Information System Evolution as Language Evolution

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Abstract

In this article we look at the evolution of information systems from the perspective of the evolution of domain languages, and provide a report on some of our *ongoing* research activities.

Many if not all analysis and design approaches for information systems base themselves on techniques involving some sort of natural language analysis. However, the view on language underlying these approaches ignores several issues concerning the nature of language.

This article primarily aims to create awareness for the issues at play, and argues that current approaches ignore most of them. We finish by presenting an overview of our research efforts concerning the tackling of the matters discussed.

1 Introduction

As stated in [FHL+98], "*information systems*" concerns the use of "*information*" by individual or groups of people in organisations, in particular through computer-based systems. The concept of information system can roughly be defined as that aspect of an organisation that provides, uses and distributes information. An information system *may* contain computerised sub-systems to automate certain elements. Some information system may not even be computerised at all. A filing cabinet used to store and retrieve several dossiers is, in essence, an information system. What we may perceive to be an information system, may vary highly in terms of their scope. Some typical examples would be:

- Personal information appliances, such as electronic agenda's, telephone registries in mobile phones, etc.
- Specific information processing applications, such a sales administration, bank account administration, etc.
- Enterprise wide information processing.

- Value-chain wide information processing.

A more precise definition (based on [FHL+98]) of the way we view the concept of information system system is:

> **Information system –** a sub-system of an organisational system, comprising the conception of how the communication and information-oriented aspects of an organisation are composed and how these operate, thus leading to a description of the (explicit and/or implicit) communication-oriented and information-providing actions and arrangements existing within the organisational system.

This definition does not require an information system to be computerised at all. However, the kind of information systems we focus on in this article are presumed to have some computerised core parts. Using the definition of information system, we may specialise this to its computerised parts as follows:

> **Computerised information system –** a sub-system of an information system, whereby all activities within that sub-system are performed by one or several computer(s).

It is our belief that the sole purpose for which a computerised information system is created is to provide information processing services to its environment. In line with this belief, we postulate that the internal structures of a computerised information system, ranging from table structures of databases to the components of applications, should essentially be a direct reflection of the domain in which the system will operate. This reflection will not only pertain to functional qualities but also to non-functional qualities, such as efficiency, reliability, maintainability, portability, usability and flexibility. For a detailed discussion on classes of quality properties, see e.g. [ISO01, ISO96]. In this article we mainly focus on functional qualities and conceptual structures.

In line with the way of thinking discussed above, one can observe how a large variety of methods and techniques used in the analysis and design of computerised information systems are indeed based on the assumption that, where it concerns functionality, the underlying structures of the system should be a direct reflection of "that what is going on" in the domain of which the computerised information system is (to become) an integral part [PW94, BFW96, Hal01]. In the remainder of this article, we will investigate this relationship further, in particular in the light of evolution of the environment of a computerised information system, obviously requiring the system to evolve accordingly. The aim of this article is first and foremost to create awareness of the issues involved and the reasons why pre-existing approaches fall short. The secondary aim of this article is to shed some light on the research efforts we are involved in in tackling these issues.

The structure of this paper is as follows. In section 2, the way of thinking presented so-far is elaborated on, leading to a discussion of what we call the "universe of discourse approach". Section 3 continues by identifying several critical issues with respect to the traditional way of looking at the design and *evolution* of information systems. If anything else, this section aims to create awareness of some of the underlying issues. Section 4 tries to take us beyond these issues and presents the concept of *discourse environment*. Before concluding, section 5 provides a discussion on the research activities we are currently involved in to further develop the concept of discourse environment as well as deal with further challenges posed.

2 The Universe of Discourse Approach

As discussed above, it is our belief that the internal structures of a computerised information system should essentially be a direct reflection of the domain in which it will operate. We now continue by observing that

in most of these methods and techniques, this relationship is rooted in the use of linguistic mechanisms at the hand of which the domain is analysed (and the system designed). The use of these mechanisms is based on a presumed parallel between the discourse in the domain and the conceptual structures that form the base of the resulting computerised information system. An elaborate discussion of this way of thinking may be found in e.g. [Hal01].

What lies beneath the above identified parallel is the insight that there is a strong relation between the concepts that are built into a computerised information system and the language that is used to communicate in, as well as over, the domain in which the system is supposed to operate.

