Mapping Visual to Textual Representation of Knowledge in DESIRE

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Abstract

In this paper, graphical representations for knowledge structures in DESIRE (Brazier Dunin-Keplicz, Jennings & Treur 1995; Brazier, Treur, Wijngaards & Willems 1996) are presented, together with a graphical editor based on the Constraint Graph environment (Kremer, 1997). Moreover, a translator will be described which translates these graphical representations to textual representations in DESIRE. The strength of the combined environment is a powerful -- yet easy-to-use -- framework to support the development of knowledge based and multi-agent systems.

1 Introduction

Most languages for knowledge acquisition, elicitation, and reasoning are in pure text format. Text presentation is easier for a computer program to process. However, text form presentation is not an easily understandable form, especially for those domain experts who are not familiar with computer programming. Visual representation of knowledge relies on graphics rather than text. Visual representations are more understandable and transparent than textual representations (Nosek & Roth, 1990).

DESIRE (DEsign and Specification of Interacting REasoning components) (Brazier, Dunin-Keplicz, Jennings, Treur, 1995; Brazier, Treur, Wijngaards, Willems, 1996) is a development method used for the design of knowledge-based or multi-agent systems. DESIRE supports designers during the entire design process: from knowledge acquisition to automated prototype generation. DESIRE uses composition of processes and of knowledge composition to enhance transparency of the system and the knowledge used therein.

Originally, a textual knowledge representation language was used in DESIRE. Recently, as a continuation of the work represented in (Moeller, Willems, 1995) a graphical representation method for knowledge structures has been developed. A description of both graphical and textual representation of knowledge is given in Section 2.

Constraint Graphs (Kremer, 1997) is a concept mapping "meta-language" that allows one to visually define any number of target concept mapping languages. Once a target language is defined (for example, the DESIRE's graphical representation language) the constraint graphs program can emulate a graphical editor for the language as though it were custom build for the target language. This "custom" graphical editor can prevent the user from making syntactically illegal constructs and dynamically constraint user choices to those allowed by the syntax.

Constraint Graph's graphical environment is used to represent knowledge in a way that corresponds closely to the graphical representation language for knowledge that is used in

DESIRE. A translator is described that bridges the gap between the graphical representation and the syntax of the textual representation language used in DESIRE.

2 Graphical Knowledge Representation in DESIRE

In this section both graphical and textual representations are presented for the specification of knowledge structures in DESIRE (Brazier, Dunin-Keplicz, Jennings & Treur 1995). Knowledge structures in DESIRE consist of information types and knowledge bases. In Sections 2.1 and 2.2 graphical and textual representations of information types are discussed. In Section 2.3 representations of knowledge bases are discussed.

Information types (also called signatures) provide the ontology for the languages used in components of the system, knowledge bases and information links between components.

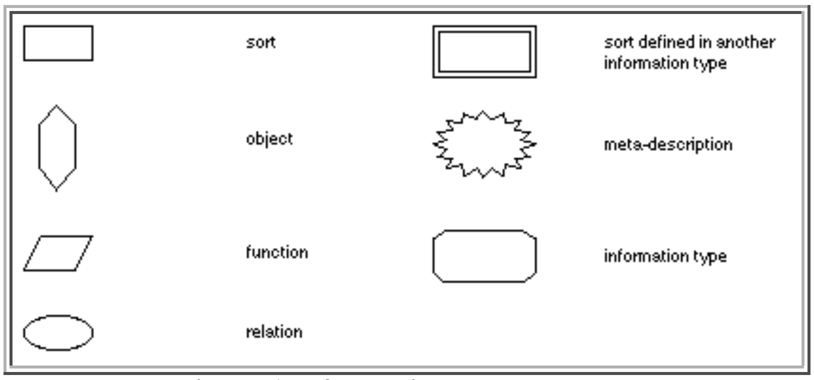


Figure 1 Information types: Legend

In information type specifications the following concepts are used: sorts, sub-sorts,objects, relations, functions, references, and meta-descriptions. For the graphical specification of information types, the icons in Figure 1 are used.

2.1 Basic concepts in information types

A sort can be viewed as a representation of a part of the domain. The set of sorts categorizes the objects and terms of the domain into groups. All objects used in a specification have to be typed, i.e., assigned to a sort. Terms are either objects, variables, or function applications. Each term belongs to a certain sort. The specification of a function consists of a name and information regarding the sorts that form the domain and the sort that forms the co-domain of the function. The function name in combination with instantiated function arguments forms a term. The term is of the sort that forms the co-domain of the function. Relations are the concepts needed to make statements. Relations are defined on a list of arguments that belong to certain sorts. If the list is empty, the relation is a nullary relation, also called a propositional atom. The information type birds is an example information type specifying sorts, objects, functions and atoms with which some knowledge concerning birds can be specified. The information type is specified graphically in Figure 2, and textually in Example 1.

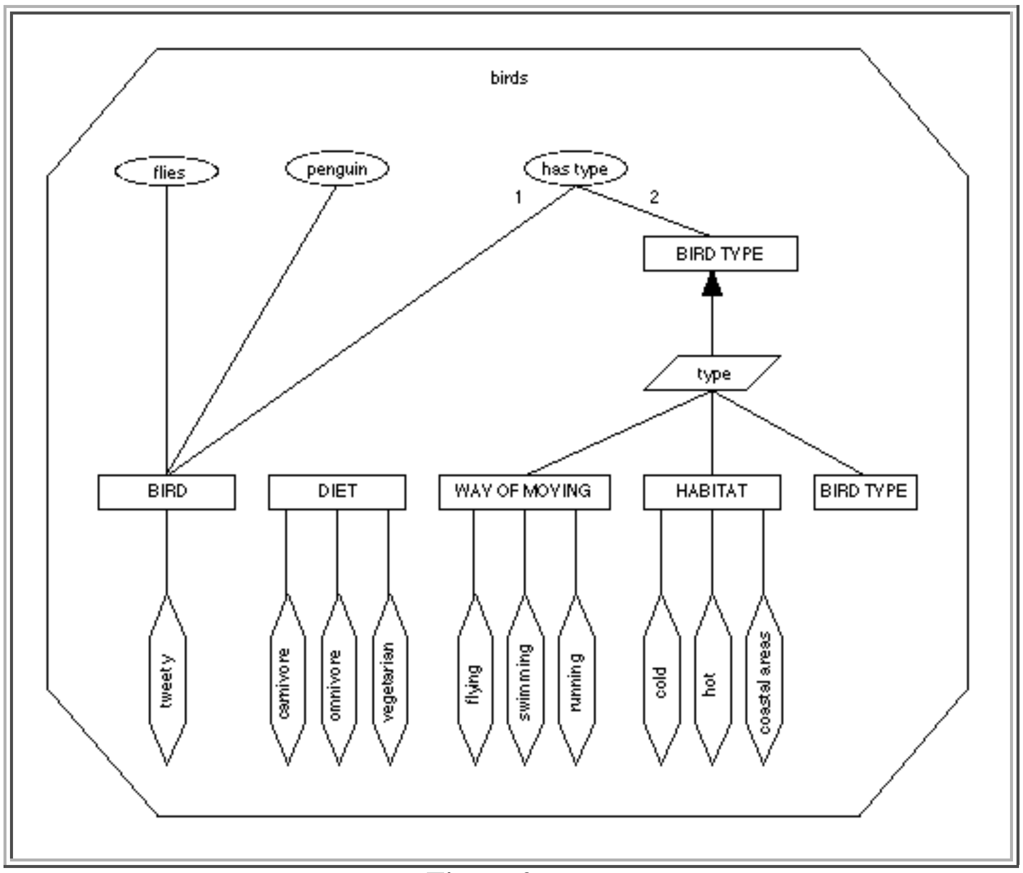


Figure 2 **birds**

```
information type birds
        sorts BIRD, DIET, WAY_OF_MOVING, HABITAT, BIRD_TYPE;

        objects tweety : BIRD; carnivore, omnivore, vegetarian : DIET;

                flying, swimming, running : WAY_OF_MOVING;

                cold, hot, coastal_areas : HABITAT;

        functions type : DIET * WAY_OF_MOVING * HABITAT -> BIRD_TYPE;

        relations flies, penguin : BIRD;

                has_type : BIRD * BIRD_TYPE;
end information type
```

