University of Piteşti
Faculty of Mathematics and Computer Science

GRAPH-BASED MECHANISMS FOR KNOWLEDGE REPRESENTATION AND REASONING. FORMALISMS AND IMPLEMENTATIONS

The Summary of the Ph.D. Thesis

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Contents of the Thesis

KEY-WORDS: deduction, derivation, join semilattice, partial algebra, morphism, knowledge management, output mapping, valuation mapping, output space, distributed reasoning system, path-based reasoning, spatial reasoning system, geometrical image generation, image synthesis, natural language processing, interpretation, compatible interpretation, recursive transition network, labeled graph, labeled stratified graph, conditional graph, conditional schema, semantic network, semantic schema, hyperschema, Java, JIProlog

1 Knowledge Representation and Reasoning

Knowledge Representation and Reasoning (shortly, KRR) is one of the most important subareas of Artificial Intelligence. The object of KRR is to express knowledge in a computer tractable form such that it can be easily manipulated using computer programs. The best known methods for KRR are the *logic-based representations*, the *procedural representations*, the *structured-objects representations* and the *graph-based representations*.

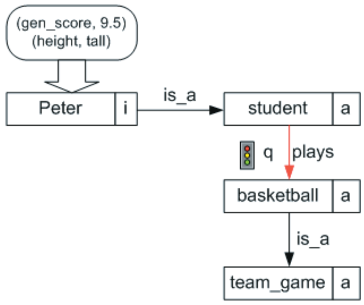


Figure 1: Conditional Graph

2 Conditional Schemas for Knowledge Representation

This is a graph-based formalism for representing conditional knowledge, that is, knowledge piece containing sentences of the form *if-then*. Our method uses the following mathematical concepts:
• directed labeled graph
• partial universal algebras (partial binary operations, morphism of partial algebras)

A classical binary relation θ over a set X is defined as follows: $\theta \subseteq X \times X; \theta = \{(x_1, y_1), \ldots, (x_n, y_n)\}$. In our representation, a conditional binary relation φ is a subset of the following cartesian product: $\varphi \subseteq X \times X \times C_{cs}; \varphi = \{((x_1, y_1), p_1), \ldots, ((x_n, y_n), p_n)\}$, for C_{cs} the set of conditional symbols. The intuitive meaning of this representation: *If* p_i *then* $(x_i, y_i) \in \varphi$, $i = \overline{1, n}$.

In order to have a single representation for both types of relations we will consider that both are conditional relations with the difference that the classical relations are unconditional *true*.

By a *knowledge piece* (shortly, KP) we understand a text in a natural language that contains a description of some objects and the binary relations between them. The information specified in KP is named *initial knowledge*. A *conditional knowledge piece* contains initial knowledge and description of some rules, that is, descriptions in a natural language of conditional binary relations.

Example of Conditional KP: *Peter is a student. His general score at university is 9.50. Every student plays basketball if he is tall. Peter is tall. The basketball is a team game.* The binary relations are:
$is\_a = \{((Peter, student), T), ((basketball, team\_game), T)\}$
$plays = \{((Peter, basketball), q)\}$
The values of the conditional symbols are stated by some rules. For q the rule is:
$R(x) : IF\ V_x(height) = tall\ THEN\ q(x) = on\ ELSE\ q(x) = off$

A conditional schema is the tuple $\mathcal{S} = (Ob = Ob_{ind} \cup Ob_{abstr}, C_{cs}, E_r, A, V, B_{cr}, h, f)$ where:
- Ob_{ind} is the set of individual objects and Ob_{abstr} is the set of the abstract objects
- C_{cs} is the set of conditional symbols
- E_r the set of the symbols for conditional relations
- $A \times V$ represents the initial knowledge of the individual objects
- $B_{cr} \subseteq 2^{((Ob \times I) \times (Ob \times I)) \times (C_{cs} \cup \{T\})}$ is the set of the conditional binary relations
- $h : E_r \rightarrow B_{cr}$ is the mapping that assigns a conditional binary relation for every symbol of E_r
- $f : Ob_{ind} \rightarrow 2^{A \times V}$ is the mapping that assigns initial knowledge to the individual objects

A conditional schema is graphical represented as a conditional graph (see Figure 1). Using the resulted conditional graph we formalize the reasoning mechanism.

We note by $D = 2^{Ob \times Ob}$ the set of the classical binary relations over Ob. For $\mu_0 : E_r \rightarrow D$ and E_r^* a superset of E_r, $E_r \subseteq E_r^*$, we obtain (E_r^*, φ), $(D, \circ)$ partial algebras where by $\circ$ we note the product operation on D. For μ an extension of the mapping μ_0, $\mu_0 \prec \mu$, we obtain that μ is a morphism of partial algebras: if $u, v \in E_r^*$, $(u, v) \in dom(\varphi) \Rightarrow \mu(\varphi(u, v)) = \mu(u) \circ \mu(v)$.

