Little work has been completed which addresses the logical composition and use of ternary relationships in entity-relationship modeling. Many modeling notations and most CASE tools do not allow for ternary relationships. Alternative methods and substitutes for ternary relationship structures do not necessarily reflect the original logic, semantics or constraints of a given situation. Furthermore, it has been shown that ternary relationships can be constrained by additional implicit binary constraints which do not occur in the logic of binary relationships. This paper develops an analytical perspective of ternary relationships. We investigate the logical relationships implicit to the ternary structure and then identify potential simplification through decomposition into binary equivalents. These alternative binary equivalents allow retention of the implicit logical structure, and consequently also retain the semantics of the original structure. The analysis investigates equivalency of lossless decompositions, preservation of functional dependencies and finally the ability to preserve update constraints (insertions and deletions). We identify which ternary relationships have true, fully equivalent, binary equivalents and those which do not. We provide an exhaustive analysis of cardinality combinations found in ternary relationships which practitioners can use to guide the way in which they deal with ternary relationships in conceptual modeling.

INTRODUCTION

One of the most widely used techniques in information analysis is the entity-relationship (ER) or extended entity-relationship model (EER, henceforth also referred to as ER), introduced by Chen (1976). While this technique is recognized as useful in its purpose, the form in which relationships are identified within such models still remains open to discussion. Certain arguments revolve around the inclusion of binary or N-ary representation of relationships in ER models. A central argument stems from the superior ability of N-ary modeling to reflect the true semantics of any given situation, whereas a binary model provides the simplest constructs for expressing information systems logical design and is equivalently represented in a relational database management system (DBMS) (McKee & Rodgers, 1992).

The purpose of conceptual models is twofold: to provide a semantically correct, conceptual representation of the organizational data, as well as to provide a platform from which to develop a logical implementation schema. Consequently, the superior methodology for model construction is to adopt the semantically superior form and provide some heuristic set to allow transformation to a result, which can be implemented in the more desired format. This course of action has been widely recognized and well researched, in the form of developing relational schema from ER diagrams; rule sets as well as automated tools have been developed which offer to guide the process of translation (e.g., Jajodia, 1983; Ling, 1985; Markowitz & Shoshani, 1992; Elmasri & Navathe, 1994).

Within these methodologies, there remains one area that has not been formally investigated. N-ary relationships in ER models continue to be constructs which are misunderstood by educators, difficult to apply for practitioners and problematic in their interpretation to relational schemas.
These problems are due to causes ranging from a difficulty in identifying legitimate ternary relationships in practical situations to the lack of understanding of the construct in relation to the basis of normalization upon which the relational model is grounded. Song et al. (1995) provides a comparative analysis of conceptual modeling notations. While all of the notations had some allowance for ternary modeling, none of the CASE tools included in the study allowed for the use and translation of ternary relationships. This indicates the recognition of ternary relationships as having semantic significance, but a practical difficulty of implementing them beyond the equivalent logical level. Very little research has been completed on the theoretical underpinnings of N-ary relationships, and that which exists, is generally created as passing references in search of other research solutions.

This paper serves to provide insight to these problems. It seeks to formally analyze the dynamics of having three entities participating in a relationship simultaneously. This is done from two perspectives:

1. The theoretical approach to understanding this type of conceptual construct and the subsequent analysis of logical and relational models founded on these theories.
2. The practical aspects of using these constructs in entity-relationship modeling and how the various construct combinations can be mapped to the logical/physical model.

The second aspect is partly founded on the first because the potential decomposition of N-ary constructs, and their final representations, can be derived from theoretical analysis of the implicit relationships.

There will, therefore, be a particular effort to explain the simultaneous existence of N-ary and binary relationships that share the same participating entities and which are semantically related; this viewpoint has never been raised in previous research and leaves several questions unanswered. It is possible that an N-ary relationship may contain, or have imposed on it, a binary relationship between two of its participating entities which is semantically related to, and therefore potentially constrains, the ternary. Jones and Song (1996) have previously analyzed the question of which semantically related N-ary and binary relationship combinations can logically coexist simultaneously. In their work, they have shown that only certain combinations of ternary/binary cardinalities may simultaneously coexist and have provided a set of rules and notation that provide for conceptually correct modeling.

In providing an explanation of these implicit dynamics of N-ary structures, this work allows a further investigation of decomposition and restructuring of N-ary relationships to multiple binary structures, based on relational theory.

Many of the foregoing theoretical arguments lead to more utilitarian questions. The conceptual concept of the N-ary construct remains difficult for practitioners. Various notions exist for representing the construct in modeling, each with its own strengths and weaknesses. One of the most difficult problems is identifying exactly when an N-ary relationship should be used or when its binary equivalent is available. No prior work offering rules or heuristics can be found dealing with these questions. Typically, questions associated with ternary relationships are discussed within the context of 4NF and 5NF without regard for the specifically conceptual modeling problems. Since some of the solutions to these problems can be addressed with the previously mentioned theoretical background, each direction of analysis can contribute to the strength of the other, in terms of clarity and relevancy. This work seeks to address both the theoretical and practical issues surrounding N-ary relationships in conceptual modeling. Using a theoretical analysis of the construct, it seeks to provide practical answers to the understanding and use of those same constructs.

**Terminology**

Before proceeding to the substance of the paper, we first present certain terminology used throughout the paper. Since some terms in this field can be interpreted differently, this section provides a solid foundation for the ensuing discussions.

**Ternary Relationship:**

A ternary relationship is a relationship of degree three. That is, a relationship that contains three participating entities. Cardinalities for ternary relationships can take the form of $1:1:1$, $1:1:M$, $1:M:N$ or $M:N:P$. The cardinality constraint of an entity in a ternary relationship is defined by a pair of two entity instances associated with the other single entity instance. For example, in a ternary relationship $R(X, Y, Z)$ of cardinality $M:N:1$, for each pair of $(X, Y)$ there is only one instance of $Z$; for each pair of $(X, Z)$ there are $N$ instances of $Y$; for each pair of $(Y, Z)$ there are $M$ instances of $X$.

**Semantically Constraining Binary (SCB) Relationship:**

A Semantically Constraining Binary (SCB) relationship defines a binary constraint between two entities participating in a ternary relationship, where the semantics of the binary relationship are associated with those of the ternary and therefore affect potential ternary combinations of entity instances. They are differentiated from Semantically Unrelated Binary (SUB) relationships, where a binary relationship exists between two entities that also participate in a ternary relationship but where the semantic of the binary relationship is unrelated to that of the ternary. A full explanation is provided in Jones and Song (1996). An example of this model type follows. We use the notation introduced by Jones and Song (1996) for the SCB relationships which consists of a broken line as opposed to a solid line used for the more common, independent relationships.

Consider a ternary relationship between entities Teacher, Course and Section. The relationship has a cardinality of $M:1:N$ respectively and models the sections associated with...
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