Example 1

2.2 Compositionality of information types

Compositionality of knowledge structures is important for the transparency and reusability of specifications. In DESIRE two features enable compositionality with respect to information types: information type references, and meta-descriptions. By means of information type references it is possible to import one (or more) information type(s) into another. Referencing is useful as it enables the definition of a generic relation on a sort (for which objects may not have been specified) in one information type, and the addition of objects, functions, relations, and sub-sorts to the sort in another information type. For example, information type birds above can be used in an information type that specifies a language for objects that might fly. Suppose that flying objects are either flying birds, flying insects, or flying machines. Given the information types birds, insects, and machines the more complex information type flying objects presented in Figure 3 and Example 2, can be constructed using information type references. Note that the sorts BIRD, INSECT, and MACHINE are specified to be sub-sorts of sort WORLD OBJECT.

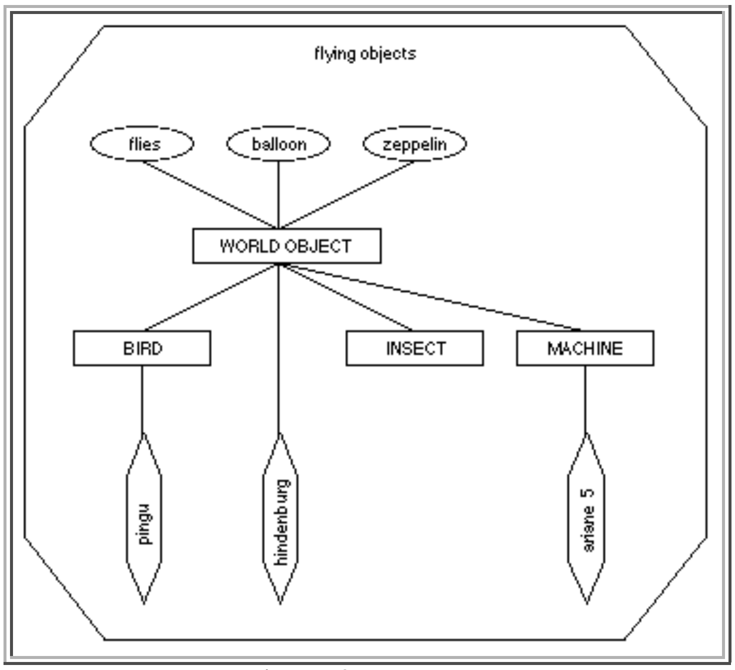


Figure 3 flying objects

information type flying_objects

information types birds, insects, machines;

sorts WORLD_OBJECT;

sub-sorts BIRD, INSECT, MACHINE : WORLD_OBJECT;

objects ariane_5 : MACHINE;

pingu : BIRD;

hindenburg : WORLD_OBJECT;

relations zeppelin, balloon, flies : WORLD_OBJECT;

end information type

Example 2

The second feature supporting compositional design of information types is the meta-description mechanism. The value of distinguishing meta-level knowledge from object level knowledge is well recognized. For meta-level reasoning a meta-language needs to be specified. Using the above constructs it is possible to specify information types that describe the meta-language of already existing languages. As an example, a meta-information type, called *about birds*, is constructed using a meta-description of the information type birds (see Figure 4). The meta-description of information type birds connected to sort BIRD ATOM ensures that every atom of information type birds is available as a term of sort BIRD ATOM. The textual specification of information type about birds is presented in Example 3.

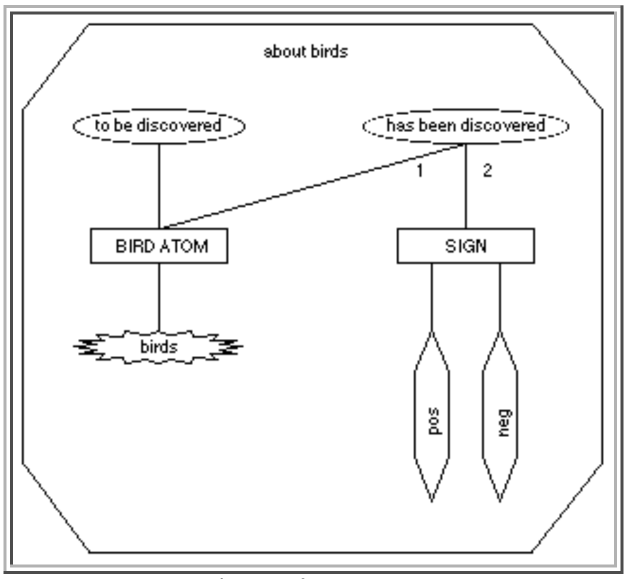


Figure 4 **about birds**

information type about_birds

sorts BIRD_ATOM, SIGN;

meta-descriptions birds : BIRD_ATOM;

objects pos, neg : SIGN;

relations has_been_discovered : BIRD_ATOM * SIGN;

to_be_discovered : BIRD_ATOM;

end information type

Example 3

2.3 Knowledge bases

Knowledge bases express relationships between, for example, domain specific concepts. Reasoning processes use these relationships to derive explicit additional information. Consider information type compare birds.

information type compare_birds
information types birds;

relations same_type: BIRD * BIRD;

end information type

The knowledge base birds kbs specified in Example 4 expresses which birds are of the same type, and which birds fly. The first rule is graphically represented in Figure 5.

knowledge base birds_kbs

information types compare_birds;
contents
if has_type(X: BIRD, Y: BIRD_TYPE)
and has_type(Z: BIRD, Y: BIRD_TYPE)

Example 4

```
                    then same_type(X: BIRD, Z: BIRD);

                    if has_type(X: BIRD, type(Y: DIET, flying, Z: HABITAT)
                    then flies(X: BIRD);
                    has_type(tweety, type(vegetarian, flying, hot));

end knowledge bas
```