The answer of a conditional schema is a sentence in a natural language (English). We note by Sen the set of such sentences. We define $Ans : Ob \times Ob \rightarrow 2^{Sen}$, $Ans(n_1, n_{k+1}) = \bigcup_{d \in Path(n_1, n_{k+1})} \{ans(d)\}$, for $Path(n_1, n_{k+1})$ the set of all paths from n_1 to n_{k+1} in the conditional graph. Let us consider that $d = ([(n_1, w_1), \ldots, (n_{k+1}, w_{k+1})], [a_1, \ldots, a_k])$, $CS(d) = [t_1, \ldots, t_k]$ the list of the conditional symbols of

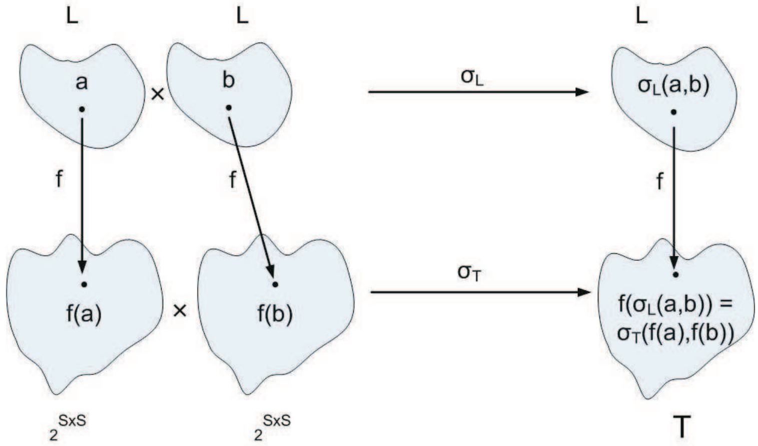


Figure 2: Labeled Stratified Graph $\mathcal{G} = (G, L, T, \sigma_T, f)$

the path d. The answers are constructed by means of a mapping g:

$$ans(d) = \begin{cases} g(n_1, \phi([a_1, \ldots, a_k]), n_{k+1}, on), \ if \ t_1[d] = \ldots = t_k[d] = on \\ g(n_1, \phi([a_1, \ldots, a_k]), n_{k+1}, off), \ if \ \exists j \in \{1, \ldots, k\} : t_j[d] = off \end{cases} \tag{1}$$

where $g(x, u, y, on)$ return the semantics of the relation symbolized by u and $g(x, u, y, off)$ is the contrary property, for the mapping ϕ defined as follows:

$$\begin{cases} \phi([a_1]) = a_1 \\ \phi([a_1, \ldots, a_{k+1}]) = \varphi(\phi([a_1, \ldots, a_k]), a_{k+1}) \end{cases} \tag{2}$$

The proposed methodology is reported in:
Nicolae Ţăndăreanu, Mihaela Ghindeanu, Towards a Mathematical Modelling of Conditional Knowledge, *Research Notes in Artificial Intelligence and Digital Communications, 3nd Romanian Conference on Artificial Intelligence and Digital Communications*, Vol.103, ISBN 973-8419-71-9, Craiova, p.5-15, 2003
Nicolae Ţăndăreanu, Mihaela Ghindeanu, Conditional schemas, *Bull. Math. Soc. Sci. Math. Roumanie*, 2008 (submitted)

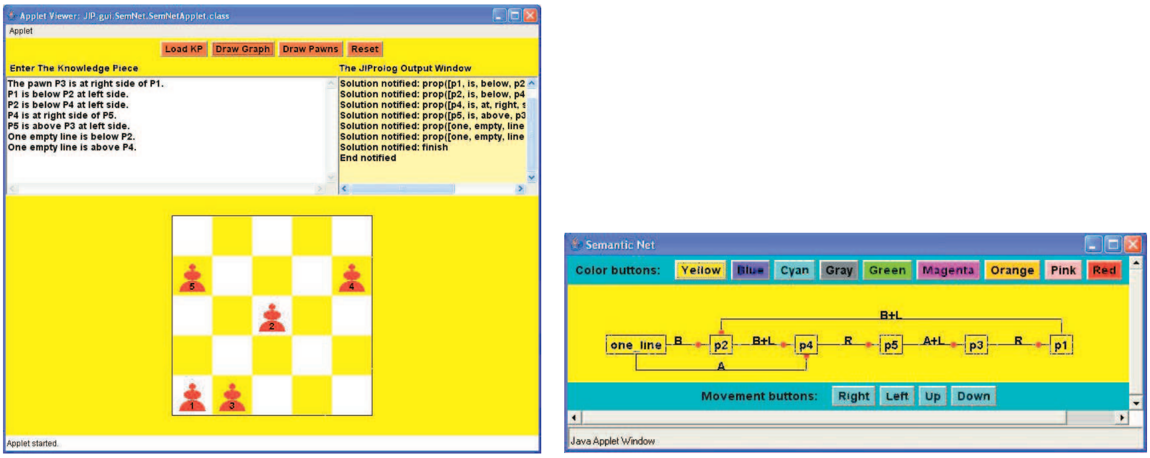
3 Image Synthesis based on Labeled Stratified Graphs

The concept of Labeled Stratified Graph (shortly, LSG) is an algebraic environment developed to manipulate some concepts from graph theory in view of obtaining a new knowledge representation mechanism. The basic concept used to build a LSG is that of labeled graph. In our theory, a labeled graph is a tuple of four entities $G = (S, L_0, T_0, f_0)$ such that: S is the set of nodes, L_0 is the set of arcs symbols, T_0 is the set of binary relations on S and $f_0 : L_0 \to T_0$ is a surjective mapping.

The labeled graph allows us to represent knowledge but not to construct an advanced mechanism for knowledge processing. For this reason, a new structure, named Labeled Stratified Graph was introduced. A LSG over G is the following system $\mathcal{G} = (G, L, T, \sigma_T, f)$ where:
- L is the Peano algebra generated by L_0 and σ_L
- σ_T is a restriction of $prod_S$, $\sigma_T \prec prod_S$, for $prod_S$ the product operation of the binary relations over S
- $T = Cl_{\sigma_T}(T_0)$ is the closure of T_0 in the partial algebra $(2^{S\times S}, \sigma_T)$
- $f : L \to T$ is an extension of f_0 and a surjective algebraic morphism (see Figure 2)

3.1 Image synthesis from text description

By *image synthesis* we understand the process of creating new images from some form of text description. We developed an image synthesis method by means of which we can reconstruct a graphical image



(a) (b)

