Several hypermedia data models have been proposed in order to face hypermedia as a paradigm to develop information-oriented systems. However, hypermedia modeling introduces very specific requirements not found within conventional database modeling due to several issues must be considered during a design effort, such as modeling of data navigation, data perception, and human-machine interaction. Most of present data models oriented to hypermedia present differences on abstraction level, modeling issues, and considered data aspects. An Abstract Categorization Map is proposed as a graphical tool through which it is possible to assess and compare existing specification mechanisms of data models oriented to hypermedia. The map allows an analysis of existing models as an exercise to relate them and therefore derive strengths, weaknesses, overlaps, or omissions. It also allows observing existing gaps between the modeling of data considering different levels of abstraction.

1 Introduction

The term hypertext, originally defined as “non sequential writing” [1], has been continuously evolving. Presently, it covers much more than its creators could imagine. Hypertext introduces a new organizational perspective to data modeling, allowing a customization for the order into which data perception can be performed.

Multimedia corresponds to the use of different media types to register information in the same application. Through multimedia it is possible to create very complex information objects that present basic components interrelated differently and which can be used to explore the different perception abilities of humans.

Hypermedia extends the combination of hypertext characteristics with those of multimedia allowing the composition of an associative structure equivalent to a semantic network where nodes can be expanded into a variety of forms, visual,

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audible, and, why not, sensorial. Hypermedia modeling introduces very specific requirements not found within other types of conventional modeling.

Considering hypermedia as a paradigm to develop information-oriented systems, there is a need for hypermedia data models. However, hypermedia modeling requirements are different from those of conventional data base modeling or structured document modeling, mainly when aspects such as navigation through data, human-machine interaction, data perception, and synchronization of components with temporal continuity are considered.

Some existing models oriented to database or document design were adapted to incorporate hypermedia, such as Hypermedia/Time-based Document Structuring Language (HyTime) [2] ascribed to Standard Generalized Markup Language (SGML) [3]. There is a great diversity of data models proposed to cover few specific issues related to multimedia and hypertext, such as modeling of time based media [4], navigation [5], data perception and exchange [6], and browsing semantics [7]. There are reference models, such as the Dexter reference model [8], and extensions, such as the Amsterdam Hypermedia Model [9]. There are also model-based approaches to hypermedia design, such as Relationship Management Methodology (RMM) [10] and Object-Oriented Hypermedia Design Methodology (OOHDM) [11].

An Abstract Categorization Map is presented as a graphical tool through which it is possible to assess and compare existing specification mechanisms of data models oriented to hypermedia regarding three different points of view: abstraction level of the modeling; manipulation services that are considered; and aspects for data specification. The map allows an analysis of existing models as an exercise to relate them and therefore derive strengths, weaknesses, overlaps, or omissions. It also allows observing existing gaps between the modeling of data considering different levels of abstraction.

2 Categorizing Hypermedia Data Models

Data models currently in use to model data with hypermedia characteristics present limited coverage related to the broad intrinsic requirements of hypermedia modeling. But it is possible to find several mechanisms among those models for the specification of several characteristics of hypermedia data. These mechanisms can present coverage overlapping for the characteristics that can be modeled through them. There are also several similar mechanisms among them, which allow the same kind of specification, configuring specification alternatives.

Integration efforts exist combining several available data models, but unfortunately those do not present a complete coverage of known characteristics that could be present in hypermedia applications. The analysis of this scenario rises the following open questions:
1. Given a data model, how is it possible to know and visualize the existence of overlapping or complementary coverage of hypermedia characteristics with another data model?

2. How is it possible to compare data models considering characteristics of their specification mechanisms?

3. How wide should be the coverage of a hypermedia system in order to support a complete set of data manipulation activities?

In the following section, an answer is proposed to these questions in the form of a graphical map, named Abstract Categorization Map, through which it is possible to categorize data models according to three points of view:

- abstract level emphasis that they support to represent data;
- services for data manipulation that are considered in order to dispose specification mechanisms; and
- specification dimensions defined for data modeling; e.g., the structural and the behavioral dimensions.

Data models usually fit at one level of abstraction, but nothing prevents that they comprehend more than one level or restrict themselves to part of one level. Data models are usually oriented to few manipulation services, such as perception and navigation, but ideally should consider each of the supported services in isolation to allow separation of concerns. Data models by convention are regarded to structural concerns but should comprehend a broader set of specification dimensions.