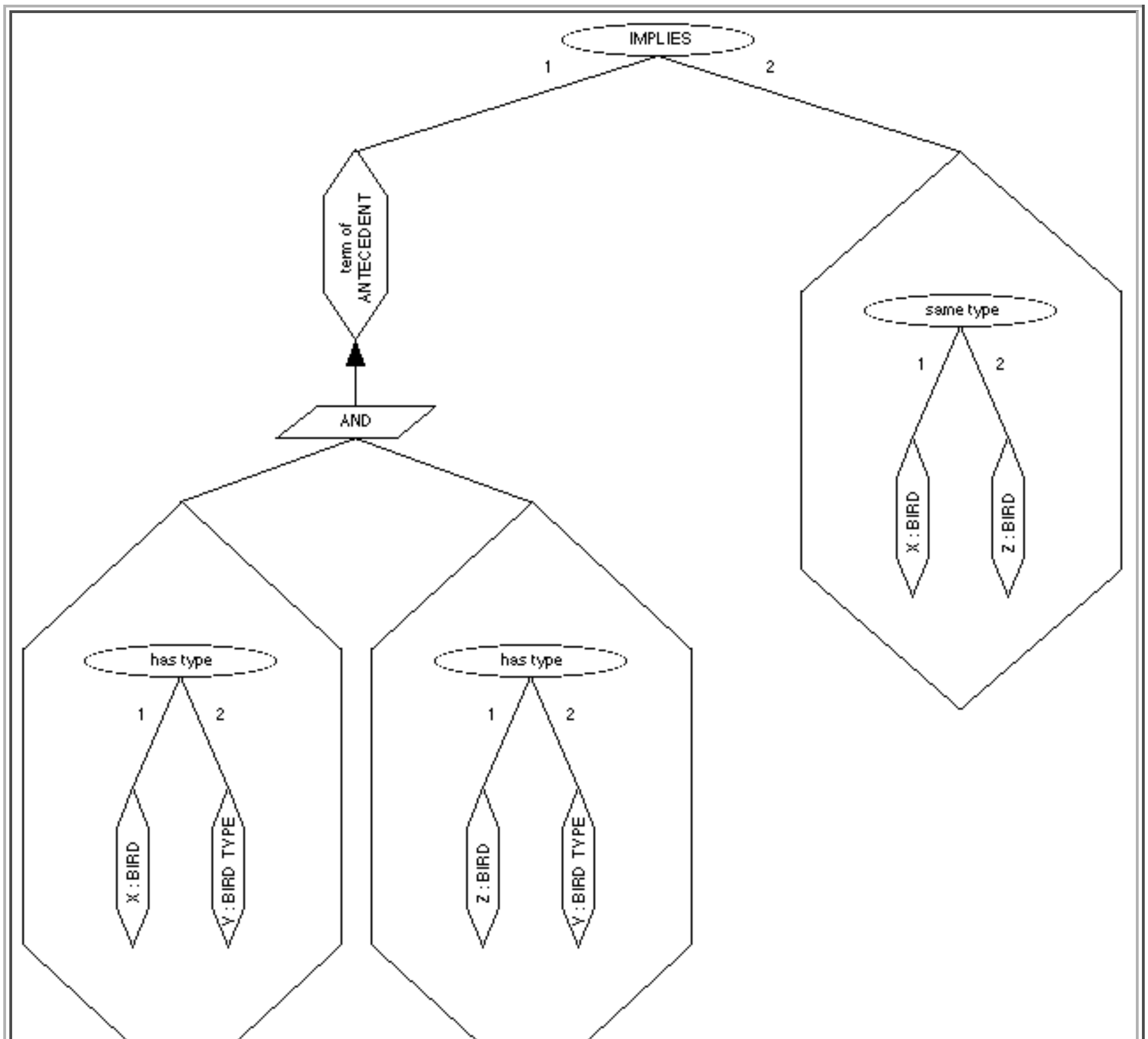


Figure 5 Graphical representation of a rule

Finally, compositionality also can be used for knowledge bases. One knowledge base can reference several other knowledge bases. The knowledge base elements of knowledge bases to which the specification refers are also used to deduce information. An Example of the graphical representation of knowledge base referencing is presented in Figure 6.

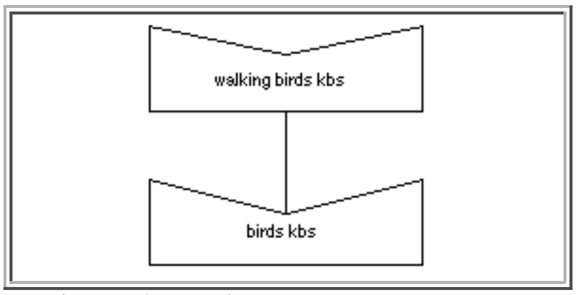


Figure 6 Relations between Knowledge bases

In Figure 7 an example is given of the graphical representation of relations between knowledge bases and information types.

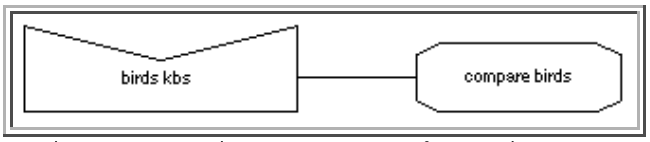


Figure 7 Relations between Information types and Knowledge bases

3 Constraint Graphs

Constraint graphs is a concept mapping "meta-language" that allows one to visually define any number of target concept mapping languages. Once a target language is defined (for example, the DESIRE knowledge representation language) the constraint graphs program can emulate a graphical editor for the language as though it were custom build for the target language. This "custom" graphical editor can prevent the user making synactically illegal constructs and dynamically constraint user choices to those allowed by the syntax.

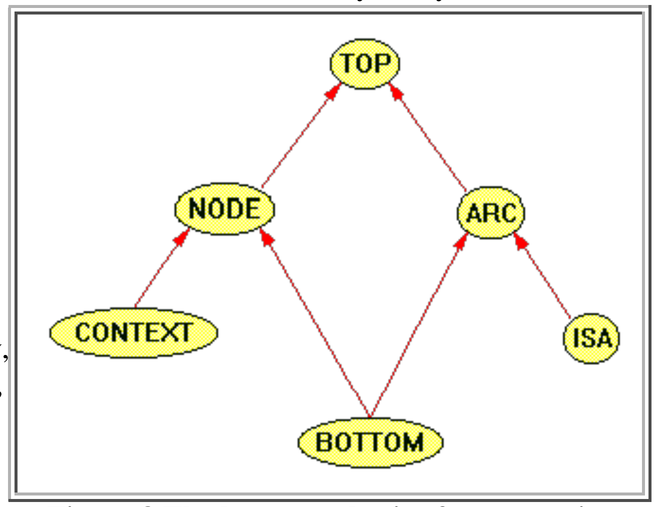


Figure 8 The base type lattice for constraint graphs

In order to accomodate a large number of visual languages, constraint graphs must make as few assumptions about concept mapping languages as possible. To this end, constraint graphs defines only four base components: *node*, *arc*, *context*, and *isa* (see Figure 8). Nodes and arcs are mutually exclusive, where nodes are the *vertices* from graph theory, and arcs interconnect other components, and are analogous to *edges* in graph theory. Both nodes and arcs may (or may not) be labeled, typed, and visual distinguished by color, shape, style, etc. *Contexts* are a subtype of node and may contain a partition of the graph. *Isa* arcs are a subtype of *arc* and are used by the system to define the subtype relation: one defines one component to the be a subtype of another component merely by drawing an *isa* arc from the subtype to the supertype.