Figure 3: The two windows of the first approach of the image synthesis problem

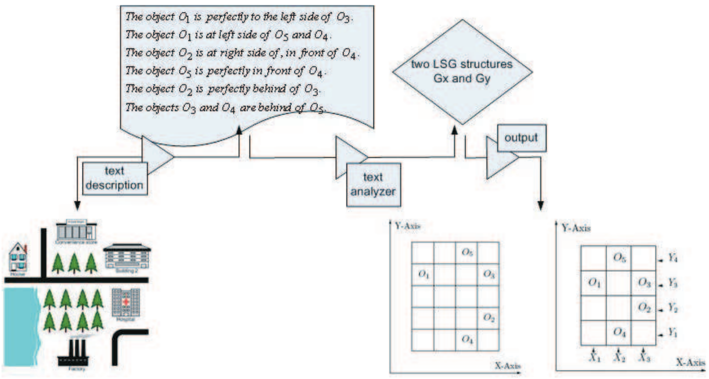


Figure 4: The second approach of the image synthesis problem

from a linguistic spatial description given in a natural language (English). Our linguistic spatial description is a qualitative description of some objects positions inside a scene. It is based on the primitive directional relations *left of, right of, above, below, behind, in front of.*

Our first approach for image synthesis takes as input a text description of an image consisting of some pawns arranged on a chess-board. Using a *Recursive Transition Network* (RTN), the objects and the directional relations described in text are extracted. These information are represented in a labeled graph and by constructing a LSG over this graph, the pawns positions on the chess-boards are obtained.

We implement this mechanism in a application that consist of a Java applet and a Prolog file connected using a JIProlog connection. In the Prolog file is implemented the RTN. A natural language processing method in given in **Mihaela Ghindeanu, Claudiu Popirlan, A Natural Language Processing System using Java-Prolog Technology,** ***Research Notes in Artificial Intelligence and Digital Commnunications, RCAI 5th International Conference on Artificial Intelligence and Digital Communications*****, vol. 105, ISBN 973-671-055-6, Craiova, p. 83-69, 2005**. The Java applet consist of two windows presented in Figure 3.

Unlike the first approach, the second one uses a greater number of directional relations in order to describe more precisely all the spatial relationships that can exist between the objects of the image. Also in this version we construct a LSG for each dimension of the image. For this approach we defined an equivalence relation between these kinds of grid representations. We will denote by $[G_{n,m}]$ the equivalence class of a grid with n lines and m columns. In these terms we can restate the problem as follows: *From the linguistic description, find a representative of the class* $[G_{n,m}]$ *where* $G_{n,m}$ *is the grid representation of the image* (see Figure 4).

Studies of spatial reasoning methods are given in:
Mihaela Ghindeanu, Fuzzy Controller for Spatial Objects Recognition, ***Research Notes in Artificial Intelligence and Digital Commnunications, RCAI 6th International Conference on Artificial Intelligence and Digital Communications*****, vol. 106,ISBN 973-742-413-1 978-973-742-413-6, Thesaloniki, Greece, p. 118-125, 2006**,
Nicolae Ţăndăreanu, Mihaela Ghindeanu, Hierarchical Reasoning Based on Stratified Graphs. Application in Image Synthesis, ***Proceedings of 15th International Workshop on Database and Expert Systems Applications, Proceedings of DEXA2004, IEEE Computer Society*****, Zaragoza, Spania, Los Alamitos California, p.498-502, 2004** and in
Nicolae Ţăndăreanu, Mihaela Ghindeanu, Image Synthesis from Natural Language Description, ***Research Notes in Artificial Intelligence and Digital Communications, 3nd Romanian Conference on Artificial Intelligence and Digital Communications*****, Vol.103,ISBN 973-8419-71-9, Craiova, p.82-96, 2003**

4 Semantic Schema. Properties and Applications

The concept of semantic schema was introduced in order to extend that of *semantic network*. A semantic schema is a tuple of four entities, each one specifying some features of the representation process. Let us consider a symbol θ of arity 2. A semantic θ-schema is defined as a system $\mathcal{S} = (X, A_0, A, R)$ where:
- X is a set of objects symbols
- A_0 is a set of labels symbols
- $A_0 \subseteq A \subseteq \overline{A_0}$, for $\overline{A_0}$ the Peano θ-algebra generated by A_0;
  that is $\overline{A_0} = \cup_{n\geq 0} A_n$, $A_{n+1} = A_n \cup \{\theta(u,v) \mid u, v \in A_n\}$
- $R \subseteq X \times A \times X$ is a set of relations such that:
  $(R_1) : (x, \theta(u,v), y) \in R \Rightarrow \exists z \in X : (x,u,z), (z,v,y) \in R$
  $(R_2) : \theta(u,v) \in A, (x,u,z), (z,v,y) \in R \Rightarrow (x, \theta(u,v), y) \in R$
  $(R_3) : pr_2 R = A$

We note $R_0 = R \cap (X \times A_0 \times X)$. A semantic schema implies two aspects:

- the *formal aspect* by which some formal computation in a Peano σ-algebra are obtained:
  for $M = \{h(x,a,y) \mid (x,a,y) \in R_0\}$ we denote by $\mathcal{H}$ the Peano σ-algebra generated by M.
  Because the set $\mathcal{H}$ is an infinite one, we keep only those elements of $\mathcal{H}$ that can be derived from R. Thus we define $\mathcal{G}_{\mathcal{S}} : R \to 2^{\mathcal{H}}$ as follows $\forall (x,u,y) \in R$:
  - $\mathcal{G}_{\mathcal{S}}(x,u,y) = \{w \in \mathcal{H} \mid (x,u,y) \Rightarrow^* w\}$
  - $sort(w) = u$ if $(x,u,y) \Rightarrow^* w$, $w \in \mathcal{H}$

