Developing Data Warehouse Structures from Business Process Models

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Abstract. In recent years data warehouse projects have become popular to most companies. Unfortunately many of these projects come to grief due to missing engineering strategies and modeling standards. The common method for developing multidimensional data structures is deriving relevant datasets from underlying operational data sources. But in fact developing large data schemata for decision support applications requires more knowledge about the underlying business domain. It is obvious that for efficient decision making an approach is required which additionally takes into account the goals and corresponding services of a company. This information can not be extracted by analyzing the operational data sources. We realized that commonly applied business process models can be used to handle this problem. In this paper we present an approach to warehouse development – the derivation of data warehouse structures from business process models.

1. Introduction

During the last decade data warehouse systems have become an essential component of modern decision support systems in most companies. Data warehouse systems offer efficient access to integrated and historical data from different, partly heterogeneous and autonomous information sources, to support managers in their planning and decision making.

In spite of the advantages of data warehouses, many projects fail due to the complexity of the development process. Building a data warehouse is rather different from the development of conventional operational systems; not only the structures of the underlying source systems have to be considered but also the goals and strategies of the company.

One major problem in building a data warehouse is to identify and consider information needs of potential users. Often they are not able to formulate their demands either. Faced with the same problem we realized that commonly used business process models can help to specify the informational requirements of a company. Business processes play an important role in analyzing and designing a company's behavior and organization. A data warehouse is designed according to a set of relevant business subjects [6] and each of these subjects centers around a business process. A warehouse is built to answer the questions being asked throughout the business every day, questions not focused on individual transactions but on the overall process [1]. Decision making needs metrics to evaluate business

processes according to the goals of the business. Such metrics are used in every organization to monitor business processes.
In this paper we describe a new approach to data warehouse design: the derivation of data warehouse structures from business process models. Obviously this approach bases on the *nominal* information requirements of the company as a whole.
Before building the real warehouse the result of our approach has to be compared with the *actual* information offered by the operational data sources which is not presented in this paper. But furthermore due to the difference of such a comparison, our approach shows possible extensions to the source systems for better decision making.
We explain the connection between business process models and data warehouse structures using an example: a simplified business process model of a typical German student management system. Because of a missing standard for a conceptual data warehouse model, in this paper we use the star schema to describe the resulting logical multidimensional models.
The following section shows the related work of data warehouse development strategies (not mentioning the different conceptual data warehouse models) and gives a brief introduction to the business process modeling technique SOM (Semantic Object Model) that is used throughout this paper. The derivation of the exemplary business process model is shown in section 3. For a better understanding the section starts with a short introduction to the study and higher education system at German universities. The paper concludes with a summary and an outlook on future research topics.

2. Related Work

After a short overview on existing development techniques for data warehouses we give a brief introduction to the business process modeling technique SOM.

2.1 Other Approaches

Yet there is no common strategy for the development of data warehouses from business process models. Nevertheless we describe some techniques for building a data warehouse mentioning both advantages and disadvantages:

- **User oriented warehouse development:** Most authors like HOLTHUIS [15] describe an informal way of constructing data warehouse structures. It is obvious, that the significant metrics are based on the company's critical success factors. These factors depend on the company's management strategy and goals. The corresponding dimensions relate to influences on the critical success factors. Yet there is no predetermined path to get these factors. In a more concrete way, POE [22] describes the use of interviews in gathering the informational requirements. To obtain complete understanding of the business she recommends to interview different user groups. The major problem with user oriented warehouse development is the potential ignorance of the users. According to our experience no user can describe his requirements exactly. Basically most users have only a slight idea of their demands as well as most users haven't seen a data warehouse resp. an OLAP front-end tool before.

- **Operational oriented warehouse development:** A more concrete warehouse development strategy is to analyze the data models of the underlying operational sources and to identify the relevant transactions [2]. For example GOLFARELLI et al. developed in [13] and [14] a semi-automated methodology to build a data warehouse from pre-existing ER schemata which describe an operational information system. We extended this approach ([3], [4]) to show the usability of the SERM (*Structured ERM*) [23] an extension of the ERM. The major problem with operational oriented warehouse development is the restriction of data models. Data models specify the business of a company incompletely.
- **Business process oriented warehouse development:** KIMBALL described the need for a business process oriented development strategy ([16], [17], [18]). So far no concrete approach has been published. A major advantage of the business process oriented development strategy is that the business process model contains a formal description of the informational requirements of the users. Another advantage is the possibility to identify informational requirements that could not be satisfied with the actual information offerings of the source systems.

