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Quality in Conceptual Modeling

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ABSTRACT

Conceptual data models form the basis of requirements specification and their quality can have a significant impact on the quality of the information system which is ultimately implemented, which becomes even bigger if we take into account the size and complexity of current information systems. Most of the existent work about conceptual data model quality merely lists properties, without giving quantitative measures that assess the quality of such models in an objective way. In this work, we will propose a method for metric definition and a set of closed-ended metrics, for measuring entity relationship diagram complexity.

Keywords: Quality in Conceptual Modeling, Entity Relationship Diagram Complexity, Software Metrics

1. INTRODUCTION

It is well known that the quality of the information systems depends greatly on the accuracy of the requirements specification and the major effort must be focused on the improvement of the early stages of developments [16]. Conceptual data models form the basis of requirement specification and their quality can have a significant impact on the quality of the information system which is ultimately implemented [24].

The conceptual data model is one of the first products generated during the information system design. Therefore, it is really important to build them as "good" as possible because the cost of correcting a mistake introduced in the first stages of software development grows exponentially with the project advance [2]. There are no generally accepted guidelines for evaluating the quality of data models, and little agreement even among experts as to what makes a "good" data model [20].

However, we consider that conceptual data models are the core of the information systems and it is necessary to propose and study quality measures for their design stages.

In general we agree with Krogstie et al. [14] in the sense that "Most literature provides only bread and butter lists of useful properties without giving a systematic structure for evaluating them". Even more these lists are mostly unstructured, use imprecise definitions, often overlap, and properties of models are often confused with language method properties [16].

Recently, some interesting frameworks have been proposed for addressing quality in information modelling in a more systematic way [14; 16; 20; 21; 23; 24] without providing any measure that allow designers to evaluate the quality of conceptual data models in an objective way.

Quality criteria are not enough on their own in order to ensure quality in practice because people will generally make different interpretations of the same concept. It is necessary to have quantitative and objective measures to reduce subjectivity and bias in the evaluation process.

Software metrics have mostly concentrated on the deliverables of the later phases, such as design and coding, or detailed process metrics [5; 11; 17; 18]. Lesser work has been done related to metrics for conceptual data model quality. An overview of them is presented in table 1, which classifies and compares them according to the dimensions of purpose, feature and type.

Approach	Purpose	Features	Type
Gray et al. [10]	Designing quality database systems	Metrics for evaluating some quality factors of Entity relationship diagrams	List of metrics
Eick [4]	Improving the quality of conceptual models by schema transformation	Propose a quality measure to evaluate overall quality of S-diagrams.	Framework
Kesh [13]	Evaluating Entity relationship quality	Separates ontology from behaviour. Defines metrics for evaluating quality.	Framework
Moody [19]	Evaluating the quality of ER diagrams	Extend the framework proposed Moody and Shanks (1994),and propose 25 metrics to measure quality factors.	Framework

Table 1. Proposal of metrics to measure conceptual data models quality

Although all of these proposals of metrics are a good starting point to think about quality in conceptual modeling in a numeric scale, most of them are subjective, lack theoretical verification and empirical validation. Therefore, they are not very useful in practice.

In this work we provide a set of *closed-ended metrics* [15] to assess one quality factor that has a great influence on the Entity Relationship (ER) models overall quality: *complexity*. Those closed-ended (bounded in the interval [0,1].)metrics are objective, easily computed, easily to visualize and also easy to interpret.

This paper is organized in the following way: section 2 shows the metric definition process, section 3 shows our proposal of ten closed-ended metrics for ER diagram complexity and finally section 4 presents our conclusions and the future work

2. METRIC DEFINITION PROCESS

Figure 1 shows the three steps followed in the process of metric definition:

1) When we know what we want to measure and why, we define the metrics.
2) We put them under theoretical verification in order to verify that the proposed metrics satisfy certain mathematical properties, or in order to ascertain for each each metric its scale type.
3) We put them under empirical validation in order to demonstrate that they serve for the purpose that they have been created. This validation may be carried out through controlled experiment or by case studies taking data from real cases [5].

As steps 2 and 3 are independent they must be done simultaneously.