Futhermore, the generality requirement of constraint graphs dictates that arcs are not always binary, but may also be unary or of any arbitrary arity greater than 1 (i.e., trinary and n-ary arcs are allowed). For example, the *between* relation puts a trinary arc to good use. Constraint graphs arcs may interconnect not only nodes but other arcs as well. This is not only useful, but necessary because all subtype and instance-of relations are defined using an *isa* arc, arcs between arcs are required to define the type of any arc. Finally, constraint graphs does not make hard distinctions between types and instances, but rather, follows the object-delegation model (Abadi & Cardelli 1996) where any object can function as a class or type. (Constraint graphs can *prevent* a component from acting as a type using *ad-hoc constraints* (Kremer 1997), but that is beyond the scope of this paper.)

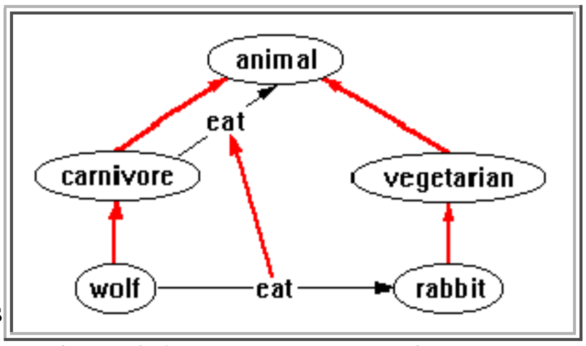


Figure 9 An example constraint graphs definition.

To illustrate some of the above points, Figure 9 shows a simple definition. Here, the red, directed arcs are the constraint graphs *isa* arcs and define *carnivore* and *vegetarian* to be subtypes of *animal, wolf* as a subtype (or instance-of) of *carnivore*, and *rabbit* as a subtype (or instance-of) of *vegetarian*. Furthermore the *eat* binary arc (or relation) is defined and starts on *carnivore* and terminates on *animal*. These terminals are important: the components at the terminals constrain all subtypes of *eat* to also terminate at some subtype of *carnivore* and *animal* respectively. The second *eat* arc is defined (by the red *isa* arc between it's label and the first *eat* arc's label) to be a subtype of the first *eat* arc. It is therefore legally drawn between *wolf* and *rabbit*, but the editor would refuse to let it be drawn in the reverse direction: the *eat* definition says that rabbits can't eat wolves.

4. The Translator

4.1 Specifying the graphical notations in Constraint Graphs

In Constraint Graphs, three basic types of objects exist: nodes, arcs and contexts. The elements of the language to be expressed in the Constraint Graphs' environment therefore need to be mapped onto these basic types. Table 1 below shows the mapping between DESIRE's knowledge elements and nodes, arcs and contexts.

	Object	Sort	Subsort	Meta description	Function	Relation	Information type	Knowledge Base
NODE	X	X	-	-	-	-	-	-
ARC	-	-	X	X	X	X	-	-
CONTEXT	-	-	-	-	-	-	X	X

Table 1: Mapping between DESIRE and Contraint Graphs

Constraint Graphs allows the user to further constrain the language definition in Constraint Graphs by, for example, restricting the shapes and connector types of the nodes and arcs the language elements are mapped onto. In our case, we restrict the shape of node Sort to a rectangle, and the shape of Object to a diamond. Furthermore, sub-sorts, meta-descriptions and relations will be represented as directed labeled arcs, where the label takes the shape of an ellipse. Moreover, functions will be depicted as directed labeled arcs as well, but the label will be a parallelogram. Finally, information types and knowledge bases are mapped onto contexts, and the shape of these contexts will be the default: a rectangle. Although these shapes do not correspond to the shapes of the graphical representation language used in DESIRE, no confusion is expected.

Figure 10 below gives an impression of a specification of the DESIRE information type birds (compare to Figure 2) in Constraint Graphs.

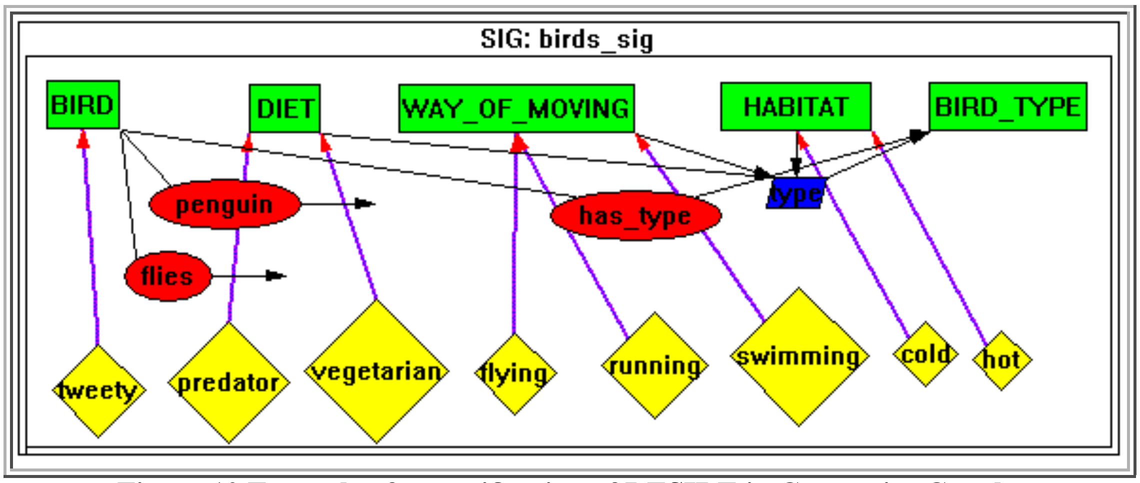


Figure 10 Example of a specification of DESIRE in Constraint Graphs

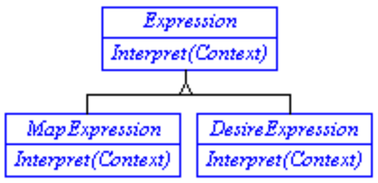
4.2 Implementation of the Translator

Every mature engineering discipline has handbooks to describe successful solutions for known problems. There now exists a software design patterns literature (beginning with a book by Gamma et al (Gamma, Helm, Johnson, and Vlissides, 1994)) describing successful solutions to common software problems. Industrial experience has proven that patterns are a valuable technique in software engineering problem-solving discipline. Not only do patterns capture successful experience, they also help improve communication among designers. They can help new developers avoid traps and pitfalls that traditionally can only learned by costly experience. Patterns do more than just describe solutions, they help reason deep rationale of the solutions. This section uses patterns to detail some aspects of the translator implementation.

The translator was implemented with Borland C++ under Windows NT. To make the program more portable, only ANSI C++ syntax is used. The implementation details that do not relate to design patterns are omitted here.

4.2.1 Interpreter Pattern

The intent of the Interpreter pattern is to represent the grammar of a language and interpret sentences in the language (Gamma, Helm, Johnson, and Vlissides, 1994, pp 243-255). The Interpret pattern represents each grammar rule as a class. Symbols on the right-hand side of grammar rule are instance variables of the class. The TerminalExpression implements an *Interpret* method associated with terminal symbol in the grammar. The NonterminalExpression implements the *Interpret* method for nonterminal symbol in the grammar. Typically the *Interpret* method of NonterminalExpression is implemented by calling the *Interpret* methods of its subexpressions. The *Interpret* method takes Context as an argument. The Context provides information global to the interpreter. What the Context should contain totally depends on what the *Interpret* method intends to do.



