Requirements Engineering for Data Warehousing

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Abstract

Data Warehouses are used in multiple domains such as management and business process performance evaluation, strategic decision making and business planning, or even to support decisions made in business processes. The main purpose of a Data Warehouse is to support decision making based on the analysis of heterogeneous and distributed information. This paper reviews some of the approaches that have been proposed and are used in practice to develop Data Warehouses. Analyzing these approaches, we found that one of their main limitations relates to the lack of guidance of requirements engineering activities. The proposal made is to adapt traditional requirements engineering techniques in the specific context of developing Data Warehouses.

Keywords

Data warehouse, Information System, Requirements Engineering, Decision Process.

1. Introduction

Decision-making requires large quantities of data. Since these data are scattered in and across organizations, it is necessary to gather and integrate them in order to apply complex requests and lay them out in a consistent way. Bill Inmon [Inmo96] defines a Data Warehouse (DW) as a "c*ollection of integrated, non volatile, subject-oriented databases designed to support the decision support system where each unit of data is relevant to some moment in time. It contains atomic data and lightly summarized data*". This definition underlines several differences with operational Information Systems (IS):

- DW are s*ubject-oriented*. Indeed, they focus on the evolution of high-level business entities (such as employees or financial forecast) in contrast to operational ISs that support business processes which make operational data evolve (e.g. employee registration or rolling up financial accounts).
- DW are *integrated*. This means that data are stored in a single and consistent format (e.g. using naming conventions, domain constraints, unified physical attributes and measurements) even though they originate from different sources in which they have different formats. On the contrary, ISs can be composed of different data repositories (such as relational databases, object oriented databases, files etc), between which exchange interfaces are usually set up.
- Data managed in DW are *time variant.* This means that every data is systematically associated to a time reference (e.g. semester, fiscal year, pay period). This is obviously not the case in IS where the association of time information to operational data depends on the need.
- Data in DW are *non-volatile*. This means that data, once in the DW, do not change (they are historised). Again, data can also be historised in IS. This is however not systematic and depends on the requirements.

Based on this simple analysis of the differences between DW and IS, it can be assumed that the development of a DW should be different from the development of an operational IS. A literature review was thus undertaken to analyze DW development techniques. A framework was built to structure this literature review. Each of the analyzed DW development technique was positioned in the framework. This allowed to underline the aspects that are most frequently dealt with by these approaches, and those that need further investigation. This analysis showed in particular the general lack of specific guidance of the requirements elicitation process, requirements analysis process and system validation process. Besides the review of existing approaches, the proposal made in this paper is to adapt traditional RE techniques and integrates them with existing DW development approaches. The result is a goal-oriented process model that provides a rich picture of how to deal with requirements in the context of a DW project. Our plan is to enrich this picture by : (i.) introducing new strategies to guide the RE part of our process, (ii.) refining and adapting further the techniques already identified, and (iii.) exploring the transition from the requirements view to the DW conceptual model view.
The remainder of this paper is structured as follows: section 2 presents our framework; in section 3, some of the existing DW development approaches are discussed

in the light of this framework; section 4 outlines our approach and show how it proposes to combine the advantages of different families of approaches. This approach integrates RE activities to solve the main issues identified with the literature review.

2. Framework for analysing existing DW development approaches

Decision makers want to found their decisions on operational data. However, conventional ISs do not provide sufficient features to process the queries that are needed to synthesize operational data. On the contrary, DW propose features that allow to :

- *extract* data from scattered sources, such as internal or external databases, enterprise resource planning, other DW, etc.
- *integrate* them in a central repository that differentiates the reconciled data from the operational data stores (ODS) in which data are stored haphazardly,
- *maintain* them through time,
- *customize* and *aggregate* them into data marts that provide synthesised views of the DW according to the decision makers interests.

These features are shown in figure 1. Besides, the figure shows that not only decision makers can use data marts to focus on some aspects of the DW, but also they can directly access the entire DW through complex queries. This usage has two main purposes, which allows to differentiate between two main categories of decision makers : those having operational decisions, and those with strategic decisions. Operational decisions are those taken in the flow of business process to define how to proceed. On the other hand, strategic decisions have an influence on organisation and they can result in changes on the structure of business processes.

