A Semiotic Approach to Conceptual Modelling

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Abstract. The work on Conceptual Modelling performed by our group at PUC-Rio is surveyed, covering four mutually dependent research topics. Regarding databases as a component of information systems, we extended the scope of the Entity-Relationship model, so as to encompass facts, events and agents in a three-schemata specification method employing a logic programming formalism. Next we proceeded to render the specifications executable, by utilizing backward-chaining planners to satisfy the agents' goals through sequences of fact-modification events. Thanks to the adoption of this plan-recognition / plan-generation paradigm, it became possible to treat both business-oriented and fictional narrative genres. To guide our conceptual modelling approach, we identified four semiotic relations, associated with the four master tropes that have been claimed to provide a system to fully grasp the world conceptually.

Keywords: Entity-Relationship Model, Information Systems, Planning, Logic Programming, Narrative Genres, Semiotics.

1 Introduction

Our understanding of information systems comprises facts, events and agents. Everywhere the Entity-Relationship model is used. The existing entity instances and their properties, i.e., their attributes and the relationships among them, are the *facts* that characterize a state of the world. States are changed by the occurrence of *events* caused by operations defined by pre-conditions and post-conditions that are in turn expressed in terms of such facts. The event-producing operations are performed by certain *agents*, in an attempt to satisfy their goals, once again expressed by facts. Accordingly, our specifications are divided into three schemas to introduce, respectively, the classes of facts (static schema), events (dynamic schema) and agents (behavioural schema).

It so happens that the pre-conditions to bring about an event may need to be first fulfilled as part of the effect (post-conditions) of other events. This partial-order dependence immediately suggests the recursive application of backward-chaining *plan-generators* in order to find one or more sequences of operations (plans) able to perform a transition from the current state to a state wherein the goals of an agent hold. By using a logic programming notation to represent the three schemas and

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having developed in Prolog a plan-generation algorithm, we gained the benefit of executable specifications, enabling to simulate and helping to gradually produce a running system. Moreover, plans previously generated by the algorithm, or originated from regulations or from customary practice, can be converted into patterns and kept in libraries from which they can be retrieved by a *plan-recognition* algorithm and reused, after the necessary adaptations, to reach similar goals.

Besides business information systems domains, we soon realized that our specification method was applicable to narrative genres in general, ranging from "serious" applications, such as maintenance procedures for an oil company, to fictional sword-and-dragon stories. Indeed plot composition can be conveniently achieved via interactive plan-generation. Alternatively, narrative *motifs* can serve as patterns to be retrieved from a library and combined to compose the plots, thus providing another opportunity to utilize plan-recognition.

When specifying any system, and when using it as well, some guidelines should be available. What properties are relevant to characterize an object? What events should be observed? How do agents interact, either collaborating or competing? Is it possible to attain modularity, by setting the focus to different degrees of detail? Which integrity constraints should be enforced? We found that four *semiotic relations* establish and delimit the information space, covering the need for helpful reasoning principles to a comprehensive extent. The *syntagmatic relations* determine – employing semiotic terminology [53] – a horizontal axis expressing the notion of connectivity between information components. Another notion is similarity expressed by *paradigmatic relations*, along a vertical axis. A depth axis, expressing granularity, results from *meronymic relations*. Finally, topological limits are imposed to this three-dimensional space by *antithetic relations*, which express negation and opposition. The four semiotic relations are associated with the so-called *four master tropes* (metonym, metaphor, synecdoche, and irony) [9], thought to constitute "a system, indeed *the* system, by which the mind comes to grasp the world conceptually in language" [23].

Our research work on conceptual modelling, motivated by the considerations above, is briefly surveyed as follows. Section 2 refers to the separate but consistently adjusted specification of facts, events and agents. Section 3 covers plan-generation and plan-recognition. Section 4 addresses application domains and narrative genres. Section 5, the longest one, discusses the semiotic relations. Section 6 presents the concluding remarks.

2 Three-Schemata Specifications

We have been working with the conceptual modeling of information systems with a database component, considering their static, dynamic and behavioral aspects.

