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DR 09014

Combining Objects with Rules to Represent Aggregation Knowledge in Data Warehouse and OLAP Systems

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DECEMBER 2009

ESSEC
BUSINESS SCHOOL
PARIS-SINGAPORE

Document de Recherche ESSEC / ISSN : 1291-9616

- DR 09014 -

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ABSTRACT:

Data warehouses are based on multidimensional modeling. Using On-Line Analytical Processing (OLAP) tools, decision makers navigate through and analyze multidimensional data. Typically, users need to analyze data at different aggregation levels (using roll-up and drill-down functions). Therefore, aggregation knowledge should be adequately represented in conceptual multidimensional models, and mapped in subsequent logical and physical models. However, current conceptual multidimensional models poorly represent aggregation knowledge, which (1) has a complex structure and dynamics and (2) is highly contextual. In order to account for the characteristics of this knowledge, we propose to represent it with objects (UML class diagrams) and rules in Production Rule Representation (PRR) language. Static aggregation knowledge is represented in the class diagrams, while rules represent the dynamics (i.e. how aggregation may be performed depending on context). We present the class diagrams, and a typology and examples of associated rules. We argue that this representation of aggregation knowledge allows an early modeling of user requirements in a data warehouse project.

Key-Words:

- Aggregation
- Conceptual Multidimensional Model
- Data Warehouse
- On-line Analytical Processing (OLAP)
- Production Rule
- UML

RESUME :

Les entrepôts de données reposent sur la modélisation multidimensionnelle. A l'aide d'outils OLAP, les décideurs analysent les données à différents niveaux d'agrégation. Il est donc nécessaire de représenter les connaissances d'agrégation dans les modèles conceptuels multidimensionnels, puis de les traduire dans les modèles logiques et physiques. Cependant, les modèles conceptuels multidimensionnels actuels représentent imparfaitement les connaissances d'agrégation, qui (1) ont une structure et une dynamique complexes et (2) sont fortement contextuelles. Afin de prendre en compte les caractéristiques de ces connaissances, nous proposons de les représenter avec des objets (diagrammes de classes UML) et des règles en langage PRR (Production Rule Representation). Les connaissances d'agrégation statiques sont représentées dans les digrammes de classes, tandis que les règles représentent la dynamique (c'est-à-dire comment l'agrégation peut être effectuée en fonction du contexte). Nous présentons les diagrammes de classes, ainsi qu'une typologie et des exemples de règles associées.

Mots-clés :

- Agrégation
- Entrepôt de données
- Modèle conceptuel multidimensionnel
- OLAP
- Règle de production
- UML

JEL classification : M15, C88

Combining Objects with Rules to Represent Aggregation Knowledge in Data Warehouse and OLAP Systems

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Abstract. Data warehouses are based on multidimensional modeling. Using On-Line Analytical Processing (OLAP) tools, decision makers navigate through and analyze multidimensional data. Typically, users need to analyze data at different aggregation levels (using roll-up and drill-down functions). Therefore, aggregation knowledge should be adequately represented in conceptual multidimensional models, and mapped in subsequent logical and physical models. However, current conceptual multidimensional models poorly represent aggregation knowledge, which (1) has a complex structure and dynamics and (2) is highly contextual. In order to account for the characteristics of this knowledge, we propose to represent it with objects (UML class diagrams) and rules in Production Rule Representation (PRR) language. Static aggregation knowledge is represented in the class diagrams, while rules represent the dynamics (i.e. how aggregation may be performed depending on context). We present the class diagrams, and a typology and examples of associated rules. We argue that this representation of aggregation knowledge allows an early modeling of user requirements in a data warehouse project.

Keywords: Data warehouse, On-line Analytical Processing (OLAP), Conceptual multidimensional model, aggregation, UML, Production rule.

1 Introduction

Data warehouses are the cornerstone of data-driven decision support systems (DSS) [11]. They rely on a multidimensional model, providing users with a business-oriented view of data. Using On-Line Analytical Processing (OLAP) tools, decision makers may then navigate through and analyze multidimensional data. Typically, users need to analyze data at different aggregation levels, which is achieved by means of the roll-up operator (and its converse operator, the drill-down operator). Therefore, in order to ensure correct and flexible aggregation, aggregation knowledge should be adequately represented in conceptual multidimensional models, and mapped in subsequent logical and physical models. This aggregation knowledge pertains to aggregation functions that can be applied, as well as to hierarchies along which they are applicable, etc.