The domain that is studied when analysing and designing a computerised information system may be referred to as the universe of discourse [ISO87], in other words "the world (or universe) we are interested in talking (or discoursing) about". So the universe of discourse is a "concept world": a world about which people communicate, and which can be described through the explicit naming of elements and relations. This assumes that when making a model of a domain (referred to as a *domain model*) one also, almost inevitably, produces a model of the language used to describe that domain. One might even go as far to say that the language and the domain model are two sides of the same coin.

In some information system analysis and design methods, the relation between the language used to describe the universe of discourse and the structure of the resulting system is made very explicit. For example, Object Role Modelling [Hal01], and its many variations (NIAM [NH89], FORM [HO92], PM [BHW91], PSM [HW93] and BRM [SZ91]), start out from verbalisations, in natural language, of so-called elementary facts that may be observed to hold in the domain. The domain model resulting from this modelling exercise is usually referred to as the *information grammar*. Also the well known ER approach [Che76] has a sound basis in a language view on domain modelling.

Also in some object-oriented analysis and design methods, verbalisations of phenomena in the universe of discourse are explicitly at the base of the resulting domain models. For example, NORM [De 91] (which is an object-oriented variation of Object-Role Modelling), OOSA [EKW92] and KISS [Kri94].

The UML [BRJ99] is an example of an approach which does not so explicitly relate the language that is used to express phenomena from the universe of discourse to the essential structures of the resulting systems. However, the resulting structures still strongly reflect the language used to describe the universe of discourse. In the case of the UML, this claim is supported by the observation that when using the UML to analyse and design a system, one usually starts out by defining so-called use-cases for the prospective system. These use-cases, and more specifically their – natural language – narrative explanations, serve as input for most other modelling steps, including the definition of a UML class diagram.

At the core of the "universe of discourse approach" therefore lies the postulate that for computerised information systems, analysis and design activities can, at least to a considerable extent, be regarded as the modelling of a *unified* language: the language used to describe phenomena in the universe of discourse. The universe of discourse approach is powerful in the sense that we, the human beings who analyse and design computerised information systems, are largely "language-driven beings" and that analysis in terms of language utterances is close to our natural way of regarding a domain. Those utterance do *not* necessarily have to be textual. A graphical depiction of a model is just as well a language utterance as a piece of text is.

3 Issues Concerning the Universe of Discourse Approach

The way most analysis and design methods employ the universe of discourse approach in practice has some serious flaws. These flaws become even more troublesome in the context of evolving domains, a feature which most real-world domains do indeed exhibit.

This section aims to raise awareness for the issues that are at play when we explicitly or implicitly model a universe of discourse in terms of a unified domain model, and use this as a base to develop a computerised information system; issues which tend to be overlooked by most approaches for information system analysis and design. A more detailed discussion of these issues can be found in [Hop03].

Issue 1: Different people will use (slightly) different words for the same entities/relations in the same situations (or domains).

The standard universe of discourse approach does not really allow for different names for the same entities or relations. In other words, if people communicate in or about the same universe of discourse (for example, an organization) and have different opinions or habits concerning how you call something, then this is not something the standard universe of discourse view can (or even wants to) deal with. It therefore ignores actual differences that occur in the languages of individuals; it assumes people just should not be so "sloppy" and get their linguistic act properly together. This is not a realistic demand in most practical case [Sch99].

Issue 2: The same person will use (slightly) different words for the same entities/relations in different situations (or domains).

The standard universe of discourse approach usually does allow for the distinction between different domains, but often it is difficult to keep the domains apart, or avoid overlap. What is more, the *same* person may very well use slightly different words for almost similar things in different situations, for example depending on who they are talking to or what they are doing.

Issue 3: There are many ways in which the same domain may be described.

The standard universe of discourse approach tends to assume that not only the language used (see issue 1) is clear and agreed upon, but that the entities and relations in a domain (the actual universe of discourse) are also clear and agreed upon by all parties involved. Yet again, in practice, this is hardly ever the case.

This issue tends to be superficially recognized, while the answer generally is simply: "then better make sure that people involved agree on it". Usually, this is done by finding a "domain expert" and letting him or her decide what a domain looks like and how you describe it. Additionally, discussion or negotiation between a small number of stakeholders is often included. The main point, however, is that in the end, a uniform domain description is strived for.

