

Concept Evolution in Information System Evolution

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Abstract. We look at the evolution of information systems from the perspective of the evolution of domain languages. Many 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. We discuss these issues, against the background of a more linguistically viable version of the standard notion of ‘universe of discourse’, and the notion of ‘environment of discourse’. Though the main aim of this paper is to provide an advanced problem analysis, we finish by sketching a direction for tackling some of the problems indicated. We also present some initial results, centering round better organized communication about concepts (‘linguistic meta-communication’ and ‘conceptualization’).

1 Introduction

As stated in [1], “*information systems*” concern the use of “information” by individuals or groups in organizations, in particular through computer-based systems. The concept of information system can roughly be defined as that aspect of an organization that provides, uses and distributes information. An information system *may* contain computerized sub-systems to automate certain elements. In line with [1], we refer to the computerized part of an information system as a *computerized information system*.

We embrace the viewpoint that the main purpose for which a (computerized) information system is created is to provide information processing services to its environment. In line with this user-oriented view, the internal structures of a computerized 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. We observe that a large variety of methods and techniques used in the analysis and design of computerized 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 which is going on” in the domain of which the computerized information system is (to become) an integral part [2, 3, 4]. In terms of information, “what is going on” is usually strongly related to *communication through language* [5, 6, 7]. We will investigate the relationship between domain language and information systems further, in particular in the light of evolution of the environment of a computerized information system. We

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criticize the traditional notion of *universe of discourse*, and point out some language-related issues that are ignored by approaches based on it. We also discuss a notion hitherto practically unknown: *environment of discourse*. The aim of this article is first and foremost to create awareness of the issues involved and some reasons why existing approaches will not solve the problems indicated. The secondary aim of this article is to introduce one possible way of coping with the problem as identified, involving *linguistic meta-communication* as a context for *conceptualization*.

2 The Standard Universe of Discourse Approach

In our discussion below, we distinguish between *domain analysis*, referring to the understanding and charting of a domain that is to be supported by an information system, and *system design*, referring to the construction of a (computerized) information system reflecting relevant aspects of the analysis. As mentioned, we take the point of view that the internal structures of a computerized information system should essentially be a direct reflection of the domain in which it will operate. We observe that in most methods and techniques for domain analysis and system design this relationship is made concrete through a language orientated approach to *explicit conceptualization*—that is, the description of concepts; see [7]. Such methods and techniques are based on a presumed parallel between the discourse in the domain and the conceptual structures that form the base of the resulting computerized information system. The parallel reflects the insight that there is a strong relation between the concepts that are to be built into a computerized information system and the language that is used to communicate about the domain in which the system is supposed to operate [8]. An elaborate discussion of this way of thinking can be found in, for example, [4].

What is studied when analyzing and designing a computerized information system is generally referred to as the *Universe of Discourse* [9], in other words the world (or universe) that people talk (or discourse) about, and that can be described through the explicit naming of, roughly speaking, elements and relations. The idea is that when making a model of a domain (referred to as a *domain model*) one inevitably also describes the language used to describe that domain. One might go as far as 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 (UoD) and the structure of the resulting system is made particularly explicit. For example, Object Role Modelling [4] and its many variations (NIAM [10], FORM [11], PM [12], PSM [13] and BRM [14]), start out from verbalizations, 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 an *information grammar*. The well known ER approach [15] also has a sound basis in a language view on domain modelling. In some cases, natural language-based domain modelling emphatically covers conceptualization of dynamic as well as static structures. These approaches can be found in some of the object-oriented approaches to analysis and design methods, e.g. NORM [16] and PSM² [3]—which essentially are object-oriented variations of ORM—, and also COLOR-X [17], OOSA [18], and KISS [19].

The UML [20] is an example of an approach which does not so explicitly relate the language that is used to express phenomena from the UoD to the essential structures of the resulting systems. However, the resulting structures still strongly reflect the language used to describe the UoD. 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 *use-cases* for the prospective system. These use-cases, and more specifically the natural language narratives explaining them [21], serve as input for most other modelling steps, including the definition of a UML class diagram.