  The computations are based on the concept of *derivation* and the set of these computations is denoted by $\mathcal{F}_{comp}(\mathcal{S})$. That is $\mathcal{F}_{comp}(\mathcal{S}) = \bigcup_{(x,u,y)\in R} \mathcal{G}_{\mathcal{S}}(x,u,y)$.
  The concept of *sort* for the formal entities of $\mathcal{F}_{comp}(\mathcal{S})$ divides this set into *equivalence classes.*
  $\forall u \in A : [u]_{\mathcal{F}} = \{w \in \mathcal{F}_{comp}(\mathcal{S}) \mid sort(w) = u\}$, $\mathcal{F}_{comp}(\mathcal{S}) = \bigcup_{u\in A} [u]_{\mathcal{F}}$

  The study is presented in **Nicolae Ţăndăreanu, Mihaela Ghindeanu, Properties of Derivations in a Semantic Schema,** ***Annals of University of Craiova, Mathematics and Computer Science Series*****, Vol.33, p.147-155, 2006**.

- In order to represent a KP by a semantic schema, the entities of the schema must be evaluated. The *evaluation aspect* is defined with respect to an *interpretation*. The interpretation corresponding to a semantic schema defines the domain of its components, as it happens in mathematical logic where an interpretation establishes a logic value for some formula. By means of an interpretation, the abstract entities of the semantic schema get values in a *semantic space* noted with Y. For every sort $u \in A$, Y_u is determined and each object of Y_u has the class u. The space Y becomes the union of some classes of objects.
  $\mathcal{I} = (Ob, ob, Y, \{Alg_u\}_{u\in A})$ - interpretation of the semantic schema $\mathcal{S} = (X, A_0, A, R)$ for Ob a finite set of objects, $ob : X \to Ob$ a bijective function. The set of the outputs elements is $Y = \bigcup_{u\in A} Y_u$ where:
  $Y_a = \{Alg_a(ob(x), ob(y)) \mid (x,a,y) \in R_0\}$ interprets the elements of R_0

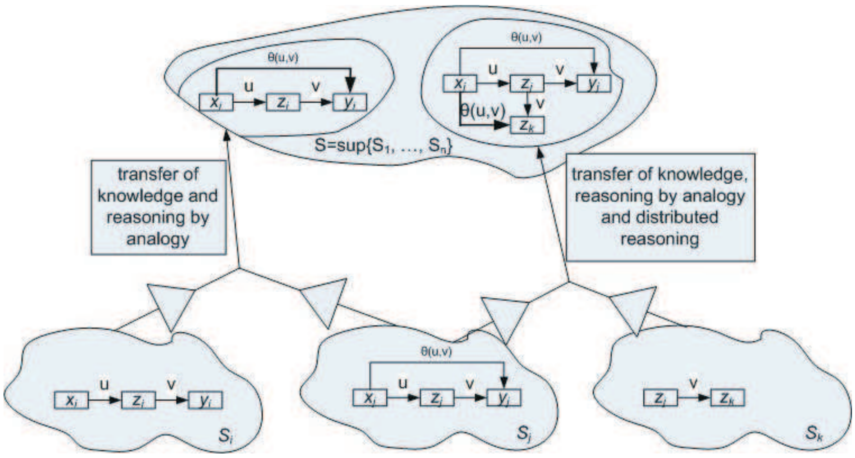


Figure 5: The advantages of the supremum structure $\mathcal{S} = sup\{\mathcal{S}_1, \ldots, \mathcal{S}_n\}$

$Y_{\theta(u,v)} = \{Alg_{\theta(u,v)}(o_1, o_2) \mid o_1 \in Y_u, o_2 \in Y_v\}$
We observe that an object of class $\theta(u, v)$ is the output of the algorithm $Alg_{\theta(u,v)}$ for two input objects of class u, respectively v. The valuation mapping $Val_{\mathcal{I}} : \mathcal{F}_{comp}(\mathcal{S}) \to Y$ is defined as follows:
$Val_{\mathcal{I}}(h(x, a, y)) = Alg_a(ob(x), ob(y))$
$Val_{\mathcal{I}}(\sigma(\alpha, \beta)) = Alg_{\theta(u,v)}(Val_{\mathcal{I}}(\alpha), Val_{\mathcal{I}}(\beta)); sort(\sigma(\alpha, \beta)) = \theta(u, v)$
The output mapping of a semantic schema generated by an interpretation computes for each pair of nodes all the meanings assigned in the output space Y. To do this, all the paths that connect the first node with the second are considered. Each such path is characterized by some element of $\mathcal{F}_{comp}(\mathcal{S})$. We take the value of the mapping $Val_{\mathcal{I}}$ at this element and we obtain the interpretation from Y:
$Out_{\mathcal{I}} : X \times X \to 2^Y$, $Out_{\mathcal{I}}(x, y) = \bigcup_{(x,u,y)\in R} \bigcup_{w \in \mathcal{G}_{\mathcal{S}}(x,u,y)} \{Val_{\mathcal{I}}(w)\}$

The existence of the supremum for a finite number of semantic schemas was also studied. Based on a partial order between two semantic schemas $\mathcal{S}_1$ and $\mathcal{S}_2$, we proved that there is $sup\{\mathcal{S}_1, \mathcal{S}_2\}$. This element can be effectively obtained in a finite number of steps from the components of $\mathcal{S}_1$ and $\mathcal{S}_2$. We generalize this construction for n semantic schemas, $n \geq 2$.