This process is iterative, and each step can feed the others, which lead us to accept, improve, change or discard the proposed metrics.

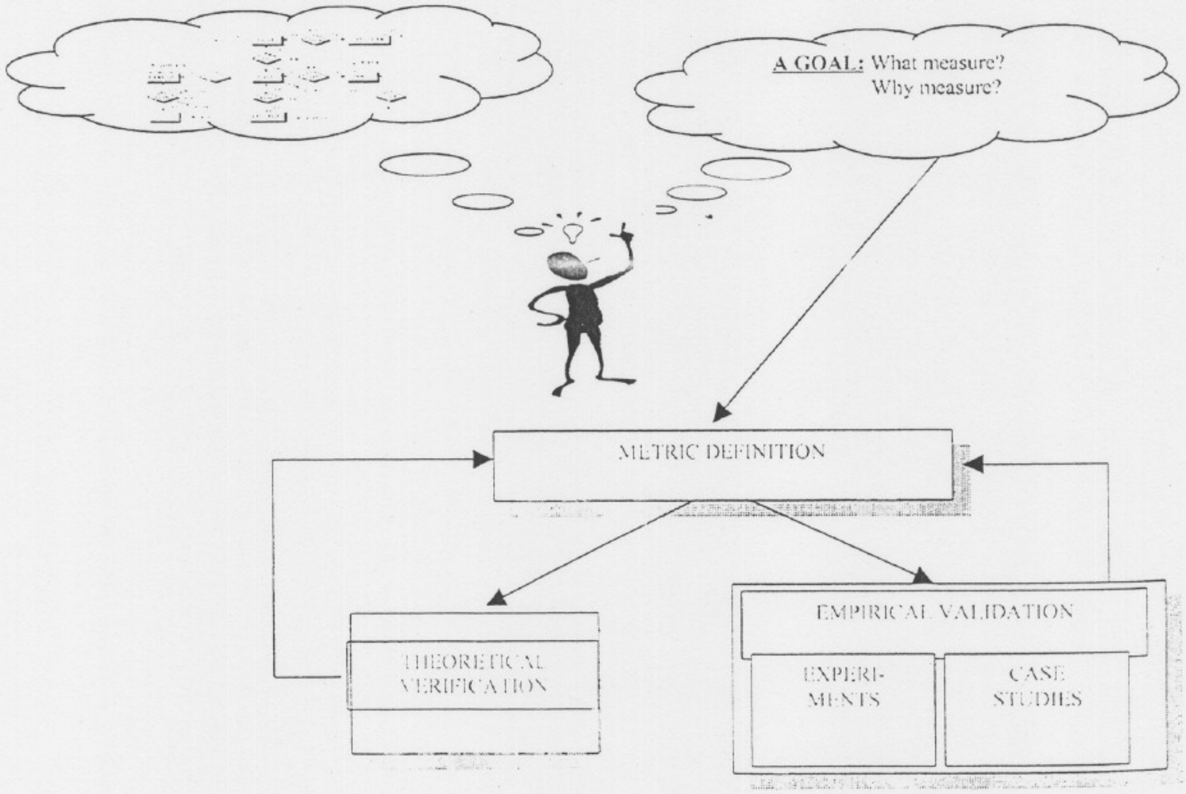


Figure 1. Metric definition process

2. METRICS FOR EVALUATING ER DIAGRAM COMPLEXITY

We must be conscious, however, that a general complexity measure is *"the impossible holy grail"* [5]. Henderson-Sellers [11] distinguishes three types of complexity, among which he quoted "product complexity", which is our focus when we refer to the concept of complexity.

In this section we propose a set of metrics to measure ER models complexity. These metrics are based on complexity theory, which defines the complexity of a system by the number of components in the system and the number of relationships among the components.

Since the aim is that of simplifying the ER model, the objective will be to minimize the value of these metrics. It is common understanding that the greatest complexity is strongly correlated with the development and maintenance efforts and the overall quality of information systems.