Abstraction levels are explored in the R-Model of the Trellis System [7] and also in the Premo proposal for standardization [12]. While the R-Model presents five abstraction levels – abstract component, abstract hypertext, concrete context, concrete hypertext, and visible hypertext – it does not consider information elements at a higher abstraction level, closer to the modeling domain of interest.

The Premo standard also presents five levels – construction, virtual, vision, logic, and realization. Premo also does not consider information elements and is mainly concerned with implementation elements to support presentation and interaction of graphical interfaces.

A very important reference to abstraction levels is the ANSI/SPARC architecture [13] developed to allow categorization of database schemas, something very close to what is proposed here for data models.

Manipulation services are explored by Steinmetz [14] when he compares the SGML standard to ODA [15] and to MHEG. One architecture is defined with three operation models: representation, presentation, and manipulation. Considering hypermedia, at least navigation and interaction should also be considered, but they are not. In the Abstract Categorization Map several other services are considered, as it is presented in the next section.
Specification aspects are explored in the most known and used data models. While in record-oriented models the structural aspect is strongly explored, little is done with the restriction-related, the content-related, and the behavioral aspects, mainly when considering information elements at high levels of abstraction. Semantic data models, extensions to the record-oriented approach, consider meaning for the structural elements. Object-oriented models are more complete, strongly directed to consider the structural and behavioral aspects in an integrated form. When restriction-related issues are considered, they are oriented to computational matters. Usually content-related issues are considered isolated and cannot be forgotten since they are essential to multimedia modeling.

3 An Abstract Categorization Map

Although three viewpoints are used in the definition of the proposed Abstract Categorization Map, the abstraction level view is followed in order to simplify its presentation.

The Abstract Categorization Map (Figure 1) presents three main abstraction levels: external, intermediate, and physical. The intermediate level is further divided into abstract and concrete sublevels.

On the top of the map are considered data models at the external level that closer to how individuals perceive the domain of interest. They are used to identify information elements, their characteristics, and relationships, without any concern with user profiles or activity types that users perform to manipulate data. On the bottom of the map are considered data models at the physical level; they provide mechanisms that allow and offer different facilities to the specification of computational elements that, when constructed, will be actually responsible by the manipulation of data. These mechanisms establish how users are going to perform different activities to manipulate data through a computer.

Models located at the intermediate levels of the map introduce abstract mechanisms that are related to the computational world and facilitate application development. Ideally, a data model at the intermediate level should allow the adaptation between information elements and computational elements.

The information-element adaptation could be done preferentially through mappings that begin at the external level, somewhat abstractly, and gradually are transformed into implementation specifications, i.e., into concrete elements at the physical level.

In practice, intermediate data models are the most common, offering abstractions to computational elements without considering information elements that exist in the domain of interest.
The easiness of a mapping between data models that belong to different abstraction levels depends on the available mechanisms supported by the higher-level data interchange.
model. If some of these mechanisms offer some adaptation type for the elements specified through them to elements that can be obtained through the lower-level data model, they are named mapping facilitators. For instance, a relationship identified through a conceptual model can be used to identify and specify links in a navigational model.

3.1 The External Level

Data models at the external level should allow representation of information elements, which are perceived as interesting in the world under investigation. This representation should be as close as possible to the real target world regarding aspects that are considered relevant to the application designer. There should be no concerns with computational matters, such as navigational links or anchors because they do not exist in the actual world. Computational elements will be specified afterwards from the already defined information elements.

Four specification aspects or dimensions are considered in the external level, in order to categorize existent mechanisms of a data model. Each mechanism is analyzed in order to identify what kind of specification aspect is considered: structural, content-oriented, behavioral, or restriction-oriented. These four specification aspects constitute a proposal for infologic data specifications named T-vision [16], which establishes for each aspect three specification components: description, meaning, and perception delimiters.

The specification component named perception delimiter allows delimitation of description parts in order to define data-component chunks for afterwards perception. Usually, data components equivalent to perception delimiters are associated to content and are defined together with computational elements, e.g., the classical definition of hypertext links. However, it is worth to note that perception delimiters are not restricted to content but can also be specified considering the other three specification aspects, allowing the delimitation of behavioral descriptions, e.g., a method; structural descriptions; and constraints descriptions, e.g., a set of rule-firing conditions. Perception delimiters applied to content can be easily mapped to anchors of data models oriented to navigation such as the Dexter reference model [8].