Consider the θ-schemas $\mathcal{S}_i = (X^i, A_0^i, A^i, R^i)$ such that A^i is finite, $i = \overline{1, n}$. We denote: $X = \cup_{i=1}^n X^i$, $A_0 = \cup_{i=1}^n A_0^i$, $A = \cup_{i=1}^n A^i$, $R_0^i = R^i \cap (X^i \times A_0^i \times X^i)$, for $i \in \{1, \ldots, n\}$. We define recursively the sets:

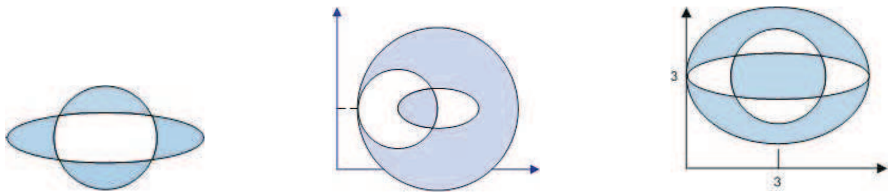
$$\begin{cases} Z_0 = R_0^1 \cup \ldots \cup R_0^n \\ Z_{j+1} = Z_j \cup \{(x, \theta(u, v), y) \in X \times A \times X \mid \exists z \in X : (x, u, z), (z, v, y) \in Z_j\} \end{cases} \quad (3)$$

The sequence $\{Z_j\}_{j\geq 0}$ satisfies the following properties:
$i)$ There is a natural number n_0 such that $Z_0 \subset Z_1 \subset \ldots \subset Z_{n_0} = Z_{n_0+1} = \ldots$
$ii)$ If we denote $\mathcal{S} = (X, A_0, A, Z_{n_0})$ then $\mathcal{S}$ is a θ-schema.
The set Z_{n_0} is constructed by means of transfer of knowledge, distributed and analogic computations, as it is exemplified in Figure 5.

4.1 Distributed System based on semantic schemas

The way in which the abstract entities and relationships of a semantic schema are interpreted allows us to obtain representations that can not be obtained using semantic networks. This is the case of the output space containing images, case implemented by means of the Distributed System presented in this section (see Figure 6). The structure of the system is the following:

- on the first level there are the observers or the agents of the system which send phrases in a natural language to the second level of the system



(a) Image of class $\theta(a, b)$ obtained by a PKM

(b) Image of class $\theta(\theta(a, b), d)$ obtained by a PKM

(c) Image of class $\theta(\theta(a, b), d)$ obtained by the GKM

Figure 6: Graphical images obtained using a Distributed System based on semantic schemas

- the second level includes several primary knowledge managers (PKM). Each PKM receives phrases from its observers, has an own semantic schema and identifies an useful part of it
- on the third level we find the general knowledge manager (GKM) of the system; it processes the schemas received from the second level by constructing the supremum of the PKM's semantic schemas. Thus, GKM is able to perform distributed and analogic computations.

The system is presented in **Nicolae Ţăndăreanu, Mihaela Ghindeanu, A Three-Level Distributed Knowledge System Based on Semantic Schemas, *Proceedings of 16th International Workshop on Database and Expert Systems Applications, Proceedings of DEXA'05 (TAKMA2005), IEEE Computer Society*, Copenhagen, p.423-427, 2005**.

5 Hierarchical Distributed Reasoning System

We defined a new kind of path for a semantic schema, named the *deductive path* formalized based on another new concept, the *ordered path*. We formalized a path-driven reasoning mechanism by means of deductive paths. This new mechanism does not change dramatically the classical reasoning of a semantic schema. But by means of deductive paths and path-based reasonings, we can link two or more semantic schemas in a new structure, named *hyper-schema*. Let us consider the θ-schema $\mathcal{S} = (X, A_0, A, R)$.
We note by $ORD(\mathcal{S})$ the set of the ordered paths of $\mathcal{S}$ defined as follows:
$(x, a, y) \in R_0 \Rightarrow ([x, y], a) \in ORD(\mathcal{S})$
$([x_i, \ldots, x_k], b_1), ([x_k, \ldots, x_r], b_2) \in ORD(\mathcal{S}) \Rightarrow ([x_i, \ldots, x_r], [b_1, b_2]) \in ORS(\mathcal{S})$
We note by $Ded(\mathcal{S})$ the set of the deductive paths of $\mathcal{S}$ defined as follows:
$([x_1, \ldots, x_k], w) \in ORD(\mathcal{S}) \Rightarrow ([x_1, \ldots, x_k], \omega(w)) \in Ded(\mathcal{S})$ for $\omega([\alpha, \beta]) = \theta(\alpha, \beta)$
Properties of the deductive paths:
$([x_1, \ldots, x_{n+1}], \theta(u, v)) \in Ded(\mathcal{S}) \Leftrightarrow \exists! k \in \{1, \ldots, n-1\} : ([x_1, \ldots, x_{k+1}], u), ([x_{k+1}, \ldots, x_{n+1}], v) \in Ded(\mathcal{S})$
$([x_1, \ldots, x_{n+1}], u) \in Ded(\mathcal{S}) \Leftrightarrow (x_1, u, x_{n+1}) \in R$
The path-based reasoning for a semantic schema is defined using a new derivation rule, noted with $\Rightarrow_{\mathcal{S}}$ which is constructed using deductive paths as follows:
$([x, y], a) \in Ded(\mathcal{S}) \Rightarrow w_1([x, y], a)w_2 \Rightarrow_{\mathcal{S}} w_1 h([x, y], a)w_2$
$([x_1, \ldots, x_{n+1}], \theta(u, v)) \in Ded(\mathcal{S})$ for $u, v \in A$. If $([x_1, \ldots, x_{k+1}], u), ([x_{k+1}, \ldots, x_{n+1}], v) \in Ded(\mathcal{S})$ then: $w_1([x_1, \ldots, x_{n+1}], \theta(u, v))w_2 \Rightarrow_{\mathcal{S}} w_1 \sigma(([x_1, \ldots, x_{k+1}], u), ([x_{k+1}, \ldots, x_{n+1}], v))w_2$
We denote by $\mathcal{H}_{\mathcal{S}}$ the Peano σ-algebra generated by M, $M = \{h([x, y], a) \mid (x, a, y) \in R_0\}$. We extract from $\mathcal{H}_{\mathcal{S}}$ those elements that can de derived from $Ded(\mathcal{S})$ and we denote this set by $\mathcal{F}(\mathcal{S})$:
$\mathcal{F}(\mathcal{S}) = \{w \in \mathcal{H}_{\mathcal{S}} \mid \exists d \in Ded(\mathcal{S}) : d \Rightarrow^*_{\mathcal{S}} w\}$