The static aspect concerns what *facts* hold at some database state, conveniently described in terms of the entity-relationship model.

The dynamic aspect corresponds to events that can produce state transitions. Events result from the execution of operations, defined in a declarative style by their pre-conditions and post-conditions, according to the STRIPS proposal [25].

Pre-conditions involve the presence or absence of facts, whereas post-conditions comprise the sets of facts added or deleted as the effect of the operation. Adopting the notion of abstract data types, implicit in object-oriented approaches, we require that facts can only be modified through the execution of such operations, whose pre- and post-conditions are adjusted so as to preserve all integrity constraints.

The behavioural aspect refers to the agents authorized to cause events by performing the operations. To model this aspect we mainly use goal-inference rules, which indicate what facts should hold, or cease to hold, at a target state that an agent will be motivated to bring about in view of a situation, again expressed in terms of facts holding or not holding, prevailing at the current state [22]. In order to reach the desired target state, an agent would execute – or ask the authorized agents to execute – some appropriate plan, composed of one or more pre-defined operations. As a further development, we have started to look at agent profiles involving three kinds of personality factors, from which a decision-making process could operate: drives for the emergence of goals from situations, attitudes for the choice of plans to achieve the preferred goal, and emotions to decide whether or not to commit to the execution of the chosen plan, depending on the expected emotional gain when passing from the current to the target state [4,40]. As an inducement to revise individual decisions, we included competition and collaboration interferences, as prescribed for multi-agent contexts [54].

3 The Plan-Recognition / Plan-Generation Paradigm

The three aspects treated in the preceding section were integrated through the application of a plan-recognition / plan-generation paradigm [35,38].

In order to make our conceptual specifications executable [32], we created an environment where entity and relationship classes, operations, and goal-inference rules and agent profiles are all represented as Prolog clauses. Also written in Prolog, algorithms were provided for planning and for the simulated execution of the generated plans [17,18,19,29]. Moreover it was noted that simulation can become a useful resource to support learning or training [20].

The plan-recognition side of the paradigm is relevant, after the system has been made operational, as a means to extend conventional query facilities towards truly cooperative responses. Cooperation, as discussed in section 5, is most effective when one can detect what the user is trying to accomplish. The plan-recognition algorithm, which we adapted from [46], matches a few observed actions of the user against a library of previously recorded typical plans. The observed actions can be taken from the execution log, which is updated whenever each operation of a transaction of the user's initiative is executed. As we explained in [39], the library of typical plans, in turn, can be constructed by inspecting the log and extracting and filtering sequences of executed operations, whereby the transition indicated in some goal-inference rule has been achieved.

4 Application Domains and Narrative Genres

Treating databases as a component of information systems encompassing facts, events and agents permits a shift from a purely descriptive to a *narrative context* [27]. Indeed in a workshop devoted to the application of natural languages to information systems, we showed how to generate template-based natural language text, by inspecting the plot-structured execution log and analyzing it against our three-level conceptual schemas [37]. It is therefore not surprising that all the discussion in this section applies in essentially the same way to literary genres [15,28,36], whenever the fictional events can be equally attributed to a pre-defined repertoire of operations performed by agents (cf. the functions and *dramatis personae* in [50]). Recognizing that literary genres ruled by identifiable conventions can thus be treated as one more kind of application domain, we have adopted plan-based plot composition, coupled with several dramatization techniques and visual media, within an ongoing digital storytelling project [16,21].

The application of the plan-recognition / plan-generation paradigm to the narrative domain [28] was presented at the XIX Brazilian Symposium on Data Bases as an invited talk, on which occasion the author received a prize from the Brazilian Computer Society, acknowledging his contributions to database research.

Having started in the fictional genres with folktale sword-and-dragon stories, we have recently moved to genres where, besides action events, communicative events must be specified and play a decisive role, such as detective stories [5].