Again this is not in line with how people use language. People are people, and will have diverging views on a domain and the entities that play a role in it.

Issue 4: Words may mean more than one thing; or several words may mean the same thing.

This issue is recognized by standard approaches, which include the "resolving" of homonyms (one word meaning more than one thing) and synonyms (several words meaning the same thing). However, the word "resolving" suggests that homonymy and synonymy are "wrong" and should be avoided. And again, this is not always realistic in situation where many people and many languages bump into each other.

Issue 5: People need contextual knowledge to really interpret what is said in/about a domain.

If the actual meaning of words is taken into account at all, one still tends to presume that it is possible to provide a definition that covers precisely what a word means in some domain. However, context really has a very strong influence on interpretation. High-level, general descriptions of word meaning are, therefore, almost guaranteed to cause problems if the contexts in which they are used, and the people that use them, vary substantially [Cla92, Cru00].

Issue 6: If a domain evolves, the words used in it tend to evolve with it. Domains will evolve.

The statement that most domains in which information systems play a role *evolve* shall need no further arguing. When a domain evolves, the issues discussed above are likely escalate. Agreement on terms and concepts that has been reached in the past will be put under pressure because of the divergent forces brought about by evolution. Unless pro-active action is undertaken to re-negotiate and coordinate the meaning of terms and concepts, the laws of increasing entropy will dictate an erosion of past agreement and understanding.

In other words, we will have to accept that if a domain changes, the languages used will change and unless explicitly managed will lead to new divergence of languages. At the very least, mechanisms for the checking and (re)specification of the meaning of words seems to be in order.

The issues as raised above are worsened when we realise that most information systems as they are used in practice operate in an evolving and interconnected world. For example, in [Kee91, TC93] and [Tap96], an elaborate discussions can be found on the changes in context and culture that occur inside organisations as well as across their environments as a result of different socio-economic changes in combination with technological developments in information technology (such as the Internet and mobile computing). Development of information systems in such rapidly evolving contexts becomes like shooting at a moving target [PW95a, PW94, PW95b]. This requires us to look at organisations and their information systems as evolving systems [Pro94] that are in a constant state of co-evolution.

One may argue that the above discussion is not new. For example, the concept of having a 'unified' corporate data model has long since been abandoned. However, what we still do see, both in theory and in practice, is that even though corporate data models are not strived for any more, the development of a single information system still requires an organisation to standardise the terminology when referring to entities/relations in a large part of the associated universe of discourse. Sometimes this may indeed be regarded as desirable, but even then, the above raised issues may render a unified terminology unattainable. One might even go as far to state that even when an information system is developed using a modern development approach, such as component-based or object-oriented development approaches [Kru00, DW99], the resulting system may indeed have a well thought out component structures, but it is still likely to be a terminological monolith. The monolithic nature of these systems with respect to their 'built-in' terminologies makes it harder for such systems to be integrated in dynamic and evolving environments. Both authors have witnessed several of such terminological monoliths on consultancy assignments for different Dutch organisations.

The development of web-based e-commerce, has also lead to a situation in which the computerised information system is actually the *only* communication channel between customers and sales people. In such situations, combined with the multi-national aspects of e-commerce, the above discussed issues become even more pressing as their impact on business activities comes to the fore. A common response to this is the development of standard ontologies in order to improve the grip on concepts as used in particular domains. This attempted standardisation is a denial of the divergent nature of language evolution [BLHL01].

In sum, in many respects the standard universe of discourse approach is somewhat simplistic if confronted with the complexities and dynamism of real life. In an interconnected, diverse and evolving world, the traditional universe of discourse approach falls short, as its basic postulate does not hold that for computerised information systems, analysis and design activities can be regarded as the modelling of a *unified* language; the language used to describe phenomena in the universe of discourse. The issues raised above point out that it is not realistic to presume that there is indeed a unified language in which phenomena in the universe of discourse can be described.

4 Discourse environments

We believe that, in order to better deal with the issues as discussed in the previous section, two elementary changes are needed in our way of thinking with regards to the universe of discourse approach:

1. We should acknowledge the fact that a language, and an underderlying domain model, exists by the virtue of some group of people using it to communicate about some domain.
2. We should also acknowledge the fact that different groups of people will communicate, in *their own* language, about the same (parts of) a domain, leading to many different (and equally valid!) domain models pertaining to (parts of) the same .