3.2 The Physical Level

The physical level represents something like a computational platform where a support is provided to users perform different types of activities based on data manipulation. During data modeling, several user profiles should be considered together with their possible activity necessities and presently this is partially accomplished through the use of different data models.
The activities that users can perform are better supported if divided into services that are traditionally considered in the computational arena. In addition, separation of services allows different degrees of data independence, e.g., the separation of concerns between navigation and interface allows the construction of different interfaces for the same navigation modeling [11].

Usually, data models at the physical level are oriented to at most two services, thus an integration of data models should be provided in order to obtain a broad, complete, and consistent coverage of services.

Present hypermedia data models, with abstraction levels higher than physical, consider at most three different services: navigation, presentation, and interaction. In the physical level, these three services are also considered, but “perception” is used instead of “presentation” because several media explore cognitive sensations other than visual and audible. Other services considered are search, manipulation, maintenance, and authoring.

At the base of the physical level in Figure 1 the existence of several basic distributed services is considered, amongst which two are closely related to hypermedia – interchange and storage, that are basic rendering services. In principle, the facilities of these services are activated transparently to the user by other physical level services providing higher physical abstractions. This does not prevent the existence of specific data models for interchange and storage, establishing how data should be represented in order to be better operated upon.

It is interesting to note that some services give support to other services, such as the manipulation, perception, and interaction services. Every support service comprehends a support-interface between itself and each of the supported services. These support-interfaces correspond, in abstract terms, to the real role of the “anchoring” and “presentation specifications” interfaces in the Dexter reference model. In the graphical representation of the Abstract Categorization Map, those interfaces are not represented for sake of visibility.

Data can be retrieved in traditional database systems through identifiers, attributes, and keywords. The same facilities are expected for hypermedia data, although they present high generation and maintenance costs, besides not being easily available to some types of descriptions, such as with continuous media.

A search-service support to hypermedia modeling should provide specification mechanisms that allow the definition of elements through which the user should be able to search and query data, based on the different data aspects. An infrastructure with dictionaries, thesaurus, taxonomies, templates, ontologies, and subjectivity levels is the objective of the search-oriented modeling service.

Manipulation mechanisms aim the calling and articulation control of other services in order to establish computational requirements, such as non-volatile storage, real-time, transactions, and exception handling treatment. Manipulation modeling regards to the basic operations for data manipulation from repositories,
through networks, until availability to other services. The user through the manipulation service might define rules and restrictions directly or indirectly.

Maintenance issues comprehend configuration, failures, security, performance, and service billing [17]. Considering data modeling, manipulation mechanisms should support the specification of policies related to behavioral control and monitoring of the other services, which require planning, monitoring, and modification of computational resources.

Authoring covers all steps necessary to define hypermedia data, amongst which are capturing or content generation, composition, and final art. Hypermedia information definition is the objective of the authoring service. Software engineering issues beyond hypermedia data specific issues are covered by the authoring service. For instance, policies for configuration management, reuse management, and facilities to maintain different representations for the same information are examples of authoring issues.

3.3 The Intermediate Level

Data models at the intermediate level support mechanisms that allow information element adaptation into computational elements, or, at least, they introduce computational-oriented mechanisms that are not related to the domain of interest.

Intermediate data models present mechanisms that allow the specification of computational elements in very high levels of abstraction, such as an index or a tour mechanism considering the navigation service. Elements modeled through intermediate mechanisms with high levels of abstraction, in order to be implemented, must be specified through mechanisms of other data models with lower levels of abstraction belonging to the intermediate or physical level. If they belong to the intermediate level, other lower level adaptations must be provided until a modeling is obtained at the physical level in order to permit the realization of the original modeling. Sometimes, these adaptations produce computational elements that do not preserve the characteristics of the respective information element or to the respective higher level element. Other times, the computational elements do not correspond to any information element.

The intermediate level is divided into two sublevels to allow the localization of data models regarding the abstract influence of the other two levels. If the influence is due to the external level and its four specification aspects of information, the data model belongs to the abstract sublevel. If, otherwise, the influence is due the physical level and its computational services, then it belongs to the concrete sublevel.