5 Semiotic Completeness

Based on studies [9,12,51,55] asserting the completeness as reasoning processes of the so-called four master tropes – metonymy, metaphor, irony and synecdoche, we identified four types of semiotic relations that can exist not only between facts, but also between events and between agents, which we denominated, respectively, syntagmatic, paradigmatic, antithetic and meronymic relations. Informally speaking, syntagmatic relations refer to connectivity, paradigmatic relations to similarity and analogy, antithetic relations to negation, and meronymic relations to hierarchy.

Meronymy was, curiously, treated in our very first participation in Entity-Relationship events [52], when we proposed to include semantic is-a and part-of hierarchies into the ER model. Not much later we learned about the seminal contribution of [56], where six types of part-of were distinguished.

The paradigmatic relations were the next to attract our attention. In a SIGPLAN Notices paper [26], belonging to logic programming rather than to the database area, we argued that a powerful kind of reasoning by analogy is provided by combining unification with most specific generalization. We presented a revised version of an existing algorithm to compute the most specific generalization of terms, which correctly decides whether or not new variables should be introduced in each case. We also provided programs to perform unification and most specific generalization over frames, a data structure which would be of major importance for the practical application of our ideas, as will be repeatedly stressed in the sequel.

Our paper presented at SBBD 2007 [2] can be regarded as a first attempt to deal with paradigmatic relations in the context of databases. The motivating problem was that databases, particularly when storing heterogeneous, sparse semi-structured data, tend to provide incomplete information and information which is difficult to categorize. The paper first considers how to classify entity instances as members of entity classes organized in a lattice-like generalization/specialization hierarchy. Then, it describes how the frame representation employed for instances and classes, as well as the closeness criterion involved in the classification method, favors the practical use of similarity and analogy, where similarity refers to instances within the same class, and analogy involves different classes. Finally, the paper argues that similarity and analogy facilitate querying semi-structured data.

A more in-depth investigation of classification methods based on frames was the object of a more recent work [48]. In fact, the problem of data classification goes back to the definition of taxonomies covering knowledge areas. With the advent of the Web, the amount of data available increased several orders of magnitude, making manual data classification impossible. The paper presents a tool to automatically classify semi-structured data, represented by frames, without any previous knowledge about structured classes. The tool uses a variation of the K-Medoid algorithm and organizes a set of frames into classes, structured as a strict hierarchy.

The next step, still focusing on paradigmatic relations and the corresponding trope, metaphor, was to promote a reuse strategy, whereby new conceptual specifications might be partly derived from previous ones. A paper along this line was presented at CIKM [8]. Metaphor is not merely a rhetorical device, characteristic of language alone, but rather a fundamental feature of the human conceptual system. A metaphor is understood by finding an analogy mapping between two domains. The paper argued that analogy mappings facilitate conceptual modeling by allowing the designer to reinterpret fragments of familiar conceptual models in other contexts. The contributions of the paper were expressed within the tradition of the ER model, the Description Logic framework and as extensions of the OWL.

This reuse strategy was further examined in [7,30]. These papers argued in favor of a database conceptual schema and Semantic Web ontology design discipline that explores analogy mappings to reuse the structure and integrity constraints of conceptual models, stored in a repository. We presupposed that a team of expert conceptual designers would build a standard repository of source conceptual models, which less experienced designers would use to create new target conceptual models in other domains. The target models will then borrow the structure and the integrity constraints from the source models by analogy. The concepts were once again expressed in the contexts of Description Logic, the RDF model and OWL to reinforce the basic principles and explore additional questions, such as the consistency of the target model.

Reusing a conceptual schema is of course a multi-phase process. After finding a suitable source schema, adaptations will often be needed in view of conflicts with the target schema being designed. The notion of *blending* [24] was exploited for this objective in [10]. To support the generation of database schemas of information systems, the paper proposed a five-step design process that explores the notions of generic and blended spaces and favors the reuse of predefined schemas. The use of generic and blended spaces is essential to achieve the passage from the source space into the target space in such a way that differences and conflicts can be detected and, whenever possible, conciliated. The convenience of working with multiple source schemas to cover distinct aspects of a target schema, as well as the possibility of creating schemas at the generic and blended spaces, was also considered. Notice that, as we would indicate more explicitly in later articles, the presence of conflicts already suggests the need to deal with antithetic relations.