This essentially leads to the contrast between the traditional view on a universe of discourse and the more refined view we propose, as depicted in figure 1. The ER diagram on the left-hand side reflects the traditional situation, in which a universe of discourse is presumed to use a single, unified, language (and underlying domain model). The ER diagram on the right-hand side contrasts this situation, by acknowleding the fact that a universe of discourse may involve different groups of people, who may use different languages.

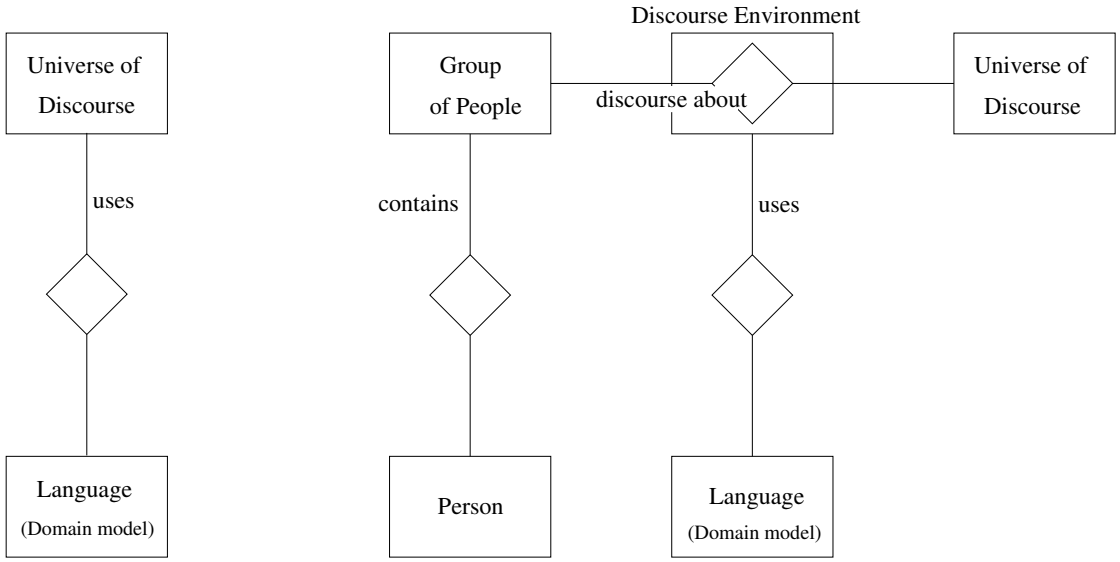

Figure 1: Contrasting viewpoints on a universe of discourse

As can be seen in figure 1, the combination of a group of people and a universe of discourse is referred to as a discourse environment. A discourse environment is therefore essentially defined as a group of people who discourse in, or about, part of a universe of discourse. In other words, it links a group of individuals to a (part of a) universe of discourse, and in doing so allows for the recognition of the fact that it is this combination to which a language may be associated. In addition, recognising discourse environments allows for a differentiated look at the conceptual needs of various groups within one large universe of discourse. Also, there is more to a discourse environment than just people and concepts: both discoursing and the ongoing creation and adaption of concepts entail the existance of concept related processes that have specific requirements in specific discourse environments [HW00, Hop00].

The concept of discourse environment presents a rather radical departure from the standard universe of discourse approach. It much more reflects the point of view that concepts are “in the eye of the beholder”

and while it does not explicitly deny the existence of a "real world out there", it focuses on the human interpretation of that world and its reflection in human language. This includes the possibility that different humans view the universe of discourse through different "conceptual eyes", bound to lead to different domain models, and yet have to cooperate and communicate about that same universe of discourse. We do not assume a uniform domain model to hold, but rather embrace the possible occurrence of variations and then wonder how to deal with them.

It is of course not the case that because two groups of people are involved in a similar activity, they automatically speak the same language. The groups also need to be in some way cooperatively related: to be both capable and willing use, and if necessary learn, a certain shared vocabulary or terminology. If a situation occurs in which two groups come together to communicate (usually via some individuals representing larger groups), a new discourse environment comes into existence, with its own dynamics and common goals. It may be the case that conventions or agreements in one discourse environment and then *carry over* to another domain environment.