For the translator, the class hierarchy for the Interpreter pattern has a common abstract class *Expression*. *Expression* declares a pure virtual *Interpret* method which will be inherited and implemented by all its concrete subclass. It has two direct subclasses: *MapExpression* and *DesireExpression*. These two classes are also abstract classes. They act as the base classes of Constraint Graph and DESIRE object hierarchies respectively. All Constraint Graph expression nodes are subclasses of *MapExpression;* all DESIRE expression nodes are subclasses of *DesireExpression*.

Terminal Expression

For TerminalExpression, the implementation of the representing class is simple and straightforward. Besides the attributes and methods needed for normal functioning, it must implement the virtual *Interpret* method inherited from base class. The *Interpret* method will interpret the corresponding terminal symbol that the class represents. For example, DESIRE has a grammar rule defining variables:

```
<variable> ::= <variable_name> ":" <sort_name>
```

This is a terminal expression. This grammar rule was modeled as class *DesireVariable* shown in Listing 2.

```
class DesireVariable : public DesireExpression {

public:

   ...

   int Interpret(Context);

   ...

protected:

   String varName;

   String sortName;

};
```

Listing 2: Class Definition of DesireVariable

This class has two instance variables, *variable_name* and *sort_name*, which correspond to the symbols appearing on the right-hand side of its grammar rule. It also implements the *Interpret* method declared in its parent class. The *Interpret* method checks whether an expression is valid according to the Context. For variables, a variable is legal if the sort is defined. Through the Context, one can check whether a symbol is defined and the type of the symbol. The *Interpret* method can be defined as:

```
int DesireVariable::Interpret(Context c)

{

   if(c.defined(sortName) && c.typeOf(sortName) == "sorts")

      return 1;

   else

     return 0;

}
```

Listing 3: Interpret Method of DesireVariable Class

In the above code, *defined* and *typeOf* are methods defined in Context that checks whether a symbol is defined and what its type is.

Nonterminal Expression

For NonterminalExperssion, as described in Gamma, et al:

- "one such class is required for each rule $R::=R_1R_2...R_n$ in the grammar".
- "maintains an instance variable of type AbstractExpression for each of the symbols R_1 through R_n in the grammar".
- "implements an Interpret operation for nonterminal symbols in the grammar. Interpret typically calls itself recursively on the variables representing R_1 through R_n" (Gamma, Helm, Johnson, and Vlissides, 1994, p. 246).

The second point, *maintains an instance variable of type AbstractExpression for each of the symbols R_1 through R_n in the grammar*, deserves further explanation. At the first glance, the sentence may seem that the authors were advocating using class AbstractExpression as instance variables types. But further investigating shows that is not what the authors means.

Note the use of the word *type*, instead of *class* before AbstractExpression. This should be taken to imply that the instance variable is *some subtype of* AbstractExpression, not *precisely* AbstractExpression. In class-based languages (e.g., C++), subclassing is subtyping (Abadi and Cardelli, 1996). By subsumption, a value of type A can be viewed as a value of a supertype B. So, if c' is a subclass of c, then an instance of class c' is an instance of class c. A subtype can be used in any place where a supertype can be used. Since any subclass type is of its base class type, the instance variables type can be the type of any subclasses of AbstractExpression.

For example, consider the following grammar rule of DESIRE.

```
knowledge_base::= knowledge base <kb_name>

                  [knowledge_base_interface]

                  [knowledge_base_reference]

                  knowledge_base_contents

                  end knowledge base.
```

Listing 4: Grammar Rule of Knowledge Base in DESIRE

Knowledge_base_interface has been modeled as class *DesireKBInterface*. *Knowledge_base_reference* has been modeled as *DesireKBRef*. And *Knowledge_base_contents* has been modeled as *DesireKBContent*. How does one model *Knowledge_base*? Of course, all the instance variables can be subsumed to DesireExpression, one *could* use the DesireExpression class as the type of all instance variables. Doing so has no run-time effect. But it has the consequence of reducing static knowledge about the true type of objects. So subtypes are used as the instance variable types if the instance type information is evident from the grammar syntax. The above grammar rule is implemented as in Listing 5.

```
class DesireKB : public DesireExpression {

public:

   ...

   Interpret(Context);

```

Listing 5: Class Definition of DesireKB

```
   ...

protected:

   string name;

   DesireKBInterface* kbInterface;

   DesireKBReference* kbReference;

   DesireKBContent kbContent;

};
```

Each R_1, R_2, ..., R_n in the grammar rule is maintained as an instance variable of a specific subclasse type. These can be treated as type DesireExpression or Expression by subsumption if necessary. This approach is advantageous for the following reasons:

- The static object types of symbols in NonterminalExpression are made obvious. It is easier to relate classes to grammar rules.
- It is more type-safe. Since the type of instance variables are all specific subclasses type, not the generic AbstractExpression, there are no need to get the instance types at run time. While using these instance variables, there are no need to use `dynamic_cast<>` to get their actual types dynamically.
- Statically specifying instance variable's type can also ensure objects of the wrong type cannot be set/added to the NonterminalExpression. Therefore, the instance of NonterminalExpression will not contain wrong types of instance variables. The creation of NonterminalExpressions will be less error-prone.

The *Interpret* method for NonterminalExpression calls the *Interpret* method of instance variables representing R_1 through R_n. For example, to check whether a symbol is valid, the *Interpret* method of class *DesireKB* can be implemented as in Listing 6.

```
int DesireKB::Interpret(Context c)

{

   int ret = 1;

   if(kbInterface)

      ret = ret && kbInterface->Interpret(c);

   if(kbReference)

      ret = ret && kbReference->Interpret(c);

   ret = ret && kbContent.Interpret(c);

   return ret;

}
```

Listing 6: Interpret Method of DesireKB

Class Structure

The class structure of the implementation is shown in Figure 11.

