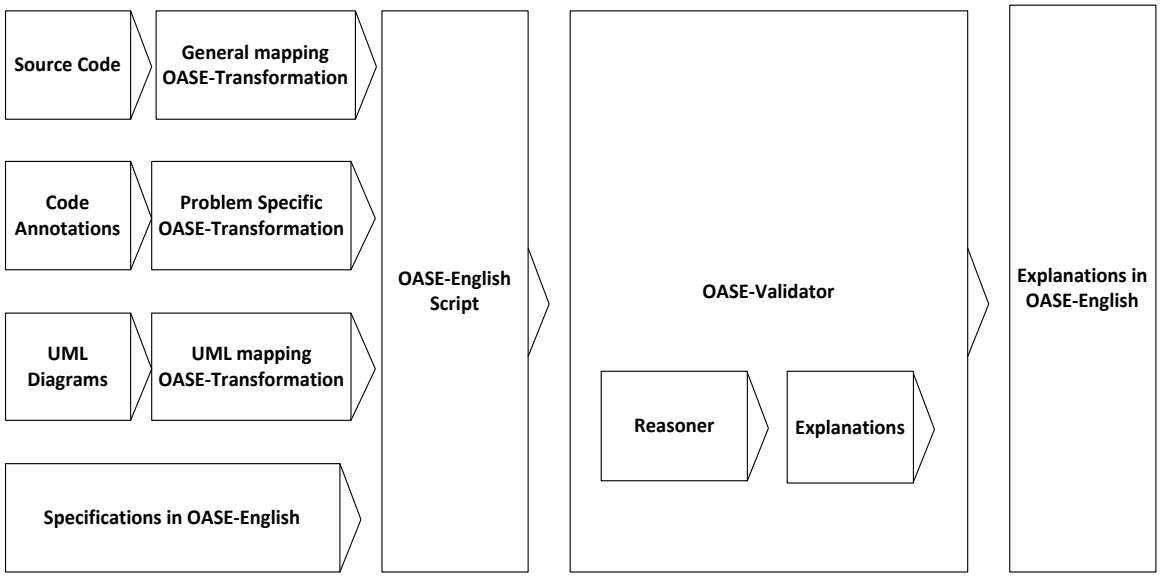
OPIS METODY OASE

Wynaleziona przez nas metoda rozwoju oprogramowania nazwana jest OASE (ang. *Ontology-Aided Software Engineering*), w nawiązaniu do metody CASE (ang. *Computer-Aided Software Engeenring*). OASE implementuje semiotyczny system formalny, lecz koncentruje się bezpośrednio na wytwarzaniu oprogramowania. Artefakty, będące produktami procesu wytwarzania oprogramowania, są wejściem dla głównego procesu wspieranego przez OASE (patrz Rysunek 1). Proces ten składa się z następujących etapów:

1) Artefakty oprogramowania (wymienione poniżej) stworzone przy wsparciu narzędzi OASE-Tool są przekształcane do skryptów w języku OASE-English za pomocą transformacji OASE-Transformation.
    a. Kod źródłowy – tworzony przez programistów
    b. Adnotacje i asercje semantyczne OASE-Annotations i OASE-Assertions – tworzone przez projektantów i programistów.
    c. Diagramy UML - wykonane przez projektantów (wyposażone w notatki zapisane w języku OASE-English)

d. Inne specyfikacje w języku OASE-English – takie jak wymagania dotyczące tworzonego programu, wiedza domenowa itp.

2) W drugim kroku, zbiorczy skrypt zapisany w języku OASE-English jest przetwarzany przez narzędzie o nazwie OASE-Validator. OASE-Validator interpretuje wyrażenia pseudo-modalne i uruchamia algorytmy wnioskowania w logice opisowej. Warto zauważyć, że właściwości logiki opisowej (jej rozstrzygalność) gwarantują, że proces wnioskowania się skończy.
3) OASE-Validator zwraca objaśnienia w formie ciągu wyrażeń w języku OASE-English. Objaśnienia są cenne dla użytkowników metody, gdyż opisują powody sytuacji konfliktowych.