As mentioned before, since our already referred SBBD paper [2], we have been using frames and frame-sets as a more flexible data structure than relational tuples and tables. At the 27th ER Conference [33], as we proceeded to show how to extend the reuse strategy to the design of dynamic schemas, we employed *plots*, also defined as a frame-like data structure. A plot is a partially ordered set of events. Plot analysis is a relevant source of knowledge about the agents' behavior when accessing data stored in the database. It relies on logical logs, which register the actions of individual agents. The paper proposed techniques to analyze and reuse plots based on the concepts of similarity and analogy. The concept of similarity was applied to organize plots as a library and to explore the reuse of plots in the same domain. By contrast, the concept of analogy helps reuse plots across different domains. The techniques proposed in the paper find applications in areas such as digital storytelling and emergency response information system, as well as some traditional business applications.

Our first study wherein all four semiotic relations were explicitly discussed was indeed presented at a digital storytelling conference, namely SBGames [14]. In that paper, the process of plot composition in the context of interactive storytelling was considered under a fourfold perspective, in view of syntagmatic, paradigmatic, antithetic and meronymic relations between the constituent events. These relations were then shown to be associated with the four major tropes of semiotic research. A conceptual model and set of facilities for interactive plot composition and adaptation dealing with the four relations was described. To accommodate antithetic relations, corresponding to the irony trope, our plan-based approach leaves room for the unplanned. A simple storyboarding prototype tool has been implemented to conduct experiments. In another paper [4], already mentioned in Section 2, we utilized the semiotic relations to characterize classes of characters (agents, in the context of business information systems) according to their mutually interfering behavior in decision-making processes.

As remarked earlier, frames and plots became increasingly important to our research projects. The ER model is arguably today's most widely accepted basis for the conceptual specification of information systems. A further common practice is to use the relational model at an intermediate logical stage, in order to adequately prepare for physical implementation. Although the relational model still works well in contexts relying on standard databases, it imposes certain restrictions, not inherent in ER specifications, which make it less suitable in Web environments. Our 28th ER Conference invited paper [34], mentioned at the end of Section 3, recommends frames as an alternative to move from ER specifications to logical stage modeling, and treats frames as an abstract data type equipped with a Frame Manipulation Algebra. It is argued that frames, with a long tradition in AI applications, are able to accommodate the irregularities of semi-structured data, and that frame-sets generalize relational tables, allowing to drop the strict homogeneity requirement. The paper includes examples to help describe the use of the operators.

Likewise, a Plot Manipulation Algebra was proposed to handle plots in an ICEC conference [45]. The seven basic operators, equally named in both the Frame Manipulation Algebra and in the Plot Manipulation Algebra, and working respectively on frames and plots, were introduced in view of the four fundamental semiotic relations, as indicated below:

- syntagmatic relations - product, projection
- paradigmatic relations - union, selection
- antithetic relations - difference
- meronymic relations - combination, factoring

The operators in the first three lines above encompass the equivalent to the five basic operators of Codd's relational algebra (product, projection, union, selection, difference). The additional two operators (combination, factoring) handle the hierarchical structures induced by the meronymic relations, a notion that would correspond to non-first-normal form (NF2) relations in the relational model (cf. our algebra of quotient relations [41]). Thus, it seems fair to claim that our algebras are *semiotically complete*, a notion that covers an ampler scope than that of Codd's relational algebra. Prototype logic-programming tools have been developed to experiment with the Frame Manipulation Algebra and the Plot Manipulation Algebra.

The pragmatic aspects of information systems constitute the main thrust of our present work, strongly influenced by the fundamental semiotic concepts exposed in this section. At the Second Workshop of the Brazilian Institute for Web Science Research [3], we argued for this orientation, which becomes increasingly relevant with the transition from the closed world of the old proprietary databases to the open world of the Web. Our view of information systems recognizes that, in order to serve as a basis for an effective communication process, their conceptual specification is comparable to the definition of a specialized language. Accordingly, it must pass through four levels: lexical, syntactic, semantic, and pragmatic [47]. At the semantic level, the correspondence between the stored data and real world facts is considered, but to design systems of practical usefulness, one still needs to investigate what purposes they will serve, which falls in the scope of the pragmatic level.