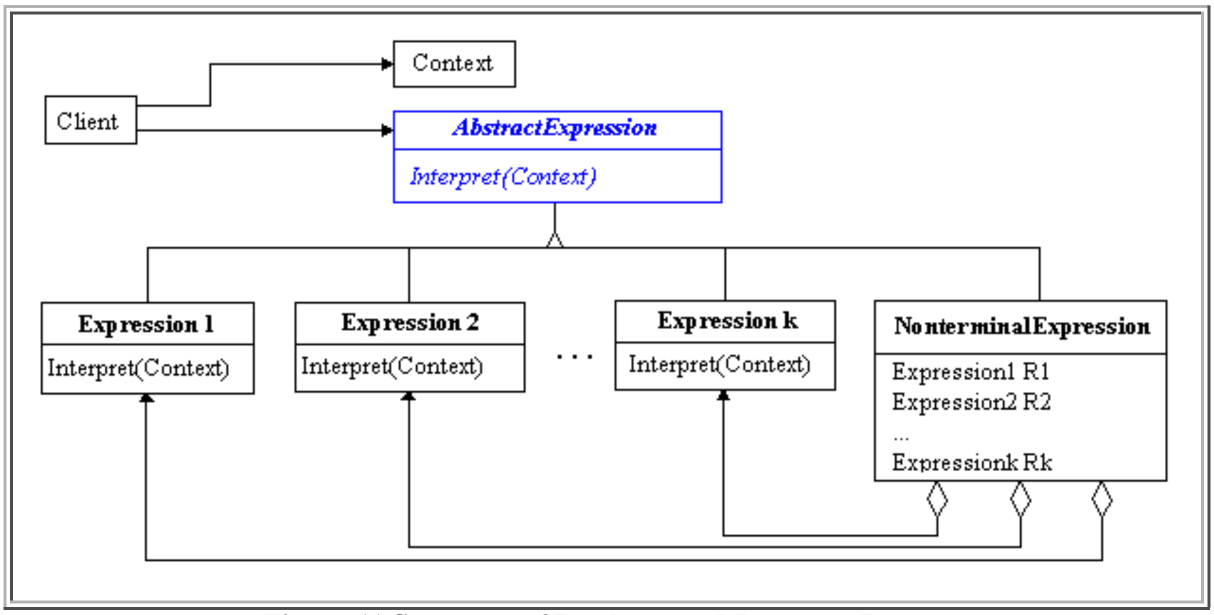


Figure 11 Structure of Implemented Interpret Pattern

In Figure 11, *Expression1*, *Expression2*, *Expressionk* can be either TerminalExpression or NonterminalExpression. If it is NonterminalExpression, their structures will be similar to the one shown in the figure.

Context

Context provides information that is global to the Interpreter. The kind of attributes and methods that class Context should have depend on what kind of operation the *Interpret* method intends to do. One *Interpret* method of Constraint Graph is to draw the graphics. So the Context class provides the device handle of the drawing, and the drawing position, as shown in Listing 7.

```
class Context {

public:

  Context();

  virtual ~Context();

  void SetPoint1(TPoint&);

  void SetPoint2(TPoint&);

  void SetDevice(DEVICE);

  TPoint GetPoint1();

  TPoint GetPoint2();

  DEVICE GetDevice();

protected:

  TPoint p1;

  TPoint p2;

  DEVICE Device;
```

Listing 7: Class Definition of Context

```
};
```

The grammar of both languages is not likely to have major changes; at most they will undergo minor changes. Therefore, it is preferable that the classes of Interpreter class structures can be kept unchanged unless the grammar of the language changes. In the mean time, new ways of interpreting the languages should be convenient to add. How can new interpretation operations be added without changing classes of the class structure?

The Interpreter pattern distributes the *Interpret* method over the whole class structure. Every class in the class structure needs to be modified if another kind of interpretation is needed, i.e., new *Interpret* methods must be added into each class. When there are many classes in the class structure, it will be very time-consuming and error-prone to make such changes.

The Visitor pattern represents an operation to be performed on the elements of a class structure (Gamma, Helm, Johnson, and Vlissides, 1994, pp 331-344). Each Visitor is a set of related operations that can be performed on the elements of the class structure. New operations can be introduced without changing the classes of the elements on which it operates. The Visitor pattern deals with two class hierarchies: the *Visitor*, and the *Elements* on which the *Visitor* operates. For each concrete class in the *Element* class hierarchy, a visit method is defined in the *Visitor* class. Each class of the Element hierarchy defines an *Accept* method which introduces *Visitor* into the class hierarchy. Element class sends a request to *Visitor* by calling the *Accept* method which takes an object of the Visitor class as its argument. The *Accept* method invokes the *visit* method defined in the Visitor class and passes the object itself as the argument to the *visit* method.

The *Elements* of current system are the class hierarchy of the Interpreter pattern implementations. The subsection below describes the implementation of the *Visitor*.

Visitor

An abstract *Visitor* class is defined so that more than one operation can be defined. Each kind of operation can be defined as a concrete subclass of the abstract *Visitor* class. In the abstract *Visitor* class, a pure virtual method *visit* is defined for each TerminalExpression class; however, for NonterminalExpression, two visit methods, *visit* and *postVisit*, are defined. The *visit* method visits the element before visiting its composing components. The *postVisit* method visits the element after visiting its composing components.

The reason for defining two *visit* methods for NonterminalExpression is due to its inherent structure. NonterminalExpression is composed of other expressions. No presumption can be made about when *Visitor* should "visit" its composing components, either before or after visiting itself. In addition, such nodes may need some pre-processing before they process their constituent components, and some post-processing after they have processed their constituent components. Defining two *visit* methods for NonterminalExpression classes solves both problems.

Element

Each element defines an *Accept* method which takes *Visitor* as an argument. By calling *Accept*, the element sends a request to *Visitor*, and passes itself as the argument. The *Visitor* will then perform the desired operation for the element. Listing 8 shows the *Accept* method of *DesireVariable* class.

As mentioned above, no presumptions can be made about when its composing components should be visited for NonterminalExpression, the *Accept* method of such nodes must send requests to *Visitor* twice: one before visiting its composing components, the `Visit` function call, and again after visiting its composing components, the `postVisit` function call, as shown in Listing 9.

Sample Code

Below is some code segments of the pretty printing visitor pattern used in the translator.

```
void DesireVariable::Accept(DesireVisitor& v)

{

  v.Visit(this);

}

void DPrettyPrintVisitor::visit(DesireVariable* v)

{

  if(needComma) out << ',';

  else needComma = 1;

  out << v->GetName() << ":" << v->GetSort();

  currentCol += (v->GetName().length() + v->GetSort().length() + 1);

  needComma = 1;

}
```

Listing 8: Pretty Printing Visitor for class DesireVariable

In the above code, *out*, *needComma*, *currentCol* are instance variables defined in class *DPrettyPrintVisitor*. They support and control the behavior of the DPrettyPrintVisitor. *numberOfTabs* is also an instance variable of class *DPrettyPrintVisitor* to control the position of printing.

```
void DesireKB::Accept(DesireVisitor& v)

{

  v.Visit(this);

  if(kbInterface)

    kbInterface->Accept(v);

  if(kbReference)

    kbReference->Accept(v);

  kbContent.Accept(v);

  v.postVisit(this);

}

void DPrettyPrintVisitor::visit(DesireKB* kb)

{

  if(currentCol)
```

Listing 9: Pretty Printing Visitor for DesireKB

```
    out << endl;
  numberOfTabs = 1;
  out << "knowledge base " << kb->GetName() << endl;
  currentCol = 0;
}
void DPrettyPrintVisitor::postVisit(DesireKB*)
{
  if(currentCol)
    out << endl;
  out << "end knowledge base." << endl << endl;
  numberOfTabs = 0;
  currentCol = 0;
}
```

Class Structure

The class structure of the implemented *Visitor* pattern is shown in Figure 12.