Rysunek 1. OASE

OASE tworzy kanał komunikacyjny pomiędzy uczestnikami procesu wytwarzania oprogramowania. Jako, że kanał komunikacyjny musi spełniać wymogi semiotyki, OASE został wyposażony we wszystkie warstwy semiotyczne: składniową (ikony i symbole), semantyczną (logika opisowa) i pragmatyczną (narzędzia), aby jednak można było uznać OASE za użyteczną metodę rozwoju oprogramowania, musi ona dawać „coś więcej" niż obecne w literaturze i niejednokrotnie sprawdzone metody. Aby temu sprostać, kładziemy duży nacisk na ewaluację metody OASE w warunkach jak najbardziej zbliżonych do tych, z którymi będzie ona konfrontowana w rzeczywistości. Również z tego powodu postanowiliśmy wspierać w OASE, obecnie popularne, modelowanie graficzne w języku UML. Wynika to również z poczynionej przez nas obserwacji, że struktury oprogramowania mogą być widziane z wielu perspektyw. Wybrane perspektywy są z kolei preferowane przez osoby na skojarzonych z nimi stanowiskach. I tak, diagramy UML preferowane są przez projektantów i architektów oprogramowania i każda próba ograniczenia ich dostępności skazana jest na niepowodzenie. Narzędzia wspierające OASE umożli-

wiają konwertowanie diagramów UML do skryptów zapisanych w języku OASE-English, dzięki czemu narzędzia wspierające OASE eliminują to ograniczenie.

OASE-English jest werbalizacja logiki opisowej. Logika opisowa jest rozstrzygalnym podzbiorem logiki pierwszego rzędu (FOL) i z tego względu logika opisowa, jest idealnym kandydatem dla struktur statycznych występujących powszechnie w obiektowych metodach wytwarzania oprogramowania.

a) Logika opisowa koncentruje się na umożliwieniu zapisywania ontologii, a wiele struktur występujących w procesie wytwarzania oprogramowania jest ontologiami. Ta właściwość logiki opisowej pozwala na korzystanie z jednego i tego samego sposobu reprezentacji wiedzy zarówno do zapisu wymagań, projektu jak i do zapisu wysokopoziomowej architektury systemów informatycznych.
b) Logika opisowa jest rozstrzygalna z definicji, ponadto ma ona dialekty o wielomianowej złożoności obliczeniowej (np. $\mathcal{EL}^{++}$).
c) Dla logiki opisowej opracowano wydajne algorytmy wnioskowania, które umożliwiają stworzenie narzędzi zapewniających logiczną spójność artefaktów powstałych na różnych etapach rozwoju oprogramowania. Algorytmy te również zapewniają spójności pomiędzy artefaktami tworzonymi przez rzadko komunikujące się grupy osób (uczestniczących w danym projekcie informatycznym).

Struktury oprogramowania, w połączeniu z wiedzą formalną (w postaci ontologii zapisanych w logice opisowej), wspierane przez odpowiednie narzędzia, po poddaniu procesowi wnioskowania w logice, prowadzą do zdobycia dodatkowej wiedzy na temat programu komputerowego. Wiedza ta może być następnie użyta do weryfikacji ograniczeń projektowych lub może prowadzić do powstania potrzeby modyfikacji oprogramowania. Odpowiednio zarządzając ww. wiedzą można wytworzyć cykliczny proces wytwarzania oprogramowania, który jednocześnie zapewni głębokie zrozumienia problemów występujących w ww. procesie. Logika opisowa w tym procesie: jest zarówno formalizmem semantycznym pozwalającym na jego przetwarzanie przez maszynę w ograniczanym czasie i przestrzeni, zapewnia dobre rozumienie wiedzy przez szerokie grono ekspertów, oraz pozwala na formalne modelowanie oprogramowania.

Warstwa pragmatyczna metody OASE jest pokryta poprzez narzędzia np.: edytor predyktywny umożliwiający szybkie wprowadzenie poprawnych pod względem gramatycznym zdań w języku OASE-English. Narzędzia te pozwalają w łatwy sposób zintegrować OASE z istniejącym w organizacji środowiskiem programistycznym. Warto mieć na uwadze, że potrzeba używania edytora predyktywnego ważna jest jedynie w kontekście edycji wiedzy, natomiast sam proces czytania wyrażeń języka OASE-English nie przysparza trudności nawet początkującym użytkownikom tego języka, jako że jest to podzbiór języka angielskiego. Z drugiej strony osoby, które posługujące się w codziennej pracy językiem UML mogą w łatwy sposób przestawić

się na metodę OASE dzięki narzędzia wspierającego język UML o nazwie OASE-Diagrammer.