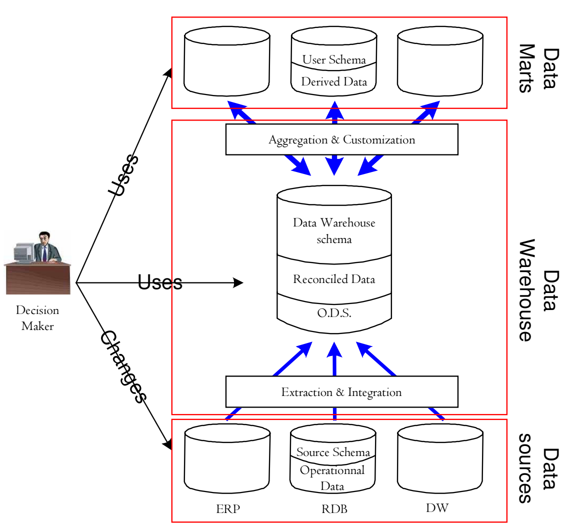

Figure 1: A general view of the architecture of DW

Developing a DW involves defining the structure of its repository, defining the different operations that allow to feed it in with data as well as to exploit it. A number of approaches can be found in the literature ([Gol98], [Inmo96], [Kim96], [Kim2002], [Moo2000], [Poe96], [Sap98]) and are used in practice ([Inmo96], [Kim96], [Poe96]).

We believe that, like scenario-based RE approaches [Rol98b] or like process engineering approaches [Rol98c], the DW development approaches can be categorized according to four perspectives : (i.) the system perspective, (ii.) the subject perspective, (iii.) the usage perspective, and (iv.) the development perspective. Therefore we developed a framework that views each DW development technique according to each of these perspectives. As figure 2 shows, each perspective is itself decomposed into several options. It is the choice of different options in the different perspectives that allow to compare the different approaches.

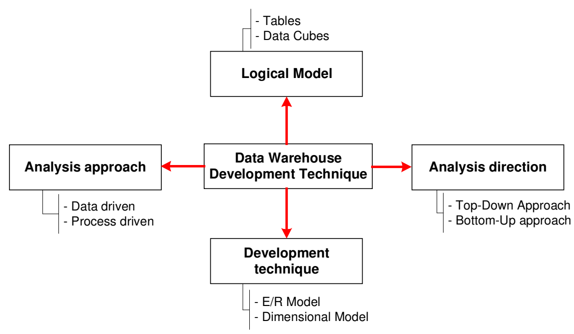

Figure 2: Framework for DW approaches

The remainder of this section is divided into four subsections. Each of those is devoted to the review of the existing DW development techniques within one of the four perspectives.

2.1 The System perspective: logical models

This perspectives proposes to categorise DW development approaches according to the logical models they use to implement DWs. Two options are available in this perspective: tabular models and dimensional models.

Tabular models are inspired from the relational model. The idea is to use universal tables (denormalized tables); this is particularly useful to avoid joints when accessing data.

The *Dimensional models* introduces the concept of Data Cube. A Data Cube is a multidimensional hierarchy structure. It generally contains summarized data as opposed to tabular models which can also contain detailed data (figure 3). Values higher in the hierarchy are more aggregated than those lower in the hierarchy. This hierarchical organisation is useful to let the user easily navigate between high and low precision views of the same aggregated data.

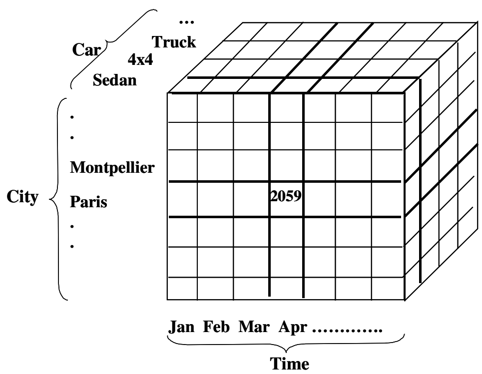

Figure 3: An example of Data Cube

In practice, most of the DWs schema are designed using the tabular model ([Gar2000], [Informix2000] [Craig99]). At the extreme, some approaches reuse the models used at the operational level, and propose universal tables to optimise queries. This approach has the advantage that it allows to reuse the existing operational data model. Although de-normalisation introduces redundancies, there is no maintenance issue in such tabular DW because data are never updated. The main drawback of this model is that it does not easily support the integration of external sources.