Whether or not the methods and techniques mentioned explicitly embrace the notion of universe of discourse, we believe it is safe to say its underlying principle is widely used. The UoD approach is powerful in the sense that we, the human beings who analyse, design, and use computerized 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. (Note that utterances do *not* necessarily have to be ‘verbal’. A structured graphical depiction of a model can be a language utterance just as well as a piece of text).

3 Issues Concerning the Standard Universe of Discourse Approach

This section aims to raise awareness of some language-related 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 computerized information system; issues which tend to be overlooked or ignored by current approaches to information system analysis and design. As a result, the way most (if not all) analysis and design methods employ the universe of discourse approach is linguistically flawed. The flaws become particularly troublesome in the context of evolving domains, a feature which most real-world domains do indeed exhibit.

Following [7], we define a language as a *set of concepts*. The relations that ‘hold between concepts’ we view as being part of the definition of the individual concepts. Concepts constitute ‘linguistic knowledge’; a concept combines one meaning that can be expressed through a language with one form which that meaning is associated with. Concepts essentially reside in the mind/brain of individuals. In the current discussion, let us call a set of concepts as belonging to one individual a *vocabulary*¹. If people share a concept, there is a *linguistic convention* that holds between them, entailing that the concept is interpreted *sufficiently the same* by each individual involved, in order for the concept to be functionally identical in communication between them. Linguistic conventions are normally *implicit*, but can be made explicit by people communicating about language (‘linguistic meta-communication’). Let us call an *explicitly* discussed and agreed set of linguistics conventions a *terminology* [22, p13-4]. It can be argued on cognitive and philosophical grounds [7, p41-63] that complete description of concepts as they reside in the individual is impossible. What can be successfully achieved, however, is to reach a pragmatic agreement about linguistic conventions (explicit or not).

At the core of the traditional ‘universe of discourse approach’ lies the postulate that for computerized information systems, analysis and design activities can, at least to a considerable extent, be regarded as the modelling of a *stable* and *unified* language: one unchanging terminology used to describe phenomena in the universe of discourse. In other words, modelling the universe of discourse amounts to describing the one terminology belonging to the domain. However, this view of what a universe of discourse is, does not take into account some crucial properties of language as it is normally used in human-human communication. We refer in particular to language *adaptability* and *diversity*. These properties are very much interrelated. In use, people constantly adapt the language they use to fit the particular situation they use it in. The pragmatic demands of the situation include what is to be done with the language as well as which people are involved in communication. The most important way in which the resulting linguistic diversity is reflected is in variation of *vocabulary and terminology* –which is why we focus on “lexis” instead of “syntax”. If a domain evolves, the language used to communicate within it usually evolves with it, and this inherently leads to diversity of language (most prominently, vocabulary). This diversity tends to originate in individuals; if no effort is made to align the languages of individuals or small groups, they tend to diverge.

Language adaption in unrestricted, “open” language use (as, for example, in regular speaking or writing) happens mostly *intuitively*, as part of our general capacity for languaging. However, the creation of domain models and the incorporation of language elements in information systems necessarily involves at least some *stable* and *uniform* description of domain language. The standard universe of discourse approach adheres to the latter view on language, and thus clashes with the former, more linguistically correct view on language. It embraces as central the creation of *closed languages*: the specification of limited sets of concepts to be used for communication about a specific domain. Importantly, within context of information system development, language change does not occur ‘intuitively’ but always requires explicit and often laborious language specification.

From a system development point of view, it can easily be explained why the standard UoD approach strives for stable and uniform concept description: it is rooted in modelling and engineering, and in those disciplines there are ample arguments that work against frequent change and diversity in language. These arguments boil down to three basic factors that come into play

¹ Matters of syntax are outside the immediate focus of this paper.

in all cases involving the *specification of limited sets of concepts* (i.e. the description of closed language)²:

Efficiency A minimal, well chosen set of “highly meaningful” concepts increases efficiency of communication in the context it is tuned to; it reduces the total of actually “uttered” words needed to get a message across –assuming everyone involved “knows” the concepts.