2.1 RvsE metric

This metric measures the relation that exists between the number of relationships and the number of entities in an ER model. It is based on Lethbridge's M_{RPROP} metric (Lethbridge, 1998)

We define this metric as follows:

$RvsE = \left(\frac{N^R}{N^R + N^E} \right)^2$	N^R is the number of relationships in the ER model. N^E is the number of entities in the ER model. Where $N^R + N^E > 0$.

When we calculate the number of relationship (N^R), we also consider the IS_A relationships. In this case, we consider one relationship for each pair child-parent within the IS_A relationship. The number of relationships per entity in the ER model influence this metric. Intuitively, the greater the number of relationships the greater the complexity. RvsE metric is zero when there are no relationships, it takes the value 1 when there are a lot of relationships and very few entities.

2.2 AvsE metric

This metric measures the relations that exist between the number of attributes and the number of entities in an ER model. It is based on Lethbridge's M_{RPROP} metric (Lethbridge, 1998).

We define this metric as follows:

$AvsE = \left(\frac{N^A}{N^A + N^E} \right)^2$	N^A is the number of attributes in the ER model. N^E is the number of entities in the ER model. Where $N^A + N^E > 0$.

When we calculate the number of attributes in the ER model (N^A), in the case of composite attributes we take into account each of their simple attributes.

The number of attributes per entity in the ER model influences this metric. Intuitively, the greater the number of attributes the greater their complexity.

AvsE metric is zero when there are no attributes, it takes value 1 when there are a lot of attributes and very few entities.

2.3 DA metric

We define the Derived Attributes metric as the number of derived attributes that exist within the ER model, divided by the maximum number of derived attributes that may exist in an ER model (all attributes in the ER model except one). An attribute is derived when its value can be calculated or deduced from the values of other attributes.

We define this metric as follows:

$DA = \frac{N^{DA}}{N^A - 1}$	N^{DA} is the number of derived attributes in the ER model. N^A is the number of attributes in the ER model. Being $N^A > 1$.

When we calculate the number of attributes in the ER model (N^A), in the case of composite attributes, we consider each of their simple attributes.

The derived attributes are redundant attributes, and then it is convenient to reduce this number. A big number of derived attributes may have a negative influence on the programs that manage the future database, because they have to deal with all of the problems introduced by the redundancy.

DA metric is zero when there are no derived attributes, it scores 1 when all except one of the attributes within the ER model are derived attributes.

2.4 CA metric

The Composite Attributes metric assesses the number of composite attributes, compared with the number of attributes in an ER model. A composite attribute is an attribute composed of a set of simple attributes.

We define this metric thus:

$CA = \frac{N^{CA}}{N^A}$	N^{CA} is the number of composite attributes in the ER model. N^A is the number of attributes in the ER model. Where $N^A > 0$.

When we calculate the number of attributes in the ER model (N^A), in the case of composite attributes we consider each of their simple attributes.

CA metric is zero when there are no composite attributes, it scores 1 when all the attributes are composite.

2.5 MVA metric

The Multivaluated Attributes metric assesses the number of multivaluated attributes, compared with the number of attributes in an ER model. A multivaluated attribute is an attribute that can take several values for an individual entity.

We define this metric thus:

$MVA = \frac{N^{MVA}}{N^A}$	N^{MVA} is the number of multivaluated attributes in the ER model. N^A is the number of attributes in the ER model. Being $N^A > 0$.

When we calculate the number of attributes in the ER model (N^A), in the case of composite attributes we consider each of their simple attributes.

MVA metric is zero when there are no multivaluated attributes, it scores 1 when all of the attributes are multivaluated.

2.6 RR metric

We define the Redundant Relationship metric as the number of relationships that are redundant in an ER model, divided by the number of relationships in the ER model minus one. Redundancy exists when one relationship R_1 between two entities has the same information content as a path of relationships R_2, R_3, ..., R_n connecting exactly the same pairs of entities instances as R_1. Obviously, not all cycles of relationships are sources of redundancy. Redundancy in cycles of relationships depends on meaning [1].

We define this metric as follows:

$RR = \frac{N^{RR}}{N^R - 1}$	N^{RR} is the number of redundant relationships in the ER model. N^R is the number of relationships in the ER model. Where $N^R > 1$.