The proposed method is presented in **Nicolae Ţăndăreanu, Mihaela Ghindeanu, Path-based Reasoning in Semantic Schemas, *Annals of University Of Craiova, Mathematics and Computer Science Series*, 2008 (accepted)**.

5.1 Hyper-schemas of various orders

Let us consider two θ-schemas $\mathcal{S}_1$ and $\mathcal{S}_2$, $\mathcal{S}_i = (X_i, A_{0i}, A_i, R_i)$, for $i = \overline{1,2}$. Using these schemas we build a new structure, named *hyper-schema of first order* that relieves a special kind of cooperation between $\mathcal{S}_1$ and $\mathcal{S}_2$. In fact, from the structural point of view, a hyper-schema is another θ-schema. In comparison with a "regular" θ-schema, a hyper-schema is endowed with other semantical computations.

We say that the deductive path d_1 is *connected to right by* d_2 or d_2 is *connected to left by* d_1 if $d_1 = ([x, \ldots, y], u) \in Ded(\mathcal{S}_i)$, $d_2 = ([y, \ldots, z], v) \in Ded(\mathcal{S}_{3-1})$, $i \in \{1, 2\}$. For $d = ([x, \ldots, y], \theta(u, v)) \in Ded(\mathcal{S})$ we note by $T(d)$ the relation obtained from d by renaming $\theta(u, v)$ with an atomic symbol e, that is, $T(d) = (x, e, y)$ for the renaming function $g_{\mathcal{S}}(e) = \theta(u, v)$.

Remark A θ-schema that uses a path-driven reasoning is named *hyper-schema of order 0.* In what follows we denote by Hyp_k the set if all hyper-schema of order k, $k \geq 0$.

Let us consider $L_i \subseteq Ded(\mathcal{S}_i)$, $i = \overline{1,2}$. If $L_1 \cup L_2 \neq \emptyset$ is a pairwise connected set of deductive paths then an hyper-schema of order one over $\mathcal{S}_1$ and $\mathcal{S}_2$ by means of $L_1 \cup L_2$ is the θ-schema $\mathcal{S} = (X, C_0, C, P)$ where $P_0 \supseteq \{T(d) \mid d \in L_i\}$, $C_0 = pr_2(P_0)$, $C = pr_2(P)$, $X = pr_1(P) \cup pr_2(P)$. We note $\mathcal{S} \in Hyp_1(\{\mathcal{S}_1, \mathcal{S}_2\})$. Using a similar method, an *hyper-schema of higher order*, over two hyper-schemas, $\mathcal{S}_1$ and $\mathcal{S}_2$ is $\mathcal{S} \in Hyp_k(\{\mathcal{S}_1, \mathcal{S}_2\})$, for $\mathcal{S}_i \in Hyp_{k-1}$, $\mathcal{S}_{3-i} \in \bigcup_{j=0}^{k-1} Hyp_j$, $i \in \{1, 2\}$.

Observation As a mathematical structure, an hyper-schema $\mathcal{S} \in Hyp_k(\{\mathcal{S}_1, \mathcal{S}_2\})$ is an aggregation of $\mathcal{S}_1$ and $\mathcal{S}_2$. From the syntactic point of view, $\mathcal{S}_1$ and $\mathcal{S}_2$ are not embedded into $\mathcal{S}$ and this is due to the fact that we intend to obtain an usefull structure for distributed knowledge.

Observation An hyper-schema benefits of a transfer of knowledge from $\mathcal{S}_1$ and $\mathcal{S}_2$ to $\mathcal{S}$. This transfer is described by means of the semantical computations performed in a hyper-schema. Indeed, the valuation mapping of $\mathcal{S}$, that is $Val_{\mathcal{I}}$ uses the valuation mappings for $\mathcal{F}(\mathcal{S}_1)$, $\mathcal{F}(\mathcal{S}_2)$.

Observation Unlike the usual semantic schemas, in an hyper-schema $\mathcal{S}$ the formal entities of $\mathcal{F}(\mathcal{S})$ are obtained using path-based computations.

5.2 Hierarchical Distributed Reasoning System based on hyper-schemas

Same as the distributed system presented in the previous section, an Hierarchical Distributed Reasoning System (shortly, HDR System) is a distributed system that uses semantic schemas for knowledge representation and reasoning. A HDR system is the tuple $H = (Q_1, Q_2, \ldots, Q_k)$ where $k \geq 2$ and

- $Q_1 = \{Ag_1, \ldots, Ag_{n_1}\}$, $n_1 > 1$, constitutes the first level of the system. The entities $\{Ag_1, \ldots, Ag_{n_1}\}$ are named the **agents** of the system and as structures they are hyper-schemas of order 0.
- $Q_2 = \{KM_{n_1+1}, \ldots, KM_{n_2}\}$, $n_2 \geq n_1 + 1$, constitutes the set of the knowledge managers of the second level of the system and as structures they are hyper-schemas of order 1.
- $Q_j = \{KM_{n_{j-1}+1}, \ldots, KM_{n_j}\}_{j \geq 3}$ represents the set of the knowledge managers for the j-th level of the system and as structures they are hyper-schemas of order $j - 1$.

