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# Enhanced entity-relationship modeling with description logic

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ABSTRACT

Based on the high expressive powers and effective reasoning services of description logics (DLs, for short), DLs have been employed in data modeling to support the development and maintenance of data models. The basic idea is that once the correspondences between data models and DLs can be established, reasoning techniques from DLs become applicable to the reasoning of data models.

This paper proposes a complete DL approach for representing and reasoning on EER (Enhanced Entity-Relationship) models. We develop an equivalence-preserving transformation approach and a prototype tool for transforming an EER model into a DL knowledge base, and propose methods to reduce reasoning on the EER model to reasoning on the transformed DL knowledge base. As one result, the reasoning capabilities of the DL can provide the basic reasoning services that are needed in EER modeling. In detail, we *firstly* propose a formal definition and semantic interpretation method of EER models, which summarizes and includes all features of EER models. *Then*, by analyzing the features of EER models, a DL called $\mathcal{ALCQI}_{\mathcal{K}}$ is presented as the language of representing and reasoning on EER models. *On this basis*, we propose an approach for transforming EER models into $\mathcal{ALCQI}_{\mathcal{K}}$ knowledge bases. The correctness of the transformation is proved and a transformation example is provided. *Further*, a prototype transformation tool is implemented. Case studies show that our approach and prototype tool actually work. *Finally*, based on the transformed $\mathcal{ALCQI}_{\mathcal{K}}$ knowledge bases, we propose methods to reduce reasoning on EER models to reasoning on the transformed $\mathcal{ALCQI}_{\mathcal{K}}$ knowledge bases.

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## 1. Introduction

The Enhanced Entity-Relationship (EER) model [49], which is an extension of the Entity-Relationship (ER) model [23], includes all the modeling concepts of the ER model and incorporates additional constructs such as subclass/superclass, specialization/generalization, categorization, and aggregation. Over the years, EER models are widely used in the conceptual analysis stage to support the developments of databases, application software, websites, and other areas [25,26,29,33,38,41,46,48,49].

In the process of EER modeling, the complex of the EER notions and their interaction may lead to various problems such as redundancies and inconsistencies. Checking such problems manually is a complex and time-consuming task [9,12,14,18]. Therefore, one issue has arisen from practical needs: namely, how to detect these problems in EER modeling. It could be addressed by the well-known knowledge representation language Description Logics (DLs, for short [11]). One of the basic ideas behind applying DLs to data management is that data models can be expressed as DL knowledge bases, so that DL reasoning techniques can be used to reason about the data models, e.g., detecting whether a model is consistent or an entity is a subtype of another entity [4,9,18,20,50]. In the last years, DLs have been shown useful for reasoning about data models (e.g., ER [18,27,37] and UML [12]). The detailed report about data modeling with DLs can be found at Section 6 of this paper.

However, to our best knowledge, *there is not a complete and detailed report on EER modeling with DL*. Some important issues including the EER constructs (e.g., categorization, aggregation, total participation constraints of entities in relationships, and etc.), the detailed transformation rules from EER to DL, the prototype transformation tool, and the reasoning of EER with DL were still missed. At present, there are still some issues need to be addressed in detail: (*i*) How to choose a DL for EER modeling. This implies that the representation and reasoning of EER with the DL are easier to be implemented and exploited; (*ii*) How to provide a complete report on EER modeling with DL. The report should give a formal approach for transforming all constructs of EER into DL knowledge bases, so as to enable readers to understand well the EER modeling with DL; (*iii*) What are the familiar reasoning problems in EER modeling? and how to deal with these reasoning problems with DL? If all of these issues are solved, the possible uses of automated reasoning scenarios to improve the quality of EER modeling are greatly expanded.

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On this basis, in this paper we propose a DL approach for representing and reasoning on EER models. We develop an approach and a tool for transforming an EER model into a DL knowledge base, and further propose methods for reasoning on the EER model with the DL. In brief, the paper makes the contributions:

- **How to formalize EER models and choose a DL?** In Section 3, we *first* propose a formal definition and semantic interpretation method of EER models. *Then*, based on the features of EER models, we propose a DL $\mathcal{ALCQI}_{\mathcal{K}}$, which will be used to represent and reason on EER models.
- **How to transform EER models into DL $\mathcal{ALCQI}_{\mathcal{K}}$ knowledge bases?** In Section 4, we propose an approach and develop a tool for transforming EER models into $\mathcal{ALCQI}_{\mathcal{K}}$ knowledge bases, including: **(*i*)** proposing complete transformation rules; **(*ii*)** giving the proof of correctness of the transformation, and providing a transformation example; (***iii***) implementing a prototype tool. Case studies show that our approach and tool actually work.
- **How to reason on EER models with the transformed $\mathcal{ALCQI}_{\mathcal{K}}$ knowledge bases?** Based on the transformed $\mathcal{ALCQI}_{\mathcal{K}}$ knowledge bases in Section 4, in Section 5, we *further* propose methods to reduce the reasoning of EER models to the reasoning of the transformed $\mathcal{ALCQI}_{\mathcal{K}}$ knowledge bases. *Also*, a reasoning example is provided. As one result, the reasoning capabilities of the DL can provide the basic reasoning services that are needed in EER modeling.