Certainty If we want to be sure everyone involved agrees on the interpretation of the concepts used (in view of the pragmatic situation), then the smaller the set of concepts is, the better the chance is that everyone indeed interprets all concepts (sufficiently) the same.

Technology If language items (words) are built into information systems (e.g. as data structures), then in order to produce utterances they are typically mapped onto *finite state mechanisms*³, and therefore the selection of a limited number of concepts is required.

To satisfy the demands related to these factors, the specification of a stable, uniform language is indeed preferable. However, since in natural language *use*, language is essentially adaptive and diverse in nature, there is an inherent field of tension between intuitive open language use and the use of engineered, closed language. The down side of closed language use is that it can lead to damaged language functionality, and therefore to damaged information system functionality: users may not be able to express themselves adequately by means of the system, or may misinterpret utterances offered to them by the system [7, p22-5].

Language-related complications get worse when we realize that most information systems as they are used in practice do operate in an evolving and interconnected world. For example, in [23, 24] and [25], elaborate discussions can be found on the changes in context and culture that occur inside organizations 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 [2, 26, 27]. This requires us to look at organizations and their information systems as evolving systems [28] that are in a constant state of co-evolution.

One may argue that the above discussion is far from 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 organization to perform long-term standardization of 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 as stating that even when an information system is developed using a modern development approach, such as component-based or object-oriented development approaches [29, 30], the resulting system may indeed have a well thought-out component structure, 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 in different Dutch organizations; for an example see [7, p183-235].

In sum, in many respects the standard universe of discourse approach is somewhat simplistic if confronted with the complexities and dynamism of real life and open languaging. In an interconnected, diverse and evolving world, the traditional universe of discourse approach falls short of its mark, as its basic postulate does not hold that for computerized information systems, analysis and design activities can be basically regarded as the modelling of a *stable and unified* language; the language used to describe phenomena in the universe of discourse.

² For a more in depth discussion of these factors, see [7, p26-31].

³ We acknowledge that the use of recursive structures makes it possible to break away from finite state language description; we merely observe that most ‘regular’ data structure specifications typically involve finite-state language engineering

4 Environments of Discourse

We propose to assume that concepts and languages are essentially different for each individual human, and therefore that there can hardly be such a thing as a single, unified language that constitutes a universe of discourse. Instead, we define a universe of discourse as the *unified vocabularies of all individuals involved in communication in a domain*. This adds considerable complexity to the analysis of a UoD, but it also shows much more respect for its nature. Once a UoD is analysed, one or more *terminologies* can be specified or adopted, depending on the various language uses related to, for example, an information system that is being *designed*. It is quite possible that the solution of choice is to specify one ‘unified terminology’, but this should be a *well considered design decision* instead of one based on a hidden linguistic oversimplification. In addition, it may be required to *remedy* any undesirable side effects resulting from closed language use, for example by providing adequate language documentation [7].

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 UoD approach:

1. We should acknowledge the fact that a language, and the underlying domain model derived from it, *exist strictly by virtue of a heterogeneous group of people using the language to communicate about some domain* (see previous discussion). We cannot capture the domain model except through the language used by the people acting in it.
2. We should acknowledge the fact that different (groups of) people will (want to) adapt their language according to the evolving situation it is used in, which may lead to many different (yet equally valid!) domain models pertaining to (parts of) the same universe of discourse.