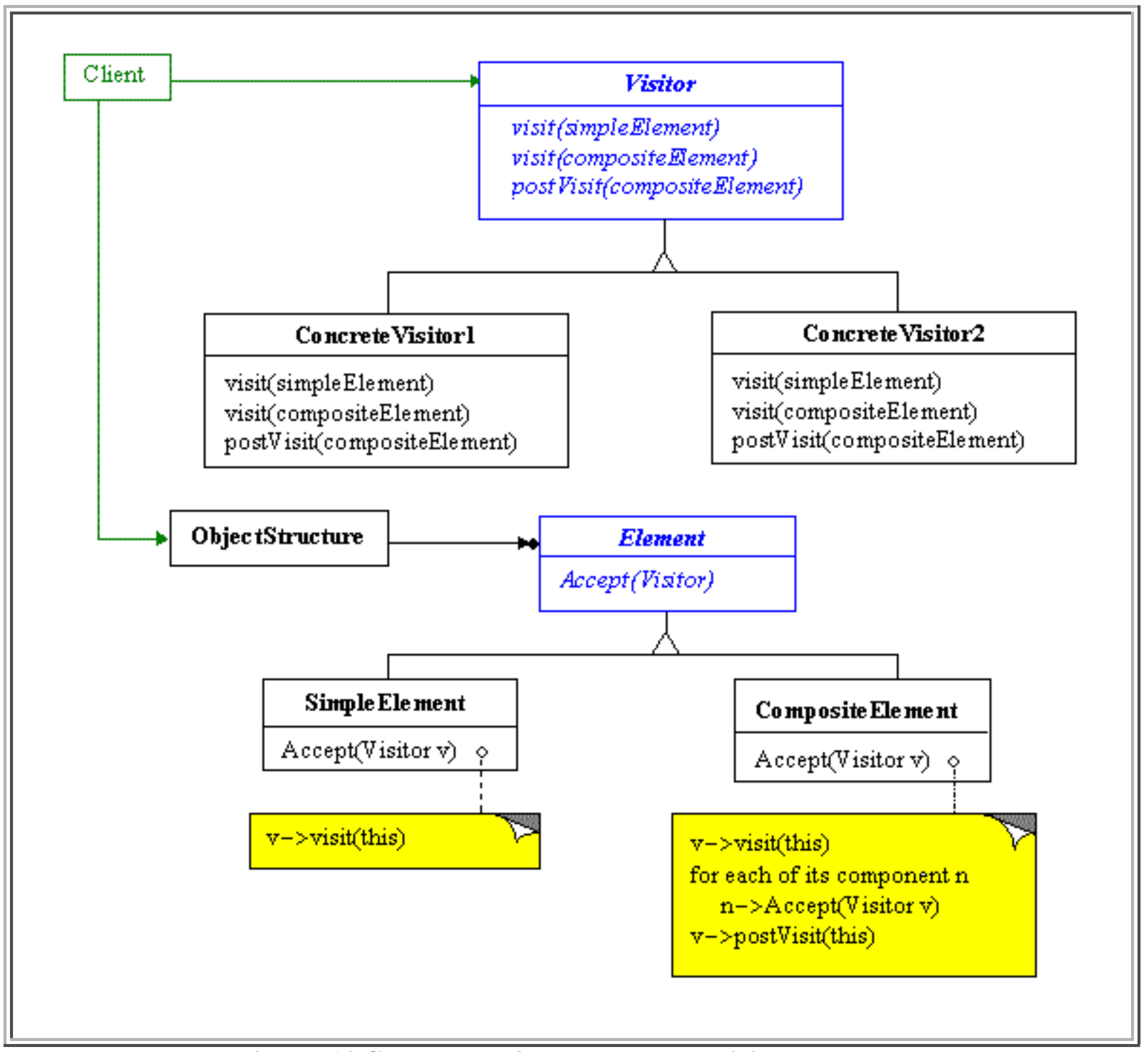


Figure 12 Structure of Implemented Visitor Pattern

5. Relation to Conceptual Graphs

In this paper, graphical notations for knowledge in DESIRE are presented, as well as a translator which translates specifications of these notations in a graphical environment called Constraint Graphs to the original textual DESIRE language. Having this graphical interface brings the knowledge modelling in DESIRE closer to other well-known knowledge representation languages, such as Conceptual Graphs (Sowa, 1984). A conceptual graph is a finite, connected, bipartite graph, which consists of two kinds of nodes: concepts and conceptual relations (Sowa, 1984, p. 73). Concepts are denoted by a rectangle, with the name of the concept within this rectangle, and a conceptual relation is represented as an ellipse, with one or more arcs, each of which must be linked to some concept. Figure 13 below shows an example conceptual graph, representing the episodic knowledge that *a girl, Sue, is eating pie fast*.

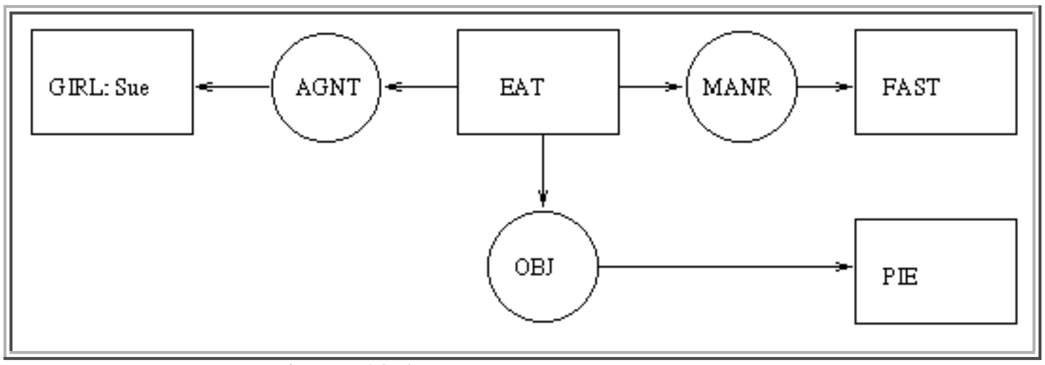


Figure 13 An example conceptual graph

When comparing conceptual graphs with the graphical notations for DESIRE, many similarities become apparent. For instance, DESIRE's relations are denoted by ellipses, like conceptual relations, and sorts appear as rectangles, like concept. Other elements however, such as objects, functions or arcs between various elements are harder to translate to a Conceptual Graph notation. Below the mapping of graphical DESIRE elements to a Conceptual Graphs equivalent is discussed in some detail. Table 2 summarizes this discussion, providing an overview of the translation of DESIRE elements to Conceptual Graphs.

Sorts: Sorts conform to generic concepts in Conceptual Graphs. The notations are the same.

Objects: Objects are instances of a sort in the real world. Sowa (1984, p. 85) denotes these instances with individual concepts, concepts with an individual marker following the concept name: [BIRD: tweety]. This notation is short for the following: [BIRD]->(NAME)->["tweety"]. The objects-diamond in DESIRE can be mapped to an individual marker in Conceptual Graphs, and the instance_of arrow in the graphical notation can be compared to the conceptual relation NAME. In the case of an anonymous individual, the graphical DESIRE notation is comparable to the notation in Conceptual Graphs: if one knows that an individual of type BIRD exists, but it is unknown which individual, then this information is represented as [BIRD: *x].