This issue is solved by the dimensional model [Kim96]. Indeed, dimension tables can be used to represent the data available in different sources. Kimball argues that besides, the design of DW schema according to the dimensional model is easier. This seems to be reflected in the choice of the dimensional model option in most of the recent approaches ([Kim96], [Bal98], [Hai95], [Jar2002], [Moo2000], [Sap98], [Win96],…).

2.2 The Subject perspective: Analysis direction

Two *analysis directions* can be taken while developing a DW : the top-down direction, and the bottom up direction.

In the *Top-Down direction*, the focus is first on the information needed to make decisions prior to the information available at the operational level. This approach is inspired from the Waterfall approach [Roy88] used in the CASE environments. The advantage of this approach is that it allows to limit the scope of the study as well as the system boundary. Experience has shown that this approach has several drawbacks [Nag93] such as: duration of the project, high cost, estimation of ROI difficult before the entire realization of the project.

Approaches that take the *Bottom-Up direction* are recommended for handling legacy systems. They consist in building Data Marts (DM: these are small DWs) first, which is faster than building a whole DW ([Inmo96], [Gol98], [Kim96], [Moo2000] approaches can be used to design DMs). Once DMs are operational, they can be federated into an enterprise wide DW. The advantages of Bottom-Up approach are its speed and easiness of use. Besides, the ROI appears immediately with the DMs. The development of new DMs is an easy way to make the whole system evolve. However, the uncontrolled proliferation of DMs can cause integration problems for building the enterprise DW. Another drawback is the difficulty of exploiting in each DM the data of the other DMs as long as the enterprise DW is not fully developed.

2.3 The Usage perspective: Analysis approaches

The purpose of the *Usage perspective* is to categorize the DW development techniques according to the approach used to analyse the system. This perspective is divided into two options: process driven and data driven.

(a) *Process driven* approaches are interested in the business processes by which DWs are populated or used as well as the decision processes during which DWs are exploited. The analysis of these processes can be driven by the requirements of each individual activity that they contain or driven by improvement goals.

User requirement oriented approaches generally propose guidelines for conducting user interviews. In these approaches, the DW is not designed to support small-scale query requirements but the decisions made in whole processes [Poe96].

Goal oriented approaches assume that the main issue of DW development is to decide which process to improve and what improvement should be made. Identifying the improvement goals helps determining the data needed to achieve the process improvement ([kim96, kim98], [Boe2000]).

(b) Data driven approaches consider first the sources of data upon which decisions are made. The priority is therefore to populate the DW. It is only when queries are submitted to the DW that data reconciliation and improvement of the DW schema are achieved. For example, Golfarelli and al. [Gol98] propose a methodology to semi-automatically build a dimensional data warehouse model from E/R models of legacy operational databases. These approaches are also often based on the analysis of the organization data model (e.g. [Inmo96]). However, in such approaches the needs of DW users are only taken into account after the DW is developed, at exploitation and continuous improvement time. The risk in inadequacy of DW developed using the data driven approaches is thus very high.

2.4 The Development perspective: Development techniques

This perspective considers the development technique used to design the DW schema. Nowadays, there are two development techniques used, the E/R model and the Dimensional model.

In the *E/R model* based approaches, DWs schemas are usually composed of flat entities (i.e. denormalized). The advantage is that the E/R formalism is well known by the designers. Extensions to E/R formalism have been proposed for better adequacy to the specific issues of DW development [Sap98].

The *Dimensional model* was introduced by Kimball [Kim96]. It applies a pattern in which there is a large table called "*facts table*" that dominates the others. This central table gathers operational data of the organization. It is combined with a number of "*dimensions tables*" that provide details on the operational data of the facts table. This formalism has the advantage to be clear and to offer an easy way to represent the measurement factors of the organization. Different patterns are proposed in the literature : star schema, snow flake model, constellation model, etc.

As shown in figure 4, in the *Star schema* dimensional model, the facts table is in the center and is connected to other dimensions by [1..n] relationships. This structure has the advantage of limiting the number of joints in queries. Several studies have also proven that the star schema dimensional model is the model that presents the best compromise in term of complexity and information redundancy.