All this does not mean that we deny that it might be a good idea to use uniform concepts in description and communication. We do, however, suggest that it might be better to acknowledge that in most real life situations, it may be undesirable or even plainly impossible to introduce or use a uniform conceptual framework (or terminology) for (parts of) a universe of discourse.

One might argue that the notion of a discourse environment, and the motivation for its introduction, are similar to the concept of an *external schema* that may be associated to a *conceptual schema* as introduced in the ISO ANSI/SPARC framework [ISO87]. A conceptual schema comprises a unique central description of the various information contents that may be in a database, while an external schema represents the way users and application programs may view the data in the database. Each external schema is presumed to be derived from the common conceptual schema. In terms of our terminology, both conceptual and external schema are domain models for (parts of) the universe of discourse.

The key difference is, however, that the ISO ANSI/SPARC framework presumes the existance of a "*unique central description*", referred to as the *conceptual schema*. One might say that some domain model, the conceptual schema, is treated as a 1th-class citizen while the other domain models, the external schemas, are treated as 2nd-class citizens. From an *evolutionary* perspective, the external schemas will follow the evolution of the *central* conceptual schema. In contrast, what we suggest is essentially to treat all domain models as equals. Each domain model will have its own pace of evolution, dictated by the group of people using the associated language, in other words, evolution is de-centralised. We have illustrated this in figure 2.

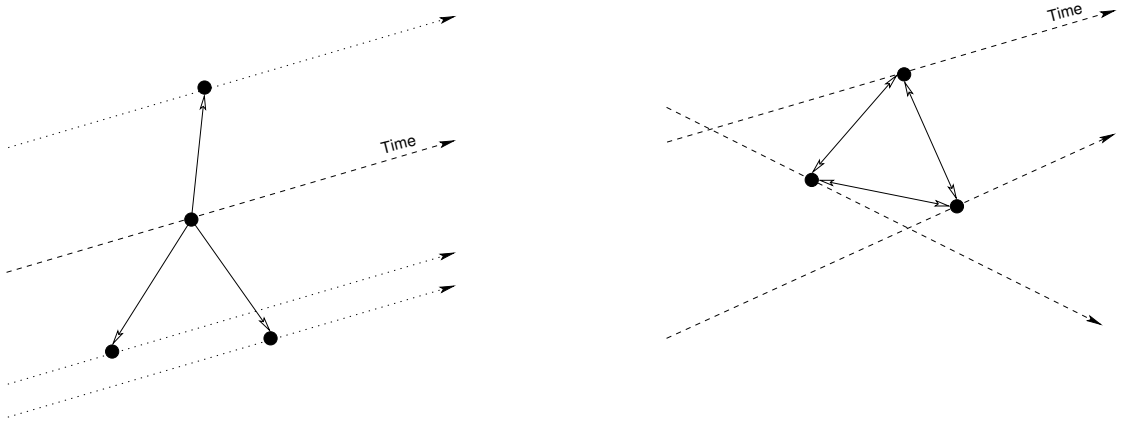

Figure 2: Centralised versus de-centralised discourse environments

In defining the concept of discourse environment, we have actually created a new problem. Rather than having to deal with the evolution of one language, we now have to deal with the (co-)evolution of multiple languages as they are in use in different discourse environments. However, as we have argued extensively, limiting ourselves to the centralised/unified situation, would be a denial of what happens in real life. In other words, the true challenge of dealing with an evolving universe of discourse lies in dealing with evolution of multiple discourse environments. As the title of this article suggests, we need to view information system evolution at least partly as language evolution.

5 Research activities

Currently, we are involved in several research activities that are aimed at tackling the above discussed issues, making the concept of discourse environment more usable in practice. These efforts are part of a larger research effort, focussing on the use of linguistic instruments for information system engineering. In our view, the use of linguistic instruments does not only pertain to analysis, design and realisation activities, which we focussed on in the previous sections, but also to operational information systems.

In the development of theories to deal with the challenges of operational use and evolution of discourse environments, we identify three phases:

1. Using the concept of discourse environments in the analysis of application domains.
2. Development of strategies/approaches for the design of information systems that are better aligned to the evolving nature of discourse environments.
3. Selection and development of enabling technologies to better equip computerised information systems with the ability to deal with discourse environments.