Metoda OASE nie jest zorientowana na konkretną metody tworzenia oprogramowania (pod warunkiem używania metod obiektowych), dzięki czemu można jej używać powszechnie.

WKŁAD W ROZWÓJ DZIEDZINY

Nasz wkład w rozwój dziedziny można podsumować następująco:

1) *Wykonaliśmy przegląd aktualnego stanu wiedzy w zakresie formalnych systemów semiotycznych, kładąc szczególny nacisk na semantykę formalną i inżynierię ontologii.* W szczególności rozważamy systemy reprezentacji wiedzy, ze szczególnym naciskiem na systemy oparte o logikę opisową (DL). Rozważamy również właściwości algorytmów wnioskowania w logice opisowej. Przyglądamy się również nowemu obszarowi badawczemu – semiotyce artefaktów powstających w procesie wytwarzania oprogramowania.
2) *Wykonaliśmy przegląd metod i narzędzi wykorzystywanych w procesie tworzenia oprogramowania.* Począwszy od klasyfikacji języków programowania i wspierających je formalizmów, poprzez podejścia do wytwarzania złożonych systemów oprogramowania, kończymy na problematyce obliczalności i złożoność struktur oprogramowania. Wskazaliśmy różnice pomiędzy zwinnymi metodami a inżynieryjnymi metodami wytwarzania oprogramowania. Ponadto dyskutujemy koncepcję języka wzorców projektowych, jako przykładu systemu semiotycznego.
3) *Zdefiniowaliśmy metodę wytwarzania oprogramowania wspieraną ontologiami (OASE).* Metoda ta pozwala na traktowanie artefaktów powstających w procesie wytwarzania oprogramowania, jako ontologii, a co za tym idzie daje możliwość stosowania narzędzi wspierających formalne systemy zarządzania wiedzą w procesie wytwarzania oprogramowania. OASE jest formalnym systemem semiotycznym stworzonym specjalnie dla wspierania procesu wytwarzania oprogramowania.
4) *Zdefiniowaliśmy kontrolowany język OASE-English.* OASE-English jest werbalizacją logiki opisowej. Przedstawiamy również, w szczegółach, mapowanie pomiędzy logiką opisową a OASE-English.
5) *Zdefiniowaliśmy transformacje OASE-Transformation*, pozwalające na bezpośrednią translację konstruktów pojawiających się w świecie oprogramowania zorientowanego obiektowo na język OASE-English. Pokazujemy jak OASE-Transformation można zastosować do formalnej specyfikacji wzorców projektowych.

6) *Stworzyliśmy narzędzia i komponenty ogólnego przeznaczenia wspierające język OASE-English*.
   a. OASE-Validator – komponent ogólnego przeznaczenia, narzędzie zapewniające komunikację z systemem dowodzenia poprzez interfejs w języku OASE-English. Przeprowadza wnioskowanie, sprawdza spójność wiedzy i zwraca wyniki walidacji w języku OASE-English.
   b. OASE-English-Predictor – komponent ogólnego przeznaczenia, edytor predyktywny języka OASE-English.
   c. OASE-Transformation Procesor – komponent ogólnego przeznaczenia działający na bazie silnika StringTemplate [Parr06]. Komponent przekształca wejście (w postaci drzewa symboli) do postaci skryptu zapisanego w OASE-English. W kontekście OASE narzędzie to pozwala na używanie OASE z poziomu zarówno języka programowania, jak i z poziomu graficznego narzędzia wspierającego język UML, bez konieczności jakiejkolwiek modyfikacji swoich codziennych nawyków pracy. Manipulacja kodu źródłowego czy diagramu UML jest transformowana, dzięki temu narzędziu, na manipulację skryptami OASE-English.
7) *Opracowanie systemu wspomagania decyzji klinicznych (CDSS), jako przykładu zastosowania narzędzi OASE-Tools w praktycznym rozwiązaniu niezwiązanym bezpośrednio z procesem rozwoju oprogramowania*. Prezentujemy dwie idee: „Wywnioskowany interfejs użytkownika", oraz „Wymaganie samo-implementujące się". CDDS implementuje obie idee i dowodzi, że komponenty składowe OASE-Tools mają szeroki wachlarz zastosowań praktycznych, również poza dziedziną z której się wywodzi.
8) *Zdefiniowaliśmy adnotacje semantyczne OASE-Annotations*, które wzbogacają samo programowanie poprzez umożliwienie korzystania z formalnych specyfikacji werbalizowanych w języku OASE-English. Adnotacje OASE-Annotations są walidowane za pomocą komponentu OASE-Validator.
9) *Zdefiniowaliśmy asercje semantyczne OASE-Assertions*, pozwalające na zapis kontraktów w postaci wyrażeń w języku OASE-English. Asercje sprawdzane są przez komponent OASE-Validator.
10) *Stworzyliśmy specjalistyczne narzędzia i komponenty zaprojektowane dla metody OASE*.
   a. OASE-Annotator – Wtyczka do środowiska MS Visual Studio, pozwalająca programistom na manipulowania asercjami i adnotacjami semantycznymi bezpośrednio z środowiska programistycznego. Narzędzie jest skierowane dla programistów.
   b. OASE-Diagrammer - Narzędzie pozwalające na korzystanie z adnotacji semantycznych jak z notatek w języku UML. Narzędzie to jest skierowane do projektantów przywykłych do obcowania z narzędziami modelowania graficznego w języku UML.