When we calculate the number of relationships (N^R), we also consider the IS_A relationships. In this case, we consider one relationship for each pair child-parent within the IS_A relationship

A big number of redundant relationships may have a big influence on the future database understandability and maintainability.

RR metric is zero when there are no redundant relationships. It scores 1 when all of the relationships are redundant except one.

2.7 M:NRel metric

The M:N Relationships metric measures the number of M:N relationships compared with the number of relationships in an ER model.

We define this metric as follows:

$M:N\,Rel = \frac{N^{M:NR}}{N^R}$	$N^{M:NR}$ is the number of M:N relationships in the ER model. N^R is the number of relationships in the ER model. Where $N^R > 0$.

When we calculate the number of relationships (N^R), we also consider the IS_A relationships. In this case, we consider one relationship for each pair child-parent within the IS_A relationship.

M:NRel metric scores zero when there are no M:N relationships, it scores 1 when there is a high percentage of M:N relationships.

2.8 N-aryRel metric

The N-ary Relationships metric measures the number of N-ary relationships (not binary) compared with the number of relationships in the ER model.

It is convenient that the number of N-ary relationships in an ER model were minimal, because they contribute to increase its complexity.

We define this metric thus:

$N-ary\,Rel = \frac{N^{N-ary R}}{N^R}$	N^{N-aryR} is the number of N-ary relationships in the ER model. N^R is the number of relationships in the ER model. Where $N^R > 0$.

When we calculate the number of relationship (N^R), we also think over the IS_A relationships. In this case, we consider one relationship for each pair child-parent within the IS_A relationship.

This metric is zero when the ER model has no N-ary relationships, it takes the value 1 when all of relationships are N-ary. Most of the available tools for building conceptual models do not allow N-ary relationship. They must be translated into binary relationships, so the majority of designs have only binary relationships.

2.8 SCO metric

With the Schema Cohesion metric we want to assess situations like the one shown in figure 2. It represents an ER model composed of three unrelated subgraphs. Some database designers consider that if the ER model has several unrelated subgraph it is more complex.

We are looking for a single value, which lets us measure the cohesion degree of the different unrelated subgraphs, taking into account the number of entities in each component.

We define the SCO metric thus:

$SCO = 1 - \frac{\sum_{i=1}^{\lvert U \rvert} \left(N_i^E\right)^2}{\left(N^E\right)^2}$	N^E is the number of entities in the ER model. $\lvert U \rvert$ is the number of unrelated subgraphs. N_i^E is the number of entities in the subgraph "i".

SCO metric is zero when all the entities are in the same subgraph, it is near to 1 when there is a high cohesion (many unrelated subgraphs with very few entities in each one).

SCO metric for the ER model in figure 2 is calculated thus:

$$SCO = 1 - \frac{\sum_{i=1}^{\lvert 3 \rvert} \left(N_i^E\right)^2}{\left(N^E\right)^2} = 1 - \frac{5^2 + 5^2 + 5^2}{15^2} = 0.6667$$

2.9 IS_ARel metric

The IS_A Relationship metric assesses the complexity of generalisation/specialisation hierarchies (IS_A) in one ER model. It is based on Lehbridge's M_{ISA} metric [15]. This metric combines two factors in order to measure the complexity of the inheritance hierarchy. The first factor is the fraction of entities that are leaves of the inheritance hierarchy. This measure, called Fleaf is calculated thus:

$FLeaf = \dfrac{N^{Leaf}}{N^{E}}$	N^{Leaf} is the number of leaves in one generalisation/specialisation hierarchy. N^{E} is the number of entities in each generalisation/specialisation hierarchy. Where $N^{E} > 0$.

S_ARel metric is calculated thus:

$$Is\_A\,Rel = FLeaf - \frac{FLeaf}{ALLSup}$$

This metric assesses the complexity of each IS_A hierarchy. The overall IS_ARel complexity is the average of all the IS_ARel complexities in the ER diagram.