The method in reported in:
Mihaela Ghindeanu, Constructing Architectures for an Hierarchical Distributed Reasoning System Based on its Inputs, *Proceedings of the 5th International Conference on Cybernetics and Information Technologies, Systems and Applications (CITSA 2008)*, Orlando, Florida, USA , 2008
Mihaela Ghindeanu, The Knowledge Domain of an Hierarchical Distributed System Determines its Architecture, *Annals of University Of Craiova, Mathematics and Computer Science Series.* Vol. 34, pag. 107-114, ISSN: 1223-6934, 2007 and in
Mihaela Ghindeanu, Joining Semantic Schemas in Vision of a Distributed System Reasoning, *Research Notes in Artificial Intelligence and Digital Commnunications, RCAI 7th International Conference on Artificial Intelligence and Digital Communications*, vol. 107, ISBN 978-973-671-135-0, Craiova, p. 123-132, 2007

5.3 A spatial HDR system

We reconsider the spatial reasoning mechanism constructed by means of *LSG*s. This implementation also constructs grid representations, but this time only by performing deductions, rather than arithmetical

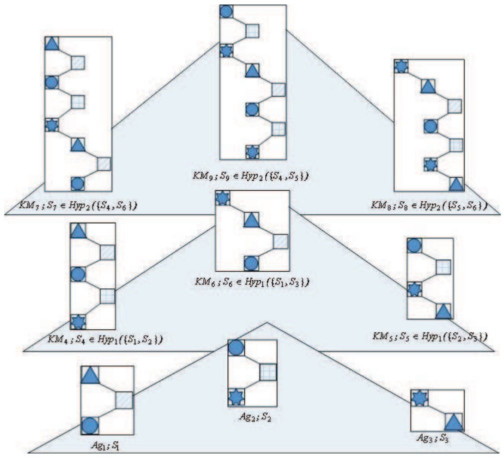


Figure 7: Graphical image generation in an HDR system

operations.

In order to synthetized a $2D$ image, we need a two levels HDR system, $HDRS = (Q_1, Q_2)$ where:
$Q_1 = \{Ag_1, Ag_2\}$ for an agent Ag_1 specialized on *left*(L), *perfectly behind*(PB) spatial relations and their combinations (ex. $\theta(PB, L)$) and an agent Ag_2 specialized on *behind*(B), *perfectly left*(PL) relations and their combinations (ex. $\theta(PL, B)$).
$Q_2 = \{KM_3\}$ constructs the hyper-schema of order 1 over the agents' schemas, $\mathcal{S}_3 \in Hyp_1(\{\mathcal{S}_1, \mathcal{S}_2\})$. In the resulted hyper-structure, the grids obtained at the first level are combined in order to obtain the image synthesis.

The algorithm is presented in **Mihaela Ghindeanu, A Spatial Reasoning HDR System, *Research Notes in Artificial Intelligence and Digital Commnunications, RCAI 8th National Conference on Artificial Intelligence and Digital Communications*, vol. 108, Craiova, pag. 88-102, ISBN 978-973-671-161-9, 2008**.

5.4 HDR system applied in computer graphics

Computer graphics concerns the pictorial synthesis of real or imaginary objects from their computer-based methods. Our image generation method by means of HDRS skills uses a recursive image generation mechanism. We do not indend to develop another rewriting system that would construct new images by *succesively replacing parts of a simple image using a set of rewriting rules or productions.* In our method, the new images are obtained using a recursive method that joins images based on a common figure of them. The images generation method of our system is defined starting from the images provided by the agents. For this reason, we name these images as the **initiators** of the system. In Figure 7 is presented an example of some graphical images generated using this system.

The generation method is presented in **Nicolae Ţăndăreanu, Mihaela Ghindeanu, Hierarchical Semantic Structures Applied in Automatic Image Generation, *Proceedings of the 11th IASTED International Conference on Intelligent Systems and Control (ISC 2008)*, 2008**
an its implementation in a HDRS is described in **Nicolae Ţăndăreanu, Mihaela Ghindeanu, Hierarchical Distributed Reasoning System for Geometric Image Generation, *International Journal of Computers, Communication and Control*, 2008 (submitted)**

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L I S T A D E L U C R Ă R I

Lista de lucrări cuprinde realizări descrise în teza de doctorat care au fost publicate de doctorand, în calitate de unic autor/prim-autor/co-autor, în raport cu cerințele criteriului de evaluare TD3 și, după caz, ale criteriilor de evaluare DD1/ DD2 a) / DD3 a), respectiv, articole/studii publicate în reviste de specialitate recunoscute național (Rn1, Rn2 etc.), articole/studii publicate în volumele unor manifestări științifice naționale recunoscute (Vn1, Vn2 etc.), brevete de invenție recunoscute național (Bn1, Bn2 etc.), creații artistice prezentate la manifestări naționale recunoscute (An1, An2 etc.), articole/studii publicate în reviste de specialitate de circulație internațională recunoscute din țară și din străinătate (Ri1, Ri2 etc.), brevete de invenție recunoscute internațional (Bi1, Bi2 etc.), creații artistice prezentate la manifestări internaționale recunoscute din țară și din străinătate (Ai1, Ai2 etc.), după cum urmează.

Rn1. Nicolae Țăndăreanu, **Mihaela Ghindeanu**, *Path-based Reasoning in Semantic Schemas*, Annals of University of Craiova, Mathematics and Computer Science Series, ISSN 1223-6934, volume 35, pp. 171-181, 11 pg., 2008.