For instance, considering the modeling of nested contexts or of m-slices through the orientation of, respectively, OOHDM [11] and RMM [18], an external physical influence takes place from the content dimension in order to obtain computational elements with very high level of abstraction oriented to the
navigation service. Afterwards these high-level elements are adapted through lower-level mechanisms, such as the ones that constitute the HTML model [19].

A modeling that is oriented entirely to a specific service relates to the abstract sublevel, if an infologic modeling previously specified influences it. The moment when abstract data models are used is the very first moment to consider computational issues, although at high levels of abstraction.

A concrete modeling represents computational elements that were identified through abstract mechanisms and to which are aggregated detailed characteristics determined by the influence of the other services, not previously considered.

For instance, consider elements related to the navigation service. Each identified navigation mechanism can have aggregated a set of characteristics influenced by the other services, such as:

- The perception service, if destination anchors should be treated like transclusions, substitutions, or new visual elements.
- The interaction service, if the navigation activation is to be triggered by the user or automatically by the system.
- The manipulation service, if the specification of the navigation mechanism is internal or external to the description; and if the destination anchors belong to a group of related anchors and should be manipulated together.
- The search service, if the destination anchors should be located through some kind of query.

3.4 A Complete Vision of the Map

In addition to the three basic levels of the Abstract Categorization Map, there are additionally two interfaces located between the external and intermediate levels, and between the intermediate and physical levels.

The seven services that appear at the upper side of the physical level are projected from the bottom of the map towards the external level, through the intermediate level and interfaces. Each resulting column represents the influence of the respective service at each abstraction sublevels and interfaces. However, the interchange and storage services, that appear at the bottom side of the physical level, are not projected towards the external level because they do not need elements with high level of abstraction in order to be activated. Furthermore, of the known data models oriented to these two services, none covers other service, i.e., they are concerned only with codification matters.

The four specification aspects of the external level are also projected towards the physical level through the intermediate level and interfaces, producing quadrants in each abstraction sublevel of each service-column. Each quadrant represents the influence of the respective aspect at the abstraction level of the considered service.
The motivation for the Abstract Categorization Map is to graphically indicate the existence of mechanisms through which it is possible to specify elements with a specific abstraction level, and related to one of the computational services and one of the information aspects. The quadrants in the intermediate sublevels establish an influence crossing between the physical level services and the four external level aspects.

Considering each quadrant of the external and intermediate levels, it could be pointed out the existence of mechanisms that facilitate data specification mappings to elements that can be obtained through a data model with adjacent lower level of abstraction. If such mechanisms exist, they play the role of mapping facilitators between models of distinct abstraction levels, and their existence is represented in the correspondent quadrant of the respective interface, i.e., the interface between the two considered levels.

A mapping facilitator is an existent mechanism of a high-level data model, regarding abstraction, whose resulting modeled elements could be mapped directly into elements produced by some other mechanism in a lower-level data model. That would be the case of an infologic data model supporting perception delimiters for content, such as attributes of a semantic data model, which could be mapped into anchors of a data model oriented to navigation which could, in turn, be used in the navigational design step in RMM. Another example that can be also observed in RMM is the mapping facilitator of relationships. Relationships that are defined during the E-R design step of RMM are mapped afterwards into links of the application diagram or of m-slices [18].

The interface between the external and intermediate levels allows the presentation of existent mechanisms of the external data model under consideration that facilitates mappings to any data model of the intermediate level. The interface division is a mirror of the division that exist in each intermediate level, allowing the indication of characteristics (abstraction, service, and aspect) for the target mechanism in the intermediate data model. The second interface plays the same role, except that it applies to the intermediate and physical levels.

Although there is the consideration of data models at each of the intermediate sublevels, there is no interface between them since there is not a real mapping between data models of the two sublevels. What happens is the production of details, not element transformation or new element introduction.

4 Using the Abstract Categorization Map

The Abstract Categorization Map is a tool that allows graphical visualization to represent the existence and sophistication of specification mechanisms according to their adequate abstraction level, computational service and specification aspect. As an example, the categorization of RMM is commented here.
RMM corresponds to one of few methodologies for model-based approaches to hypermedia design that covers most of the different abstraction levels of the map, allowing a step-by-step design development through these levels. This set of models addresses the design and construction of hypermedia applications. It is based on data models that support data representation schemes but provide few procedures for the representation usage in a design process. One of its basics is the Entity-Relationship model.