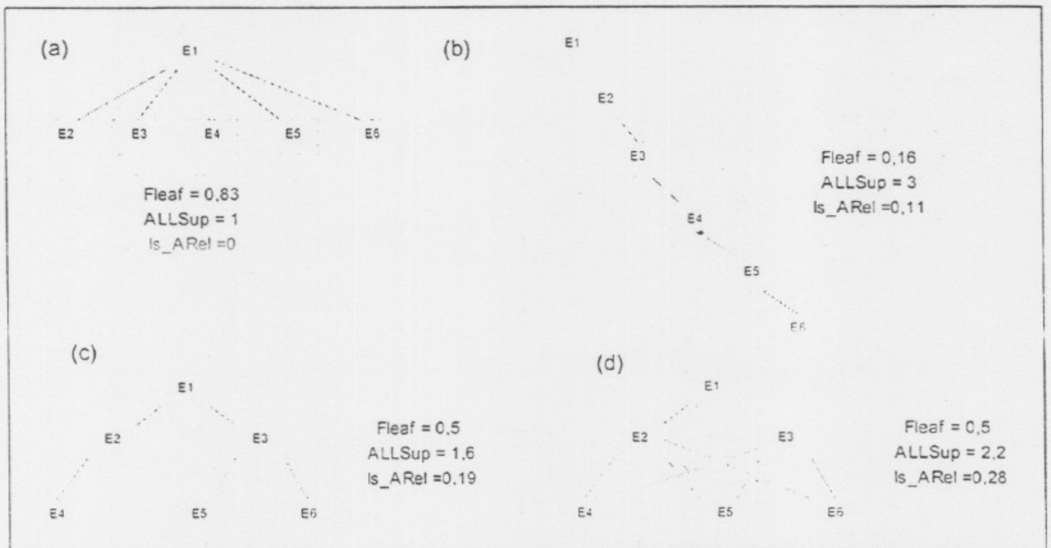
3. CONCLUSIONS AND FUTURE WORK

We have presented ten closed-ended metrics for evaluating conceptual data models complexity. These closed-ended metrics are objective and easily computed metrics which should be useful for:

1) Information system designers, since they will be able to choose between alternative design options.
2) Software quality engineers and auditors, since these metrics will help them to quantify the quality of database design.

Figure 2 shows several inheritance hierarchies along with their measures of Fleaf. Fleaf approaches 0,5 when the number of leaves is half of the number of entities. (figure 2, part c and d). It approaches zero in the ridiculous case of a unary tree (part b) and it approaches one if every entity is a subtype of the top entity (part a). On its own, Fleaf has the undesirable property that for a very shallow hierarchy (e.g. just two or three levels) with a high branching factor, it produces a measurement that is unreasonably high, from a subjective standpoint (figure 3 part a). To correct this problem with Fleaf, an additional factor is used in the calculation of IS_ARel metric: the average number of direct and indirect supertypes per non-root entity, ALLSup (the root entity is not counted since it cannot have any parents).

Figure 2. Examples of IS_A relationships



3) Project managers, as far as they will be able to estimate maintenance costs.

These metrics are only a starting point, in order to measure the overall quality of the conceptual models. However, due to the lack of objective metrics for measuring conceptual models quality, they serve the purpose of getting information systems designers to think about the quality of their conceptual data models in numeric terms.

We think that it is not enough to propose metrics, it is also necessary to put them under theoretical verification and empirical validation, in order to assure their utility. Theoretical verification of these metrics is being carried out using Briand et al.'s formal framework (Briand et al., 1996). Empirical validation is planned, using not only controlled experiments but also actual case studies from different organisations.

We can't disregard the increasing diffusion of the object-oriented paradigm in information modelling. We think that object oriented models are more appropriate than ER models to describe the kind of information systems built ~~in~~ nowadays. We are adapting these metrics to measure OMT object diagrams [6], and also we are defining new ones for UML diagrams (7; 8]) .

We will extend the proposed metrics in order to measure other quality factors such as mentioned in the [12].

We have built a metric tool, called MANTICA, for collecting, and visualising metric values. Now we are working on building a tool to analyse measurement empirical data, using a novel data analysis approach based on regression and classification of fuzzy trees [9].

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