Functions: In DESIRE, functions group sorts together by mapping them onto another sort. Functions can be regarded to be subtypes of a general concept FUNCTION, which takes one or more arguments and produces a result. Function SQRT, for example, can be defined as follows (Sowa, 1984, p. 415):

```
[NUMBER]<-(ARG)<-[SQRT]->(RSLT)->[NUMBER]
```

In this graph, SQRT is a subtype of FUNCTION, taking one argument of type NUMBER and producing a result of type NUMBER. In DESIRE, functions do not calculate a number based on another number or other numbers, but functions act as a named placeholder for an object of its result, in which the argument(s) and the name of the function ensure the placeholder's uniqueness. Function mileage_function, for example, maps a car to a number and could be represented as the following Conceptual Graph:

```
[CAR]<-(ARG)<-[MILEAGE_FUNCTION]->(RSLT)->[NUMBER].
```

This function can be used in constructions such as *smaller(mileage(R: RENAULT), 30)*, stating that the mileage of a Renault is smaller than 30.

Relations: Relations can be classified according to their arity. This arity determines the mapping to Conceptual Graphs. 0-ary relations in DESIRE will have to be translated to concepts; concepts in Conceptual Graphs form a graph in itself, like relations form a DESIRE atom in DESIRE. Relations with an arity greater than zero can be translated into either a conceptual relation with the same arity or a combination of a concept and (an)other conceptual relation(s). For example, the relation *between: space * brick * brick* in DESIRE could be translated into the following Conceptual Graph:

```
[SPACE]->(BETW)->[BRICK]

               ->[BRICK]
```

This graph is a triadic relation, which could be read as "a space is between a brick and a brick". Relation *travel: person * origin * destination* however should be translated into the graph

```
[TRAVEL] -

          (AGNT)->[PERSON]

          (ORG)->[ORIGIN]

          (DEST)->[DESTINATION]
```

In Conceptual Graphs, TRAVEL is regarded to be a concept and not a conceptual relation. This is why relation *travel* in DESIRE is translated into a concept TRAVEL, connected to person, origin and destination by conceptual relations that specify the **role** these concepts play in the TRAVEL-graph.

Sub-sorts: Sub-sorts in DESIRE correspond to the type hierarchy of concepts in Conceptual Graphs. In Conceptual Graphs, hierarchies of both concepts and conceptual relations are possible, but these hierarchical is-a relations are kept in a separate semantic net from other relations that exist in the domain. In DESIRE, hierarchical relations between sorts are allowed; the sub-sort-relation is one of the many relations that may exist between sorts in a domain.

Information types, knowledge bases, antecedents, consequents and not-boxes: DESIRE's information types, knowledge bases, antecedents, consequents and not-contexts can be regarded as contexts in Conceptual Graphs. Although the graphical DESIRE notation uses a different icons to represent these contexts, these contexts can be represented by labelled rectangles in Conceptual Graphs, where the labels of these rectangles denote the type of the context (information type, knowledge base, antecedents, consequents, and not-boxes).

Information type and knowledge base references: In DESIRE, mechanisms exist to enable compositionality of information types and knowledge bases: information type- and knowledge base references, see Figures 3 and 6. In Conceptual Graphs, contexts that contain other contexts represent this contain-relation by enclosing context-boxes in other context-boxes. Therefore, the graphical DESIRE notations for this compositionality can be translated to Conceptual Graphs notation by placing information types in information types and knowledge bases in knowledge bases.

Meta-descriptions: Another, different relation exists between information types: the meta-description. A information type A in DESIRE is said to contain a meta-description of a information type B if information type A can be used to specify as terms the atoms that can be specified using the vocabulary of information type B. This means that information type A allows for expressing statements that are at a meta-level with respect to the language defined in information type B. The meta-description relationship is expressed in the graphical notation as a connection, between the meta-described information type B to a sort in the meta-level information type A. This object-meta-level relation between information types is very specific to DESIRE. In Conceptual Graphs, this relationship between information types A and B could be expressed as the conceptual relation [Information type B]->(METALEVEL)->[Information type A], with the intended meaning that information type A is at a meta-level with respect to information type B.

Knowledge base to information type reference: The graphical DESIRE notation for a knowledge base referencing an information type is a connection from the knowledge base to that information type. This connection indicates that the knowledge base, which contains facts and rules that hold in the application domain, uses that information type as the vocabulary to express those facts and rules. One could argue that a information type can be compared to the first three parts of a cannon (Sowa, 1984, p.96), which is a set of four components used to derive canonical graphs: a type hierarchy (sorts and sub-sorts), a set of individual markers (objects), a conformity relation (the sorts the objects belong to) and a finite set of conceptual graphs (the graphs that are true in the domain). The knowledge expressed in knowledge bases would then conform to the fourth component of the canon: the set of graphs that are true in the domain.

The implies arrow: The last candidate for comparison is the labeled arrow "implies", which connects the antecedent and consequent of a rule in the graphical DESIRE notation. This arrow can be translated into a relation 'IMP', a logical operator denoting the implication between propositions (Sowa, p. 147). 'IMP' is defined as follows:

> **relation** IMP(x,y) **is** [*x] [*y] (NEG)->[[*x] (NEG)->[[*y]]].

The parameter symbols *x and *y are used to denote the coreference relations between elements in the expression. 'IMP' could be read as: there exists an x and a y and it is not true that both x is true and y is not true.

This concludes the brief comparison of the graphical DESIRE notations to Conceptual Graphs. Table 2 below summarizes the mapping sketched above.

Desire Element	**Graphical Equivalent in Constraint Graphs**	**Equivalent in Conceptual Graphs**
Object	diamond	individual concept
Sort	rectangle	generic concept
Sub-sort	rectangle connected to super-sort by instance-of arrow	type hierarchy of concepts
Meta-Description	dashed arrow from signature to sort	conceptual relation ->(METALEVEL)->
Function	parallelogram	concept FUNCTION
Relation	ellipse	conceptual relation or concept and conceptual relation(s)
Information type	context-box labeled SIG	context
Knowledge Base	context box labeled KB	context
Antecedent	context-box labeled ANT	context
Consequent	context-box labeled CONS	context
NOT-context	context-box labeled NOT	negative context
Information type Reference	arrow between information types	context enclosed in another context
Knowledge base Reference	arrow between knowledge base contexts	context enclosed in another context

KBusingSIG	arrow from kb to information type	comparable to first three and last component in a canon
Rule	arrow labeled "implies" between antecedent and consequent	conceptual relation ->(IMP)->

Table 2 mapping the graphical DESIRE notation to Conceptual Graphs

6. Conclusion

In this paper, graphical representations for knowledge structures in DESIRE (Brazier Dunin-Keplicz, Jennings & Treur 1995; Brazier, Treur, Wijngaards & Willems 1996) have been presented, together with a graphical editor based on the Constraint Graph environment (Kremer 1997). Moreover, a translator has been described which translates these graphical representations to textual representations in DESIRE. This software environment can be regarded as a graphical design tool for knowledge in DESIRE, an interface which offers many advantages to a textual interface. First, Constraint Graphs can be used to specify knowledge structures, allowing the user to work with a mouse, pull-down menu's and windows instead of typing the specification conform the textual DESIRE syntax. Second, Constraint Graphs offers a clear visual representation, facilitating communication between domain expert and knowledge engineer in the development process. Third, the graphical representations bring DESIRE closer to other knowledge representation languages, such as Conceptual Graphs (Sowa, 1984). In conclusion, the strengths of the Constraint Graphs environment as an easy to use representation tool in combination with the DESIRE environment allows for a powerful framework to support the development of knowledge based or multi-agent systems.

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