RMM focuses on applications that present regular structure, i.e., whose domain of interest offers the possibility to model entity-classes, relationships between classes, and multiple instances in each class.

RMM provides specification primitives to structure information divided into three points of view: E-R domain, slice domain, and access. In the slice domain, the slice primitive allows modeling of how the information should be presented. Access primitives model navigation through data.

RMM consists of the following eight steps, some of which can be conducted in parallel:

a) Entity-Relationship design, when the information domain of interest is modeled through entities and their relationships.

b) Application diagram design, when presentation units and links among them are defined.

c) M-Slice design, when information units are sub-divided for presentation.

d) Navigational design, when it is modeled how users will access information.

e) User-Interface design, when it is modeled how data will be presented.

f) Protocol Conversion design, when it is established how abstract constructs are to be transformed into physical-level constructs.

g) Run-time Behavior, when decisions about how link transversal, history, backtracking, and navigational mechanisms are to be implemented, and how to populate the application with data.

h) Construction and testing.

Although first presented as a linear methodology, RMM was conceived to be flexible by supporting rapid feedback loops.

The existence of mechanisms is represented by the occupation of the quadrant that corresponds to their characteristics. All parts of the map can be used to point out mechanism existence, including the three abstraction levels, the four specification aspects of the external level, and the nine computational services of the physical level (considering also interchange and storage). For RMM the considered services are mainly navigation together with perception and authoring, as can be visualized in Figure 2.

Indication of existence of mechanisms in a quadrant is performed through a graphical occupation of the quadrant which means that the data model under
consideration support one or more mechanisms with the abstraction level,
computational service, and specification aspect defining the quadrant. Comments
justifying a given categorization should be written.

**Figure 2.** Abstract categorization map for RMM.
In order to indicate the sophistication of a mechanism that is represented in the map, a simple scale with three values – basic, intermediate, sophisticated – is proposed. Different patterns used to occupy a quadrant represent the sophistication degrees.

In RMM, an infologic structural modeling is created in the first step using the E-R data model followed by an application diagram through which a global vision of the final application is defined, that is composed by presentation units.

Each presentation unit is decomposed into m-slices (with E-R attributes and nested m-slices) which can be seen as navigation nodes. The most basic m-slices constitute WWW pages equivalents or part of them.

Usually m-slices belong to one of the E-R entities but can be composed by attributes of other entities, even those that are not directly related to the owner entity. An m-slice describes which data is to be presented but does not describe how it is presented.

Very powerful mechanisms that define indexes, groups, and guided tours are available during m-slice design. It is also possible to associate conditions to the related entities in order to establish which instances are involved in the presentation.

The two interfaces that are present in the Abstract Categorization Map between the basic abstraction levels can also have existence and sophistication indications for mapping facilitators. Only the sophistication degree of a mapping facilitator must be considered in a categorization when it comes to the interface. It could happen to have different sophistication indications in two correspondent quadrants. The first at one of the interfaces and the second at the correspondent upper abstraction level, because the mechanisms considered in one quadrant are different from those considered in the other – only mapping facilitators are represented in the interface. In RMM, the domain analysis using the E-R data model helps to identify important relationships through which navigation can be supported. It is considered natural that the infologic relationships establish navigational paths.

During the protocol conversion step is necessary to map or convert the already obtained modeling into available tools that can be categorized at the concrete intermediate level or at the physical level. This step is not easily performed because of the lack of mapping facilitators to these lower abstraction levels.

A designed application through RMM can be realized with any data base tool oriented to the WWW. Depending on the information volatility, applications can be constructed using HTML (statically) or SQL query (dynamically).

4.1 Orientations for a Categorization

A categorization requires a set of guidelines in order to orient the use of the Abstract Categorization Map. These guidelines should reflect the categorization
objective and their definition is a responsibility to be accomplished before the categorization could be initialized.

Some objectives that can be considered are:

• identification of coverage overlapping between data models, aiming the analysis of potential integration;
• comparison of data models;
• specification of a new authoring methodology; or
• adherence assessment of data models to specific available tools.