Several authors have studied how data may be aggregated along hierarchies (a.k.a. summarizability), and several conceptual multidimensional models incorporate aggregation knowledge [2,6,9,14]. [2] includes summarizability constraints. [5] develops a taxonomy of the additive nature of measures (non-, semi-, fully-additive). [9] introduces non-additivity and semi-additivity as constraints on measures. Based on the typology of aggregation functions presented in [13], [6] defines aggregations using 4 restriction levels. For example, level 3 only allows COUNT operations on measures. [4] uses intentional rules to define exceptions in aggregation hierarchies; this paper illustrates the applicability of rules to model aggregation knowledge, but does not consider aggregation functions. Finally, [7] defines three necessary conditions for summarizability: disjointness, completeness of category attributes, and temporal specific conditions.

Despite the contributions of previous research, aggregation knowledge is still poorly or inadequately represented in current conceptual multidimensional models. Aggregation knowledge is difficult to represent in a simple way [15]. This knowledge (1) has a complex structure and dynamics and (2) is highly contextual in nature (e.g. the aggregation functions that may be applied at a given time may depend on the functions applied previously). In order to account for the characteristics of aggregation knowledge, we propose to represent it with objects (UML class diagrams [12]) and rules (in Production Rule Representation language [12]). Static aggregation knowledge is represented in the UML class diagrams, combined with PRR rules which represent the dynamics (i.e. how aggregation may be performed depending on context).

The rest of the paper is organized as follows. Section 2 focuses on the representation of static aggregation knowledge, using UML class diagrams. Section 3 proposes a typology of rules to represent dynamic aggregation knowledge, and illustrates how these rules may be represented and organized in the PRR formalism. Section 4 concludes and points to further research.

2 Representing Static Aggregation Knowledge: UML Class Diagrams

A conceptual multidimensional model should clearly distinguish between structure (schema) and content (instances) [15]. In our approach, this distinction is crucial, since aggregations (roll-ups) will be performed at the instance level. We therefore distinguish between the core conceptual multidimensional model (used for the conceptual representation of a data warehouse), and the data cube model. A data cube is a user view on multidimensional data (like the core conceptual multidimensional model, the data cube model is represented at the conceptual level, i.e. independently of any OLAP implementation). Aggregations operate on and result in data cubes.

The UML class diagram of Figure 1 represents the static view of the core conceptual multidimensional model. This model draw on earlier work [3,14] and focuses more specifically on concepts related to aggregation. A conceptual multidimensional schema is composed of facts and dimensions. Facts are composed of measures and dimensions are composed of hierarchies. Hierarchies are built upon rollup relationships between dimension levels. The roles of rollup relationships are characterized by their multiplicity. For example, when the lower multiplicity of the source role is 0, we have an asymmetric hierarchy [10]; when the upper multiplicity of the target role is * (i.e. the target is plural), we have a non-strict hierarchy [10], which requires the definition of a coefficient [3]. The model enables the data warehouse designer to specify some applicable aggregation functions; however, this is not compulsory since PRR rules (described in Section 3) are specifically aimed at representing dynamic aggregation knowledge, including applicable aggregation functions.