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

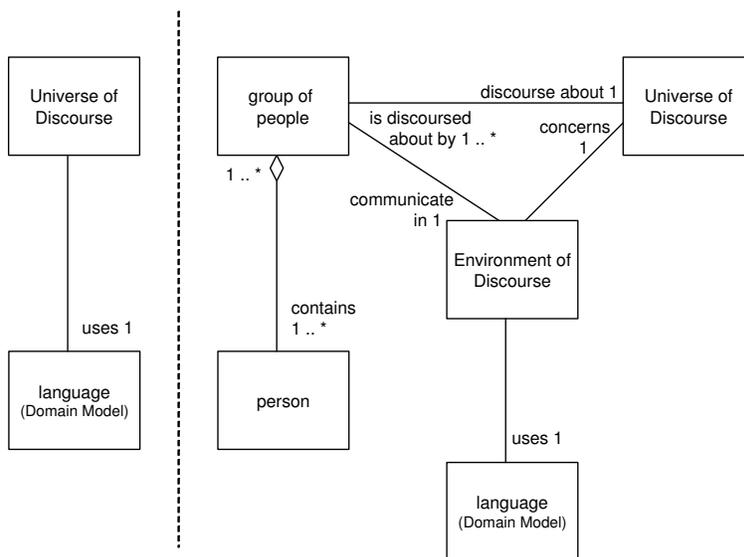


Fig. 1. Contrasting viewpoints on a universe of discourse

As can be seen in figure 1, the combination of a group of people and a universe of discourse is referred to as an *Environment of Discourse*⁴. An environment of discourse (EoD) is an environment in which processes of communication (and meta-communication) take place [7, p78]. It primarily links a group of individuals to a universe of discourse, and in doing so allows for the recognition of the fact that it is this combination of language users to which a language may be associated. Recognising environments of discourse allows for a differentiated look at the conceptual needs of various groups within one universe of discourse. Also, and even more importantly, there is more to an environment of discourse than just people and concepts: both *discoursing* and the *ongoing creation and adaption of concepts* entail the existence of *concept-related communication processes that have specific requirements in specific environments of discourse* [32, 33]. 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. They also need to be in some way cooperatively related: capable and willing to use, and if necessary negotiate or learn, a certain shared vocabulary or terminology. If a situation occurs in which two individuals or groups come together to communicate, a new environment of discourse comes into existence, with its own dynamics and common goals. It may be the case that conventions or agreements in one environment of discourse *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 [34].

One might argue that the notion of EoD, and the motivation for its introduction, resemble that of the concept *external schema* that may be associated to *conceptual schema* as introduced in the ISO ANSI/SPARC framework [9]. 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 that the ISO ANSI/SPARC framework presumes the existence of a “*unique central description*”, referred to as the “*conceptual schema*”. The conceptual schema is treated as a 1st-class citizen while the other domain models, the external schemas, are treated as 2nd-class citizens. From an *evolutionary* perspective, the external schemas will thus have to 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-centralized. We have illustrated this in figure 2. The central dot on the left represents the central conceptual schema, which dictates language evolution. On the right, no such central schema exists, leaving all languages to evolve de-centrally.

By introducing the notion of environment of discourse, we have actually created a new problem. Rather than having to deal with the evolution of one language, we now may have to deal with the (co-)evolution of multiple languages as they are in use in different environments of discourse –at the very least in analytical activities of information system development. However, as we have argued, 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 environments of discourse. We need to view information system evolution at least partly as language evolution. In the next section, we will sketch some results that may help operationalize our stance, and also some future research.

5 An adaptive approach to concept specification

As a direction for coping with evolutionary language, we propose to take an adaptive approach to concept specification. This approach is based on the previously introduced idea that even in every

⁴ The term was first introduced in [31], but we use it in a somewhat different sense.