Rn2. **Mihaela Ghindeanu**, *The Knowledge Domain of an Hierarchical Distributed System Determines its Architecture***,** Annals of University of Craiova, Mathematics and Computer Science Series, ISSN 1223-6934, volume 34, pp. 107-114, 8 pg., 2007.

Rn3. Nicolae Țăndăreanu, **Mihaela Ghindeanu**, *Properties of Derivations in a Semantic Schema***,** Annals of University of Craiova, Mathematics and Computer Science Series, ISSN 1223-6934, volume 33, pp. 147-155, 9 pg., 2006.

Vn1. Nicolae Țăndăreanu, **Mihaela Ghindeanu**, *Image Synthesis from Natural Language Description,* Research Notes in Artificial Intelligence and Digital Communications, 3rd Romanian Conference on Artificial Intelligence and Digital Communications, Craiova, Romania, pp. 82-96, 15 pg., vol. 103, ISBN 973-8419-71-9, 2003.

Vn2. Nicolae Țăndăreanu, **Mihaela Ghindeanu**, *Towards a Mathematical Modelling of Conditional Knowledge,,* Research Notes in Artificial Intelligence and Digital Communications, 3rd Romanian Conference on Artificial Intelligence and Digital Communications, Craiova, Romania, pp. 5-15, 11pg., vol. 103, ISBN 973-8419-71-9, 2003.

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Ri1. Nicolae Țăndăreanu, **Mihaela Ghindeanu**, Sergiu Nicolescu, *Hierarchical Distributed Reasoning System for Image Generation*, International Journal of Computers, Communications & Control, pp. 167- 177, 11 pg., vol. IV, no. 2, ISSN 1841-9836, E-ISSN 1841-9844, 2009.

Ri2. Nicolae Țăndăreanu, **Mihaela Ghindeanu**, *Conditional schemas*, Bulletin Mathematique de la Societe des Sciences Mathematiques de Roumanie, ISSN 1220-3874 , submitted, 2009.

Ri3. Nicolae Țăndăreanu, **Mihaela Ghindeanu**, *Hierarchical Distributed Reasoning Systems based on Hyper-schemas*, INFORMATICA International Journal, ISSN 0868-4952, submitted, 2008.

Vi1. **Mihaela Ghindeanu**, *Constructing Architectures for an Hierarchical Distributed Reasoning System Based on its Inputs*, International Multi-Conference on Engineering and Technological Innovation, Orlando, Florida, USA, pp. 231-234, 4 pg., 2008.

Vi2. Nicolae Țăndăreanu, **Mihaela Ghindeanu**, *Hierarchical Semantic Structures Applied in Automatic Image Generation*, Proceedings of the 11-th IASTED International Conference on Intelligent Systems and Control (ISC 2008), Orlando, Florida, USA, ACTA Press, ISBN 978-0-88986-777-2, 2008.

Vi3. Nicolae Țăndăreanu, **Mihaela Ghindeanu**, *A Three-Level Distributed Knowledge System Based on Semantic Schemas*, Proceedings of the 16-th International Workshop on Database and Expert Systems Applications, Proceedings of DEXA'05 (TAKMA 2005), IEEE Computer Society, Copenhagen, pp. 423-427, 5 pg., 2005.

Vi4. Nicolae Țăndăreanu, **Mihaela Ghindeanu**, *Hierarchical Reasoning Based on Stratified Graphs. Application in Image Synthesis*, Proceedings of the 15-th International Workshop on Database and Expert Systems Applications, Proceedings of DEXA 2004, IEEE Computer Society, Zaragoza, Spania, Los Alamitos California, pp. 498-502, 5 pg., 2004.

Vi5. **Mihaela Ghindeanu**, *A Spatial Reasoning HDR System*, Proceedings of the 8-th International Conference on Artificial Intelligence and Digital Communications - AIDC 2008, Craiova, Romania, volume 108, pp. 88-102, 15 pg., Reprograph Press, ISBN 978-973-671-161-9, 2008.

Vi6. **Mihaela Ghindeanu**, *Joining Semantic Schemas in Vision of a Distributed System Reasoning*, Proceedings of the 7-th International Conference on Artificial Intelligence and Digital Communications - AIDC 2007, Craiova, Romania, volume 107, pp. 123-132, 10 pg., Reprograph Press, ISBN 978-973-671-135-0, 2007.

Vi7. **Mihaela Ghindeanu**, *Fuzzy Controller for Spatial Objects Recognition*, Proceedings of the 6-th International Conference on Artificial Intelligence and Digital Communications - AIDC 2006, Thessaloniki, Greece, volume 106, pp. 118-125, 8 pg., Reprograph Press, ISBN 973-742-413-1, 2006.

Vi8. **Mihaela Ghindeanu**, Claudiu Ionuț Popîrlan, *A Natural Language Processing System using Java-Prolog Technology*, Proceedings of the 5-th International Conference on Artificial Intelligence and Digital Communications - AIDC 2005, Craiova, Romania, volume 105, pp. 63-68, 6 pg., Reprograph Press, ISBN 973-671-055-6, 2005.

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Din analiza listei de lucrări prezentate, rezultă că realizări descrise în teza de doctorat au fost publicate de doctorandă, în calitate de unic autor, prim autor şi, respectiv, co-autor, în reviste de specialitate şi în volume ale unor manifestări ştiinţifice, recunoscute pe plan intern şi internaţional: CNCSIS B, indexate în baze de date internaţionale (**IEEE Xplore, DBLP, ISI**) şi în sistemul ISI (**ISI Proceedings**). **În consecinţă, cerinţele criteriului TD3 sunt satisfăcute şi criteriul de evaluare TD3 este îndeplinit.**

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