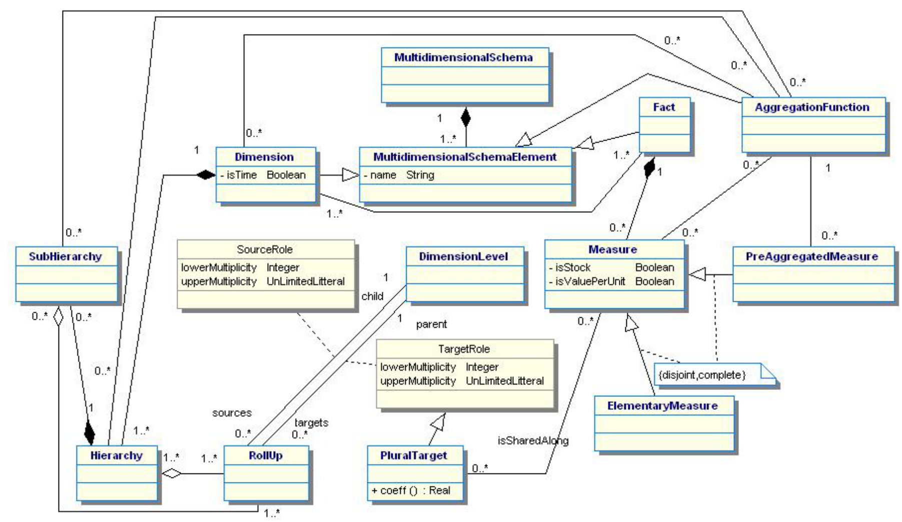

Fig. 1. Core Conceptual Multidimensional Model (MM): static view

Figure 2 represents the static view of a data cube ("MM" refers to classes of the core conceptual multidimensional model). A data cube is composed of cells and axes. Each axis has a default hierarchy (the default hierarchy used for rollup, as proposed in the Common Warehouse Metamodel [12]). A cell is composed of cell values (one value for each measure). Cell values may be base cell values or aggregated cell values (i.e. cell values resulting from previous rollups).

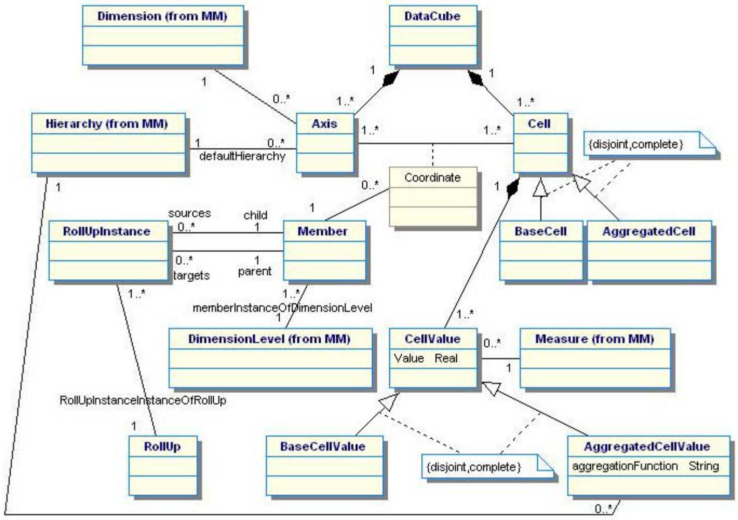

Fig. 2. Data cube model: static view

3 Representing Dynamic Aggregation Knowledge: PRR Rules

In order to completely represent aggregation knowledge, we must specify how, in a given context, aggregation may be performed on a given data cube (i.e. how to choose the aggregation function, and how to perform the aggregation once the aggregation function has been chosen). Since this knowledge is complex and highly contextual (depending on the data cube, the user preferences…), it is appropriately represented with rules. Rules also enable us to explain why a particular aggregation function has been chosen in a given context and how it has been applied.

To represent aggregation rules, we have chosen the Production Rule Representation language, complying with our choice of UML for representing the conceptual multidimensional model. The Production Rule Representation language enables the representation of rules related to the UML class diagrams presented in section 2, independently of subsequent implementations.

3.1 The Production Rule Representation Language (PRR)

The Production Rule Representation language (PRR) [12] has been proposed by OMG for high-level (tool-independent) representation of rules.

PPR rules are grouped into rulesets. A ruleset is a collection of rules with a particular mode of execution (sequential or inferencing). When inferencing is chosen as a mode of execution, priorities may be defined to constrain the order in which rules will be executed. PRR currently supports forward chaining only.

A production rule is typically represented as *if [condition] then [action-list]*. For example, an action may be the invocation of an operation associated with a class, or the assertion (creation) of a new object.

Variables may be defined at the ruleset level or the rule level. Rules variables are used for binding.

PRR rules can be represented formally, based on an extension of the Object Constraint Language (OCL) [12].

3.2 Typology and Examples of Rules

We distinguish the following types of aggregation rules:

- *Semantic aggregation rules*, which are based on the semantics of elements of the conceptual multidimensional model (e.g. semantics of dimensions, measures, aggregation functions).
- *Syntactic aggregation rules*, which express the mathematical properties of aggregation functions (e.g. commutativity, related to the concept of distributivity [8]).
- *User preferences* (e.g. "The aggregation function SUM should be used preferably to other aggregation functions.").
- *Aggregation execution rules*.

Semantic and syntactic aggregation rules indicate which aggregations are correct; user preferences indicate which aggregations are preferable (in case several candidate aggregation functions are applicable). Finally, aggregation execution rules indicate how a particular aggregation function should be executed once it has been chosen (e.g. how to perform aggregation along a non-strict [10] hierarchy).