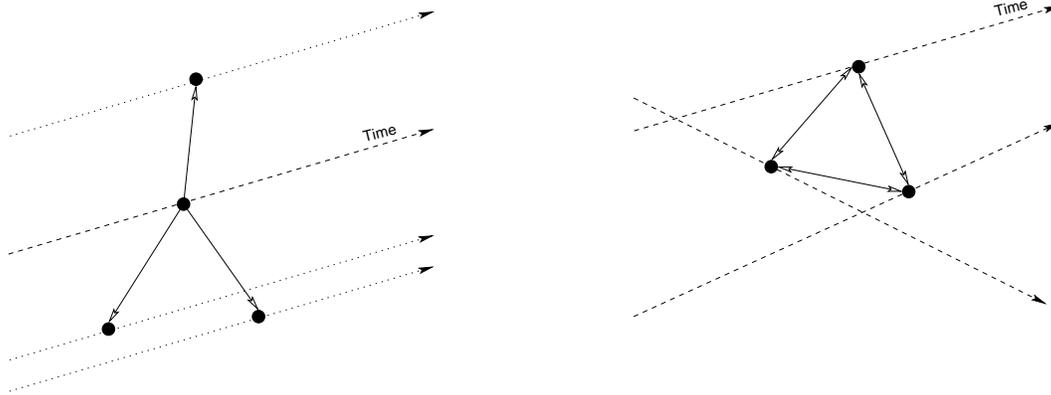


Fig. 2. Centralized versus de-centralized environments of discourse

day communication, people constantly adapt the language they use to the situation at hand. As part of their ongoing conversation, they occasionally *communicate about the language they use*. Extending this idea, it becomes clear that “language engineering” as part of information system development (i.e. data analysis and data engineering) is at least partly the result of “linguistic meta-communication”: communication about language [7, p93-101]. Four paired main types of linguistic meta-communication can be usefully distinguished here:

Constructive versus Informative meta-communication: it is possible that a conversation takes place that results in the changing of concepts that are part of the information system, but it is also possible that explanation or refinement of concepts takes place without actual system changes as a result—for example, as part of a conversation that is meant to clarify a single utterance produced through the system.

Anticipatory versus Reactive meta-communication: most if not all meta-communication involving information systems currently takes place in anticipation of future use of the system. However, it may well be possible to enable a more reactive type of meta-communication that is rooted in a conversation actually taking place, and aims at solving a particular and situational communicative problem, ‘at run time’. Outcomes of such reactive meta-communication may or may not be taken along in later, anticipatory meta-communication.

The communication-oriented approach sketched above should be seen in the wider context of *the ever present need to specify and re-specify concepts* during the evolution of an information system. Assuming this need will indeed present itself, two main approaches to minimizing the effort involved have so far been put forward in information system development practice and theory: *standardization* and *automation*. Standardization is often attempted because if it succeeds, it “solves” all problems related to diversity and evolution of language by obliterating these phenomena altogether. However, though standardization can certainly work up to a point (and in fact does in many existing cases), the problem addressed in the previous sections is not so much addressed as denied by this approach. Also, standardization of language has its limits, which are set by the adaptive and diverse nature of language.

The other option that is often suggested, automation of conceptualization, will require highly advanced, intelligent machinery that is not only capable of truly understanding our diverse concept uses, but can also decide which concepts are best used in which context (i.e. by who, in which situation). Automated concept specification and adaptation can currently be safely placed in the realm of science fiction.

Unfortunately, this still leaves us but one serious third option if we take diversity and evolution of language seriously: somehow *specify concepts “by hand”*. System users and developers will in one way or another have to be (inter)actively involved in linguistic meta-communication. That

this poses many problem in terms of capacity, willingness, and expertise is evident. Efficiency in conceptualization, and a good grasp of its goals and means, should therefore be a primary target for further research. In this light, we propose to develop two complementary instruments for supporting linguistic meta-communication:

1. A framework that helps determine what kind of concept specification is required in which situation (striving for *minimization and optimal effectiveness of conceptualization efforts*)
2. Better ways of performing explicit conceptualization (concept description), possibly in the form of semi-automated, dialogue-based ‘authoring environments’ that support people in their efforts to efficiently but effectively negotiate and specify the concepts they use.

The first instrument, or at least an initial version thereof, has been provided by [7]. A theory-based method is proposed (and a proof of concept given) concerning the analysis and evaluation of interrelated domain languages, meta-communication processes, and conceptualization processes in ICT-supported organizations. A limited overview of the elements in the framework is presented in figure 3. The relationship between the various “areas of concern” of the framework is roughly as follows:

- The concepts (language) built into an information system should optimally support user-user communication in the system context (i.e. within its EoD or EoDs)
- Yet this can only be done by taking into account both the communication *and meta-communication* requirements (as related to the system development situation) available in the relevant EoD(s)
- The meta-communication requirements thus identified provide the context for the analysis of the *conceptualization processes* in the relevant EoD(s) (including support thereof)

Though the framework is chiefly meant to enable focused analysis and evaluation of language-related issues as discussed in previous sections, it has also been shown that it can be used to systematically and in considerable detail suggest (directions for) *improvements* in meta-communication and conceptualization. Importantly, an across-the-board analysis of meta-communication and conceptualization processes in an organization should precede the introduction of the particular means to support them (e.g. modelling tools, modelling languages, modelling protocols, conceptual storage and exchange formats, presentation formats). The question who needs to define what, for what purpose, and *in relation to what other definitions* should dictate the use of modelling and definition tools, and the management of concepts and terminology.