Note that in performing the associated research, we do not expect to follow a strict linear process.

At the moment, the bulk of our research activities focusses on this phase. Most of the results of these research efforts will be reported in [Hop03].

By making discourse environments into an explicit concept we are, when analysing a domain, able to look at communication situations in/about a universe of discourse in a functional manner. By studying several key factors in a domain universe of discourse, we can analyse the situation of language use and then decide how to best deal with language evolution in specific situations. These factors include:

- The types of languages used in the domain.
- Actual concepts used by individuals in the domain.
- Terminological standards adopted for the domain.
- Official terminological agreements made for the domain.
- Media and medium systems (information systems) used in the domain.
- Levels of conceptual specification and conceptualisation processes involved.
- Texts (specifications, manuals, etc.) used in the domain.
- Conceptual interaction between different domains.
- Capacities, attitudes, and resources available in the domain concerning the creation, use, and management of concepts.

Put briefly, we take into account a number of concept/language related factors that the standard universe of discourse approach view ignores. We add factors to this approach which potentially make analysis activities more complex, but at the same time open an analysts' eyes to problems that (as argued before) are becoming increasingly important. In taking this viewpoint, we can look beyond uniform specifications of domain languages and not only look at combinations of such languages, but also take the evolution of these languages into account. In other words, we are now able to look at the language-and-meaning games people play in individual domains, and take them seriously or perhaps even influence them: manage the conceptualisation situation and the conceptualisation processes.

To better analyse discourse environments and their operation in their 'natural habitat' and their operation, one would typically have to analyse the *use* and *evolution* of artefacts such as:

- Dictionary-like texts (or elements of texts)
- Conceptual specifications for information systems (data structure etc.)
- Auxiliary documents (manuals, procedural descriptions, etc.)

and organisational roles/functions pertaining to language use and evolution:

- Who take part in discussions about language/terminology?
- Who are authors of certain language specifying texts?
- Who decide upon official/standardised terminology?
- Who are responsible for language evolution?
- Who is a facilitator for language evolution?

Among other things, the answers to these questions would allow information system designers to better judge to what extend terms/concepts may be standardised in information systems that may cut across several discourse environments. The interesting challenge being the potential role of computerised information systems with regards to the evolution of a discourse environment.

In addition to the responsibilities pertaining to the evolution of language (see above), the design phase should combine this with the more traditional functional responsibilities with regards to information systems such as:

1. Who stores actual facts about the universe of discourse (the database)?
2. Who is responsible for the execution of specific functionality/processes?

These responsibility questions become absolutely crucial in the case of multiple co-evolving discourse environments.

For the development of methods/techniques for the design and construction of computerised information systems that are better aligned with the needs of multiple (co-evolving) discourse environment, we will borrow from pre-existing fields of research. Among these are multi-database (or federated) systems as well as evolving information systems.

Multi-database (or federated) systems have as their aim the ability to access multiple autonomous databases through querying. The emphasis is on integration and sharing of distributed information. A particular database may choose to export parts of its schema which are registered in a federal dictionary. A requesting database consults the federal dictionary for existing databases and then imports schema elements that it

requires. While this approach might be appealing for a small number of interconnected databases it is clearly not scalable. Locating the right information in a large unstructured network of data dictionaries is extremely cumbersome, has limited potential for success and, more importantly, is error prone as it does not deal with terminology nuances.

More recently several research activities in the area have concentrated on the issue of creating semantically enhanced federated database dictionaries [BHP94, ACHK93, MS95, MBP95, KS97, PM98]. We expect to be able to use such mechanisms to maintain semantic ties between different discourse environments (pertaining to the same universe of discourse).

Our pre-existing work on the evolution of domain models will be used as a base to deal with the evolutionary aspects of discourse environments [PW95a, PW94, Pro97].

6 Conclusion

In this article we considered the evolution of information systems from the perspective of the evolution of domain languages and provided a brief report on some of our *ongoing* research activities.

The primary aim of this article was to create awareness for the issues at play, and argue that current universe of discourse approaches ignore most of them. We finish by presenting an overview of our research efforts concerning the tackling of the matters discussed.

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