We give illustrations for each category of rules.

Semantic aggregation rules

These rules are complex and may depend, among other things, on the semantics of measures, dimensions and hierarchies. By representing aggregation knowledge as rules, we enable easy update of semantic aggregation knowledge (new rules are added as new semantic aggregation knowledge is acquired).

Example R1: Measures of type stock are not additive along temporal dimensions [7].

Example R2: Ratios are not additive along any dimension [7].

Example R3: For a non-elementary (i.e. pre-aggregated) measure of type COUNT, along certain dimensions, aggregation may be incorrect from a certain dimension level, or a change in aggregation function may be necessary.

As an illustration of rule R3, consider the number of credits of a module (i.e. the number of credits that the student will get in the module if he passes). Suppose we have the hierarchy module → diploma→ institution. When rolling up from module to diploma, it makes sense to use the aggregation function SUM (total number of credits for the diploma). However, totaling the number of credits for the different diplomas of an institution does not make sense. Other aggregation functions may be used instead, e.g. MIN.

Syntactic aggregation rules

These rules indicate the correct sequencing of aggregation functions, within a given dimension (intra-dimension syntactic aggregation rules), or between different dimensions (inter-dimension syntactic aggregation rules, sometimes referred to as commutativity).

Example R4 (intra-dimension rule): For a given measure, for a given dimension, making the sum of averages does not make sense.

User preferences

These rules enable the representation of preferences for a given user, a profile of users, or for all users.

Example R5: If applicable aggregation functions are specified in the core conceptual multidimensional model, these functions should be applied in priority.

Example R6: SUM should be applied preferably to all other aggregation functions [13].

Example R7: AVG, MIN or MAX should be applied preferably to COUNT [13].

Example R8: For a given measure, the same aggregation function should be applied to all dimensions along all hierarchies.

Example R9: For a given measure and a given hierarchy, the same aggregation function should be applied along all levels of the hierarchy.

Example R10: Aggregation should be stopped when null values are obtained. (Null values may be obtained when aggregating measures along asymmetric hierarchies [10] for example).

Aggregation execution rules

These rules are needed, in particular, to deal with non-standard (e.g. non-strict or asymmetric) hierarchies. They may also explicit how null values are taken into account in computing aggregation, which is crucial in OLAP applications [8].

Example R11: Sums along non-strict hierarchies are performed by consider null values as 0.

3.3 PRR rules organization and examples

The context of aggregation consists in a triple <*data cube*, *measure*, *axis*>. *Data cube* is the active data cube, *measure* is the measure that the user wants to aggregate, and *axis* is the axis along which the user wants to perform the aggregation. We define a first ruleset for choosing the aggregation function. Inside the ruleset, the candidate aggregation functions are determined by means of the semantic and syntactic aggregation rules, and user preferences. These rules add or delete aggregation functions in the list of candidate aggregation functions. Ultimately, a unique aggregation function is chosen. (We illustrate a few examples of the rules described in section 3.2.)

```
RuleSet chooseAggregationFunction
   (in currentDataCube: DataCube, currentMeasure:
   Measure, currentAxis: Axis,
   out chosenAggregation: String)
Variable:
   candidateAggregationFunctions: Set =
        Set{'SUM', 'AVG', 'MIN', 'MAX', 'COUNT'}

Rule R1_stockNotAdditiveTime
Condition:
   candidateAggregationFunctions->includes('SUM') and
   currentMeasure.isStock=true and
   currentAxis.dimension.isTime=true
Action:
   candidateAggregationFunctions =
   candidateAggregationFunctions->excluding('SUM')

Rule R4_intraDimensionNotSumAfterAvg
RuleVariable:
   ?cell: Cell = currentDataCube.cells->any
        (c:Cell|currentDataCube.cells->first()=c)
   ?cellValues: Set = ?cell.cellValues->select
        (cv:CellValue|
        cv.oclIsTypeOf('AggregatedCellValue') and
        cv.measure=currentMeasure and
        cv.hierarchy.dimension=currentAxis.dimension and
        cv.aggregationFunction='AVG')
Condition:
   candidateAggregationFunctions->includes('SUM') and
   ?cellValues->notEmpty()
Action:
   candidateAggregationFunctions =
   candidateAggregationFunctions->excluding('SUM')

Rule R6_sumPreferableAggregation
Condition:
```

```
   candidateAggregationFunctions->includes('SUM') and
   candidateAggregationFunctions->size()>1
Action:
   candidateAggregationFunctions=Set{'SUM'}
```