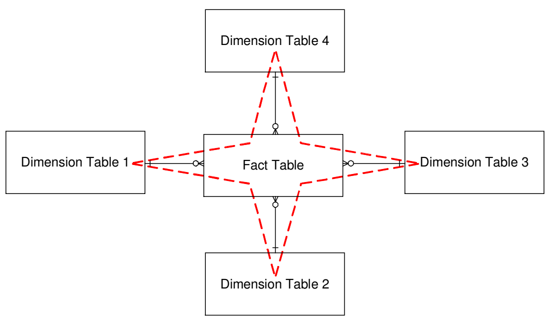

Figure 4: Generic structure of Star schema [Moo2000]

Similarly, in the *Snowflake schema,* there is a central fact table with normalised dimensions around it. Therefore, as shown in figure 5, each dimension is split into sub-dimensions.

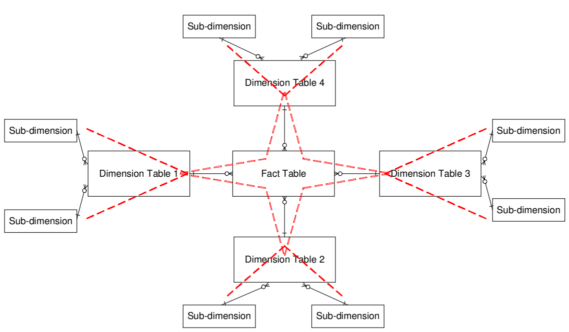

Figure 5: Generic structure of Snowflake schema

3. Discussion on existing DW development approaches

Based on the Framework presented in the former section, we reviewed 9 approaches found in the literature. Table 1 shows the characteristics of each approach by affecting yes/no values (ticks are used to characterise a yes) to each option available in the four perspectives provided by the framework.

Approach / Perspective	Option	Inmo96	Cabi98	Gol98	Kim98	Boe2000	Sap98	West2001
System	Table	✓	*	*		*	*	*
	Data Cube	✓	✓	✓	✓	✓	✓	*
Usage	Process driven/Goal oriented				✓	✓		
	Process driven / User requirements oriented							✓
	Data driven	✓	✓	✓			✓	
Subject	Top-Down				✓	✓		*
	Bottom-Up	✓	✓	✓			✓	✓
Development	E/R	✓						*
	Dimensional	*	✓	✓	✓	✓	✓	*

Table 1: Classification of some approaches

For example, in the data driven approach proposed by Inmon [Inmo96], the company change goals nor user requirements are neither not taken into account. There is therefore no information on how to ensure the adequacy of the DW schema to the usage of the DW. User needs are integrated only in the exploitation and maintenance phase. This may, of course, force designers to re-design large parts or even the complete DW. Such approaches are thus very likely to become expensive through requirements evolution.

Westerman's approach [West2001] is driven by DW user requirements. It proposes to analyse business processes through the decisions made in these processes. Then, these processes are prioritized and the most important of them are defined in terms of data structure needed to make decisions. The result is a number of services expected from the DW to support these decisions. The assumption is that the actual data will be available at the operational level to feed-in the structures. This is of course a strong assumption, and we believe that legacy data sources should be taken into account earlier in the process to avoid this risk.

Poe [Poe96] proposes a catalogue of high level guidelines for conducting user interviews in order to collect end user requirements. She recommends interviewing different user groups in order to get a complete understanding of the business. This approach is similar to Westerman's approach in that the guidelines that it proposed help understanding the requirements of the operational actors of business process.

On the contrary, Kimball's approach [Kim96] is focused on organizational improvement goals and ignores data constraints and operational users requirements. The idea is to grasp the goals of strategic decision makers that have to decide upon when/how to improve business processes. The object of the analysis is therefore the improvement intentions prior to the improved business processes. The top-down analysis

ends up with the identification of business objects managed in the changed business processes; these are modelled using pre-defined patterns of the dimensional model. Böhnlein and Ulbrich-vom Ende [Boe2000] present an approach that is based on the SOM (Semantic Object Model) process modeling technique in order to derive the initial data warehouse structure. The first stage of the derivation process determines goals and services the company provides to its customers. Then the business process is analyzed by applying the SOM interaction schema that highlights the customers and their transactions with the process studied. In a third step sequences of transactions are transformed into sequences of existing dependencies that refer to information systems. The last step identifies measures and dimensions.
Golfarelli's and Moody's approaches [Gol98] [Moo2000] are both data driven. The guidelines provided help analysing the data models of operational data sources and to transform them into dimensional models of the DW. These are bottom-up approaches in which both improvement goals and user requirements are ignored.