11) *Przeprowadziliśmy weryfikację i ocenę użyteczności metody OASE* za pomocą badania ankietowego oraz eksperymentu walidacyjnego. Badanie ankietowe miało na celu zebranie wiedzy dotyczącej poprawności założeń metody OASE. Z kolei eksperyment walidacyjny potwierdził użyteczność metody OASE.
12) *Stworzyliśmy stronę internetową [www.oase-tools.net]*. Jest ona punktem wejścia dla społeczności programistów i projektantów oraz wszystkich zainteresowanych metodą OASE.

OCENA UŻYTECZNOŚCI METODY

Semiotyczne warstwy OASE były oceniane w ramach eksperymentu walidacyjnego oraz w ramach odpowiednio spreparowanej ankiety. Ewaluacja wykazuje, że język OASE-English jest zrozumiały dla jego użytkowników, jednak okazuje się, że pewne aspekty użycia wyrażeń pseudo-modalnych mogą prowadzić do niejednoznaczności wśród programistów. Ustaliliśmy, że OASE poprawia komunikację pomiędzy projektantem i programistą dzięki zmniejszeniu ilości niezbędnych komunikacji pomiędzy nimi. Narzędzie OASE-Validator jest tutaj swoistym mediatorem, zapewniającym programistę o słuszności obranej przez niego drogi. Własność ta jest bardzo ważna w środowiskach rozproszonych (powszechnych obecnie ze względu na coraz większe znaczenie outsourcingu prac programistycznych), gdzie częsta komunikacja pomiędzy projektantem a programistą jest w znaczonym stopniu utrudniona.

DALSZE PRACE BADAWCZE

Systemy komputerowe możemy obecnie uważane są za systemy złożone z trzech typów agentów: oprogramowania, sprzętu i ludzi. Komunikacja między oprogramowaniem a sprzętem realizowane jest za pomocą kodu maszynowego, języki programowania z kolei umożliwiają komunikację człowieka z oprogramowaniem. Możliwość bezpośredniej komunikacji człowieka z maszyną (bez udziału języka programowania), staje się obecnie coraz bardziej pożądana. Naszym zdaniem warto prowadzić badania w tym kierunku. OASE-English jest podzbiorem języka angielskim. Proponujemy rozszerzenie spektrum języków o inne języki naturalne.

Chcemy również prowadzić dalsze prace nad praktycznym aspektem metody OASE, ze szczególnym uwzględnianiem pełnej integracji zespołów zajmujących się wytwarzaniem oprogramowania. W szczególności chcemy zbadać aspekt postrzegania modalności artefaktów powstających w procesie wytwarzania oprogramowania, jako, że odkryliśmy, iż ich znaczenie jest niejednoznaczne dla programistów. Spodziewamy się również znaleźć więcej potencjalnych zastosowań komponentów OASE-Tools w praktycznych aplikacjach w oderwaniu od samego procesu wytwarzania oprogramowania.

Ograniczenia metody OASE związane ze złożonością algorytmów wnioskowania w logice opisowej wskazują kolejny kierunek dalszych prac. Spodziewamy się, że wykorzystanie algorytmów dowodzenia mających złożoność wielomianową (np. $\mathcal{EL}^{++}$) lub wykorzystanie algorytmu kartograficznego [Gocz06] może zapewnić realizację narzędzi typu OASE-Validator, będących w stanie przetwarzać efektywnie kod źródłowy bardzo dużych systemów informatycznych.