The remainder of this paper is organized as follows. Section 2 recalls preliminaries. Section 3 formalize EER and present a DL $\mathcal{ALCQ}\mathcal{I}_{\mathcal{K}}$. Section 4 develops a transformation approach and tool. Section 5 studies the reasoning of EER with $\mathcal{ALCQI}_{\mathcal{K}}$. Section 6 introduces related work. Section 7 gives conclusions.

## 2. Preliminaries on EER models and DLs

In this section, some preliminaries on EER models and DLs are recalled.

### 2.1. EER models

The Enhanced Entity-Relationship (EER) model is an extension of Entity-Relationship (ER) model [23]. Since 1980s there has been an increase in emergence of new database applications with more demanding requirements. Basic concepts of ER modeling are not sufficient to represent requirements of newer, more complex applications. Therefore, Enhanced Entity-Relationship (EER) model comes into being successively.

EER includes the notions of ER (e.g., *entity, attribute, relationship*), and incorporates additional constraints such as *subclass/superclass, specialization/generalization, categorization*, and *aggregation*. Unfortunately, there are not standard terminologies for these notions, so we use the most common terminologies. Fig. 1 describes a diagrammatic technique for displaying these notions when they arise in an EER

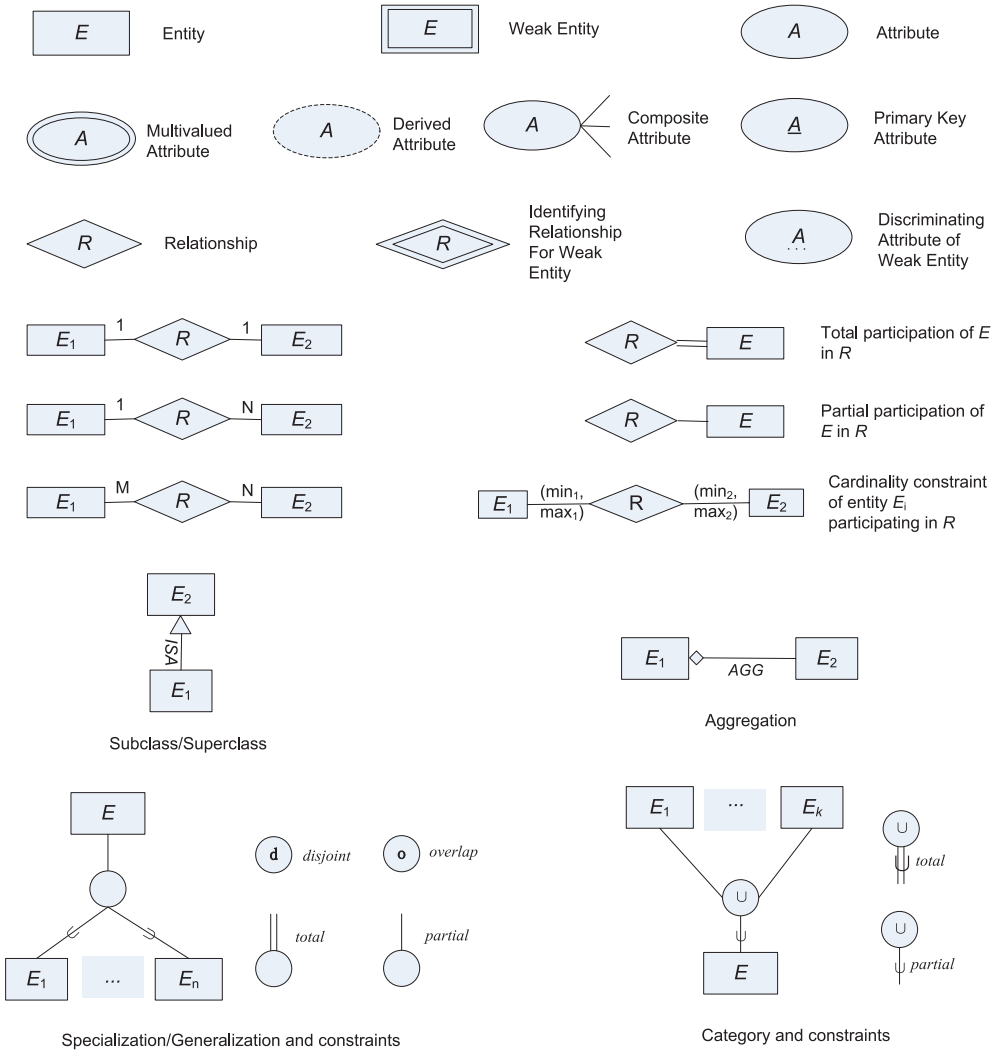


**Fig. 1.** EER diagram notations.

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