To sum up, three major observations can be drawn from our framework-based review of DW development approaches:
(i.) two main families of approaches can be distinguished : (a) top-down process-driven approaches and (b) data-driven bottom-up approaches;
(ii.) the majority of approaches are data-driven. Indeed, it is considered that while approaches in the first family are more appropriate to build enterprise-wide DW, those from the bottom-up data-driven family are easier to use and generate initial results faster;
(iii.) very few approaches are requirements-driven; this is mainly due to the time constraints imposed to DW projects and general belief that requirements-driven approaches are time consuming.
We observed in this review of (some of the) existing approaches that most of the works done in the DW development domain deal with how data should be structured, stored and managed in DWs. Only few approaches consider the services provided by DWs. Besides, we believe that these approaches have a number of drawbacks in common :

- Their usage is focused on one option at the exclusion of the other options available. All the approaches are either goal-oriented, or user requirements driven or data driven. None proposes to combine change goals to user requirements analysis or data analysis.
- These approaches are not or partially automated. There is for example very few detailed guidelines on how to transform DW requirements into a conceptual DW model, or how to elicit DW requirements through user requirements analysis or goal analysis.
- These approaches are based on the expertise of DW designers; none of them proposes to capitalise knowledge from one project to another.

This review of existing approaches is not complete in the sense that:

- not all existing approaches have been classified yet
- the framework on which it is based is still shallow and can be considerably enriched to refine our understanding of the common aspects of and differences between DW development approaches.

However, we used the aforementioned observations to lay out the process model of our approach.

4. The approach

As shown in figure 6, our position is that of a DW development approach that uses both business process requirements, strategic decision processes and improvement goals, and operational data models of existing systems. Besides, our proposal is to combine DW requirements to DW models (ℝ). On the one hand, *DW requirements* can be elicited using both business process requirements (i.e. by analysing the usage of the future DW in the decisions made in To-Be business processes) and strategic decision processes and improvement goals (i.e. by analysing the usage of the DW to make strategic decisions about change). On the other hand *DW models* are produced using a combination of DW requirements and As-Is data models. Therefore, while the DW requirements are elicited in a top down fashion, the operational data models are drawn in a bottom up fashion to produce the DW data models.
Once produced, DW data models can also be used to elicit new requirements. This can be based on the exploitation of the similarities between requirements for DW systems to be used within the same domains, as well as on the possibility to transpose patterns of DW design solutions from one domain to the other .

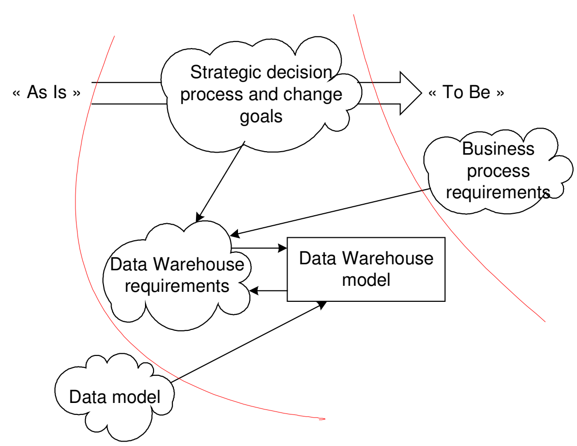

Figure 6: A product view of the position taken on DW development methods

On the process point of view, our method is developed around two main goals : elicit requirements, and design DW models.

The main usage of DW is decision making. Therefore, we believe that *decision analysis* has to be the main strategy to guide DW requirements elicitation. Similar techniques should be used to analyse the decisions made in business processes and the decisions made in strategic decisional processes. The models used can for instance be adapted from the NATURE process meta model (that defines a process as a set of decisions to be taken in the context of different situations and goals) [Grosz97], or from the MAP process meta model (according to which process models should integrate the decisions of which goal to achieve as well as how to achieve it) [Benj99]. Further adaptations for a better adequacy to the needs of DW usage processes can also be inspired from decision theories such as [Roy85], [Roy93], [Ash95].