This pragmatic orientation, as we soon realized, is fully consistent with our conceptual design method that, as gradually exposed in the preceding sections, encompasses not only facts, but also events and agents. Motivated by their goals, defined in terms of database facts, agents try to cause the occurrence of events whereby a database state is reached where the goals are satisfied. And our plan-recognition / plan-generation paradigm puts together all these aspects and leads to executable specifications, which allow simulation experiments to effectively test the usability of the proposed conceptual design.

6 Concluding Remarks

An early proposal on the subject of database modelling [1] introduced an architecture that puzzled both theoreticians and practitioners. What could be a "conceptual schema"? None of the existing models seemed to offer an adequate basis to formulate what was intended, namely the *semantic* contents of the stored data. As we all know, this gap was appropriately filled by the Entity-Relationship model. Recognizing the wise orientation taken by the model of describing the application domains in their own language, our group proceeded to extend this direct and highly intuitive way to characterize factual information to events and agents.

In the present time, the Web gives access to a continuously growing number of information sources and once again the word "navigation" is employed, no longer in the sense of traversing an intricate network of physical pointers, but to designate the novel opportunities opened by connectivity across linked Web pages. We are convinced that detecting semiotic relations helps to guide navigation, not only exploring connectivity but enriching the quest for information with similarity and inter-domain analogy, allowing to zoom in and out to alternate between summaries and details, and limiting excessive recall, in favour of precision, by negative directives purporting to exclude irrelevant responses. With the objective of meeting the Semantic Web standards, some new formalisms have been proposed, but they clearly keep supporting the conceptual modelling principles. Peter Chen himself has endorsed the statement that "…RDF can be viewed as a member of the Entity-Relationship model family" [13].

Another contribution of the ANSI/X3/SPARC report that will continue to receive close attention in our research project is the identification of *external schemas*, whereby the participation of the different *users* should be duly taken into consideration. By making the external schemas branch from the conceptual schema, the report implicitly imposes, as a consequence, that they cannot be simply confused with views extracted from relational tables. Conceptual modelling should first be applied to their specification, which extends in one more direction the scope of the Entity-Relationship model family.

A crucial semiotic notion applies whenever users, as human – rather than supposedly tightly-controlled software agents – are concerned: to the *signifier-signified* correspondence between an object and its representation [53], an *interpretant* [49] must be interposed as a third component to stress that the correspondence is subject to each person's understanding, which may be faulty or incomplete. Conceptual modelling at the individual users' level must then deal with *beliefs*, as a correct or incorrect rendering of facts. When specifying an information system meeting, not only semantic, but also *pragmatic* requirements, serious efforts should be invested in the design of adequate interfaces that, as much as possible, avoid misconceptions and misconstruals [42,43], and seek to identify the users' goals and plans [11], to maximize their satisfaction while pursuing activities in consonance with ethical conduct and the adopted procedural norms.

In Web environments, the possibility to tackle multiple sources raises to an especially critical level the problem of dealing with conflicting information. Examining the process of *communication* as described in [44], showing a *sender* in the act of delivering a *message* expressed in some *code* to a *receiver*, we get a feeling of how many are the chances of mistranslation or misunderstanding. Recalling Peirce's notion of interpretant, those who act as senders, installing information on a Web page, may have failed when observing, or interpreting, or "coding" the reality in terms of the adopted models. Moreover, the stored "message" is subject to the same sorts of failures from users on the receiver side. Choosing the most likely version among conflicting data requires suitable heuristic criteria, such as the reputation of the source (*provenance*), but no easy solution seems attainable at the present state of the art. With the continuation of our project, we intend to investigate to what extent our semiotic approach can be further developed to cope with this very relevant issue.

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