Once a unique aggregation function has been chosen, aggregation execution rules are used to perform the aggregation. For this purpose, we define a second ruleset. (In the sequel, we assume, for the sake of brevity, that there is only one measure, one axis, and no non-strict hierarchies). The first 3 rules are always executed, while the last rule implements rule r11 presented above.

```
RuleSet executeAggregation
   (in currentDataCube: DataCube, currentMeasure:
   Measure, currentAxis: Axis,
   chosenAggregation: String)
Variable:
   newDataCube: DataCube
   theAggregatedCell: AggregatedCell
   theMembers: Set = Set{}

Rule R0a_intializeNewDataCube (priority = 3)
Action:
   newDataCube = assert DataCube
   assert Axis (dimension = currentAxis.dimension ;
        hierarchy = currentAxis.hierarchy)

Rule R0b_findParentMembers (priority = 2)
RuleVariable:
   ?cell: Cell = currentDataCube.cells->any()
   ?coordinate: Coordinate = ?cell.coordinate-> any
        (c: Coordinate|c.axis=currentAxis)
   ?rollUpInstance: RollUpInstance =
        ?coordinate.member.sources->any
        (r:RollUpInstance|r.rollUp.hierarchies->
        includes(currentAxis.hierarchy))
Condition:
   theMembers->excludes(?rollUpInstance.parent)
Action:
   theMembers = theMembers->
        including(?rollUpInstance.parent)

Rule R0c_initializeCellsAndCellValues (priority = 1)
RuleVariable:
   ?parentMember: Member= theMembers->any()
Action:
   theAggregatedCell = assert AggregatedCell
        (dataCube=newDataCube)
   assert Coordinate(axis = currentAxis; cell =
        theAggregatedCell; member = ?parentMember)
   assert AggregatedCellValue
        (cell = theAggregatedCell; hierarchy =
        currentAxis.hierarchy; aggregationFunction =
        chosenAggregation; measure = currentMeasure;
        value = 0)
```

```
Rule R11_executeSum⊥0  (priority = 0)

RuleVariable:
   ?aggregatedCell: AggregatedCell =
        newDataCube.cells->any()
   ?aggregatedCellvalue: AggregatedCellValue =
        ?aggregatedCell.cellValues->any()
   ?parentMember: Member =
        ?aggregatedCell.coordinate->any()
   ?rollUpInstance: RollUpInstance  =
        ?parentMember.targets->any
        (r:RollupInstance|r.rollUp.hierarchies
        ->includes(currentAxis.hierarchy))
   ?sourceCell: Cell = currentDataCube.cells->any
        (c:Cell|c.coordinate.member=
        ?rollUpInstance.child)
   ?sourceCellValue: CellValue =
        ?sourceCell.cellValues->any()
Condition:

   ?sourceCellValue.value<>⊥

Action:
   ?aggregatedCellValue.value =
        ?aggregatedCellValue.value +
        ?sourceCellValue.value
```

4 Conclusion and Further Research

The aggregation concept is of central concern in data warehouse design and multidimensional modeling. However, it is generally poorly represented, due to the fact that multidimensional models mainly focus on static knowledge representation. To overcome this limitation, we proposed in this paper to use Production Rule Representation to enrich UML class diagrams with dynamic aggregation knowledge. The literature mentions approaches which mainly represent information on aggregation hierarchies. We go beyond by proposing PRR as a means to incorporate dynamic aggregation knowledge in the multidimensional model. In order to achieve this objective, we extended PRR allowing us to define variables representing collection types as in standard OCL. The main contributions of this paper are in i) collecting knowledge on aggregation in the literature, ii) classifying it into semantic rules, syntactic rules, user-preference rules, and execution rules, iii) homogenizing the description of these rules in a unique formalism using PRR language, and iv) demonstrating the expressive power of PRR language. Beyond the examples of PRR rules as illustrated in this paper, we plan to perform larger experiments based on a prototype. The next step of our research will consist of the definition of mapping rules to transform PRR aggregation rules into commands that could be executed by an OLAP tool. The typology of aggregation rules can also be refined and used to define rule execution strategies. Finally, sequence diagrams could be used to combine rulesets, as proposed in [1].

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