In addition to the decision analysis strategy, we propose to guide requirements elicitation with a *reuse-based strategy* and an *improvement strategy*. Domain-based reuse strategies are already proposed in packaged solutions e.g. with ERPs. The idea is to provide with the operational systems a pre-defined DW that can be adapted. New requirements can be elicited in reference to the existing solution supplementary however guidance is needed to elicit those requirements and to concretise them into the adapted DW.

The idea behind the improvement strategy is that once developed, a DW should be validated. When it is found that the solution does not adequately support the decision-making processes then a new requirements analysis should be undertaken and changes made to the DW.

Once the requirements are elicited, they can be used to *design the DW model*. This can be done:

(i.) *by matching* them with existing data models of the operational data sources (after transforming them into an equivalent formalism).

(ii.) *by mapping* them into a DW model using mapping rules. Contrary to the former strategy, such mapping rules must be independent of the data available in the operational data sources.

(iii.) by directly using the information available at the data-source level, and without taking requirements into account. This *data driven bottom-up* strategy is the one proposed by [Inmo96]. It is only during the improvement phase that requirements are elicited to make the DW system evolve.

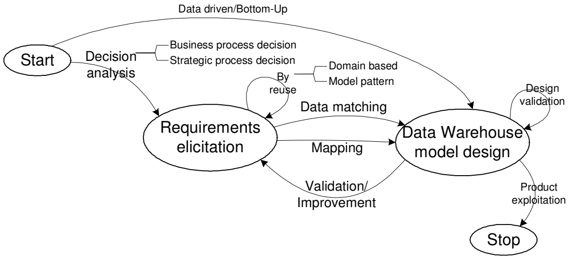

Figure 7: Process view of the position taken on DW development.

We have already developed parts of this approach. In particular, in [Fren2002] we proposed to use the requirements elicitation method *L'Ecritoire* to draw requirements in the form of business process goals. Guidance was proposed under the form of a semi-automated rule that analyses the scenarios documenting goals and maps them into an E/R DW model. Additional guidance was given to translate this E/R model into a dimensional DW model using Moody's approach [Moo2000].

The approach is not complete. However, we already evaluated it and found that:

• it is very partial and does not yet fully combine the advantages of the requirements-driven approach to those of the data-driven approach;

• it is time consuming; transitory E/R models are un-necessary and the guidance could directly aim at dimensional models; there is also a risk of loss of information in the transition from E/R to dimensional models;

• the goal-scenario approach used in *L'Ecritoire* is efficient to elicit requirements, but could be enriched for better adequacy to the specific issues of decision making in strategic and business processes; the decisions and the information needed to make decisions could for instance be made more explicit;

• this approach does not exploit the information provided by existing operational data-models. We believe that data sources could provide early in the process useful information on the availability of information to support decisions with the DW.

5. Conclusion

Data Warehouse development is not new. It started in the early of 80' and all large organizations now have DWs to support their strategic and business decisions. In a recent study [Nag93] of DW development and use experiences, "*managing the expectations of users and management*" was quoted as one of the six "*outstanding issues and challenges associated with data warehouse*". Our goal in this paper was thus double :

(i.) to improve our understanding of the gaps of existing DW development approaches, and

(ii.) to lay out an innovative requirements-based DW development approach that would fill those gaps.

Our review of DW development is structured according to a framework. This framework is composed of four perspectives on DW development, each perspective identifies a number of options that are used in the existing approaches. The use of the framework in our review allowed to identify two large families of approaches: process-driven top-down approaches and data-driven bottom-up approaches. Both families of approaches have advantages and raise specific issues; there is to our knowledge no approach that tries to solve these issues by combining the strategies used in each family. Of course, the framework has to be improved (by introducing more options in each view or by refining the existing options); more approaches should also be analysed for a more exhaustive review.

One major issue that we met in all approaches is the lack of guidance of the requirements engineering part of the DW development process. Our position is to guide requirements analysis by combining the DW user point of view and the operational system point of view. The former stands in the top-down analysis of decisions made in strategic or business processes while the latter introduces bottom-up analysis of the operational data used in business processes.

In the system perspective, we aim at an approach that is technology–independent: the DW data models should be usable to produce data cubes or tables indistinctively. This transition is however outside the scope of our proposal.

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