The second instrument is subject to ongoing research at the Information Retrieval and Information Systems group of the Nijmegen Institute for Informatics and Information Science. We envisage the development of a broadly viable model for concept specification processes, meant to clearly chart concept specification activities in view of their situational use. In other words, we aim to understand conceptualization in relation to the level of specificity, precision, and validation that must be reached in a particular concept description. In due time, we hope to create and experiment with a goal-driven *concept specification environment* that semi-automatically supports the various levels and sorts of concept specification, and that includes a dedicated, dialog-based expert system *guiding* the conceptualization process.

6 Conclusion

In most methods and techniques for domain analysis and design, a strong relationship is assumed between language used to communicate about a domain and the domain’s conceptual structure. This assumption is based on what what is called the “universe of discourse approach”. At the core of this approach lies the postulate that analysis and design activities in information system development can be regarded as the modelling of a stable and unified language. However, this postulate ignores some important properties of the way language is normally (i.e., naturally) used: language adaptivity and diversity. This may result in damaged language functionality and therefore to damaged human-human communication, which is a crucial part of basic information system functionality.

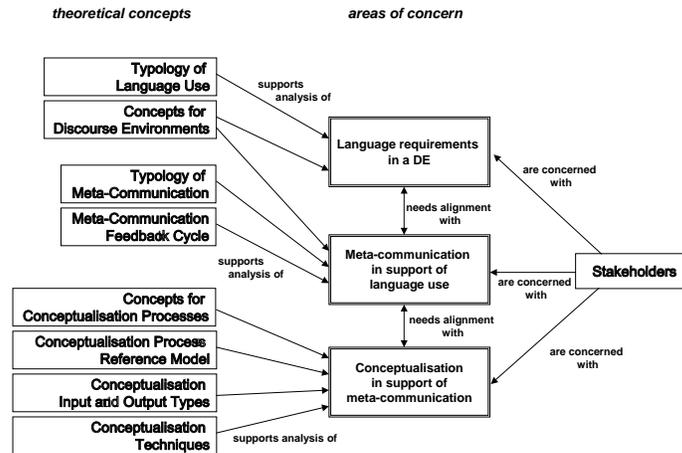


Fig. 3. An Analytical Framework for Language, Meta-Communication, and Conceptualization

However, from a system development point of view, it is quite understandable why conceptual modelling strives for the charting of a stable and uniform domain language description. The factors underlying this goal are efficiency and certainty in communication, as well as the technology-driven requirement to limit the number of concepts to be specified. Still, in our increasingly interconnected, diverse, and fast-evolving world, the standard universe of discourse approach is under considerable and increasing pressure.

As an alternative, we proposed a more linguistically viable approach to language and conceptualization by acknowledging the adaptive and diverse nature of language. We base our notion of UoD on the combined vocabularies of all individuals in an *environment of discourse*. An EoD is an environment in which certain processes of communication and meta-communication take place. The identification of various related EoDs in one organization, each with its specific goals and means for conceptualization and communication, provides a good basis for focused, goal-oriented analysis of language specification processes. Enabling such analysis is particularly important because if our version of the UoD approach holds, well-guided and nuanced concept specification will have to be performed frequently and adaptively. This will be especially the case in evolutionary system development environments: the true challenge of dealing with evolving UoDs lies in dealing with evolution of (multiple) EoDs.

We briefly presented the outline of an analytical framework that was developed to perform a focused analysis of concept specifications, meta-communication processes, and conceptualisation processes, between which clear goal-means dependencies exist. We also briefly discussed future research involving the detailed, goal-driven modelling of concept specification processes in order to better understand them, guide them, and ultimately better support them.

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