Considering the first objective, several categorizations were produced [16]. In order to perform these categorizations, the following orientations were established:

1. Any mechanism that is oriented to one of the computational services, mainly to those strongly related to hypermedia, i.e., navigation, perception, and interaction, cannot be considered at the external level.
2. The existence of a mechanism is pointed out at least as basic, no matter how simple it is.
3. The reference for a mechanism to be considered intermediate sophisticated, related to the navigational service, is the Dexter reference model. Related to the perception service, the reference is the HyTime standard. For the interaction service, ADVcharts [20] were adopted. For the remaining services there is no referential other than the decision of the analyst responsible by the assessment.
4. The determination of the abstraction level for a given mechanism should follow the motivations that are presented below together with the definition of the Abstract Categorization Map.
5. If several different mechanisms exist and relate to the same quadrant in the Abstract Categorization Map, the indication of the most sophisticated prevails.
6. A given mechanism of a given data model can only be considered a mapping facilitator if, through it, it is possible to specify elements which are going to be used as a specification basis for other elements with lower abstraction level, which can be specified through another data model.

It is also recommended that each graphical categorization be produced together with the following textual information:

a) A presentation of the data model.
b) Observations and justifications for the map coverage, regarding abstraction levels, computational services, and specification aspects.
c) Observations and justification about how each of the basic abstractions levels is explored.
d) Observations and justifications for mapping facilitators.
e) Relevant features of the data model.
f) Other observations.
4.2 Map User Profiles

The Abstract Categorization Map is directed to designers that work with hypermedia, mainly those involved with:

- Application development and whose interest is to choose a set of data models that can be used to support their work.
- Hypermedia systems and who are interested in determining how broad a system is regarding the map coverage.
- Hypermedia systems and whose interest is to define mapping facilitators and mapping rules, mainly when involving data models at the physical level.
- New data models which are the result of an integration effort, involving existing or new data models.
- Development methodologies to information systems and whose interest is with coverage and transition strategies between abstraction levels, computational services, and specification aspects.

5 Conclusions

The Abstract Categorization Map has two main objectives. First, it allows comparisons and assessment of each mechanism for multimedia and hypermedia modeling that composes data models, according to an abstraction level, a computational service, and a specification aspect. Second, it constitutes a reference framework for the definition of new data models or for the integration of existing data models in order to support multimedia and hypermedia information applications. The map can also be used for the analysis of conventional data models.

When a specific data model is categorized, representations for all of its specification mechanisms should be located in the Abstract Categorization Map according to the abstraction level, the service to which it is oriented, and the specification aspect that is considered. In addition if any of the mechanisms plays a role of mapping facilitator, its existence should be displayed in the respective quadrant of the applicable interface.

Through the analysis of several data models using the Abstract Categorization Map, it was observed that the abstraction emphasis is directed to the concrete intermediate level, i.e., it is operationally oriented, presenting more concern with computational elements than with information elements.

The Abstract Categorization Map allows figuring out how broad should be a support environment for multimedia and hypermedia. Actually it is possible to find good, if not excellent, data models supporting several aspects and services that are considered in the external and intermediate levels. It is also possible to find good authoring methodologies that focus some of the computational services. However,
they usually do not offer a complete vertical coverage with support to different abstraction levels. The reasons for this situation should be investigated and some questions are proposed in order to orient further efforts:

1. Is it possible to integrate some of the good models in order to obtain either a complete vertical coverage for any of the services or a horizontal coverage for one of the abstraction levels?

2. Is there any model oriented to some of the quadrants, mainly to those located through the intersections of the search, manipulation, and maintenance services, in addition to those of the behavioral and restriction-oriented specification aspects?

3. How broad are the available tools in terms of map coverage?

4. How much effort should be located on creating more abstract data models for multimedia and hypermedia?

5. What mechanisms of existent data models can be considered mapping facilitators?

The Abstract Categorization Map can be improved through the introduction of a graphical representation for the existence of elements, regarding one computational service, which give support to other services.

Orientations and criteria for the use of the Abstract Categorization Map vary according to the defined objectives of the categorization and are not fixed. One important open issue to consider is the definition of metrics to measure the sophistication scale for the different representation and manipulation mechanisms.

The subjective scale presented here can be adequate for one to compare different models. However, in order to enable the use of the map as a tool to exchange information, the sophistication scale can be refined to consider deeper details of data models.

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