2.2 Semantic Object Model (SOM)

The Semantic Object Model (SOM) is a comprehensive and integrated methodology for business engineering ([8], [9], [10], [11], [12]). It supports sound modeling of business systems and can be used for analysis and design. A business system is understood as an open, goal-oriented and socio-technical system [8]. The enterprise architecture builds the essential backbone of the SOM methodology (figure 1). It is an architectural framework for business processes which is split into three layers. The different layers of the enterprise architecture help to build flexible and manageable business systems. Each of them looks at the whole system under a specific viewpoint to manage complexity:

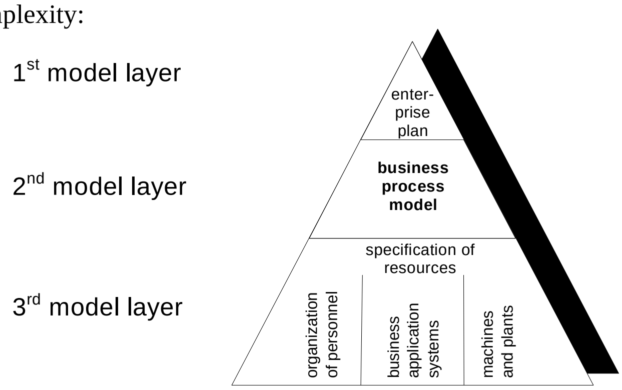

Fig. 1. Enterprise architecture [11]

Enterprise plan: It demarcates the system which is to be modeled from the system environment. Furthermore it distinguishes between two kinds of goals of business systems. While one kind specifies the products and services to be provided, the other determines to which extent the goals have to be pursued.

Business process model: The business process model specifies a procedure to carry out the enterprise plan. It consists of a distributed system of business processes. They contain autonomous and loosely coupled components which cooperate in pursuing the system‘s joint goals to produce products and services and deliver them to the customers. There are main and service processes. While main processes contribute directly to the goals of the business system, service processes provide their output to other processes.

Specification of resources: This layer deals with the specification of resources for carrying out the tasks of business processes, especially organization of personnel, business application systems and machines or plants.

Now we intensify the understanding of the layer of the business process model. A business process is described by business objects which are connected by business transactions. Each business process can be described by three characteristics: (1) It participates in the production and delivery of one or more kinds of services, (2) it coordinates the business objects through transactions which are involved in the production and delivery of these services and (3) it describes the sequence of tasks which are carried out when performing the process.

The first two structural characteristics are represented in a semi formal diagram called interaction schema, the third behavioral one in a task-event schema (figure 2). The understanding of a business process is often restricted to its third characteristic, the behavioral aspect. Extending the notion of a business process to structural characteristics leads to a more comprehensive view of the business:

Interaction schema: An interaction schema focuses on the static structure of a business process. It consists of business objects and transactions. A business object comprises a set of tasks pursuing joint goals. Business objects are connected by transactions and each transaction is performed by exactly two tasks of involved business objects. Therefore tasks drive transactions. Business objects and corresponding transactions can be decomposed to a more detailed level. We distinguish between two essential coordination principles used within decomposition:

- **negotiation principle**: Using the negotiation principle a transaction between two business objects is decomposed into three successive transactions (1) an initiating transaction (i), where the involved business objects get in contact with each other and exchange information on deliverable services, (2) a contracting transaction (c), where both objects form an agreement on the delivery of services, and (3) an enforcing transaction (e), where the objects exchange the service.
- **feedback control principle**: A business object is decomposed into two sub-objects and two transactions, a controlling and a servicing object as well as a control (r) and a feedback (f) transaction. These components establish a feedback control loop.

Task-event schema: The task-event schema represents the dynamic behavior of a business process. It consists of tasks, transactions and events and shows the sequence of tasks to be performed by the business objects. To simplify the assignment of task names, they are initialized by “>task” or “task>” meaning sending or receiving the corresponding transaction. Task-event schemata are based on the petri-net concept and can be formally translated into petri-nets [8].

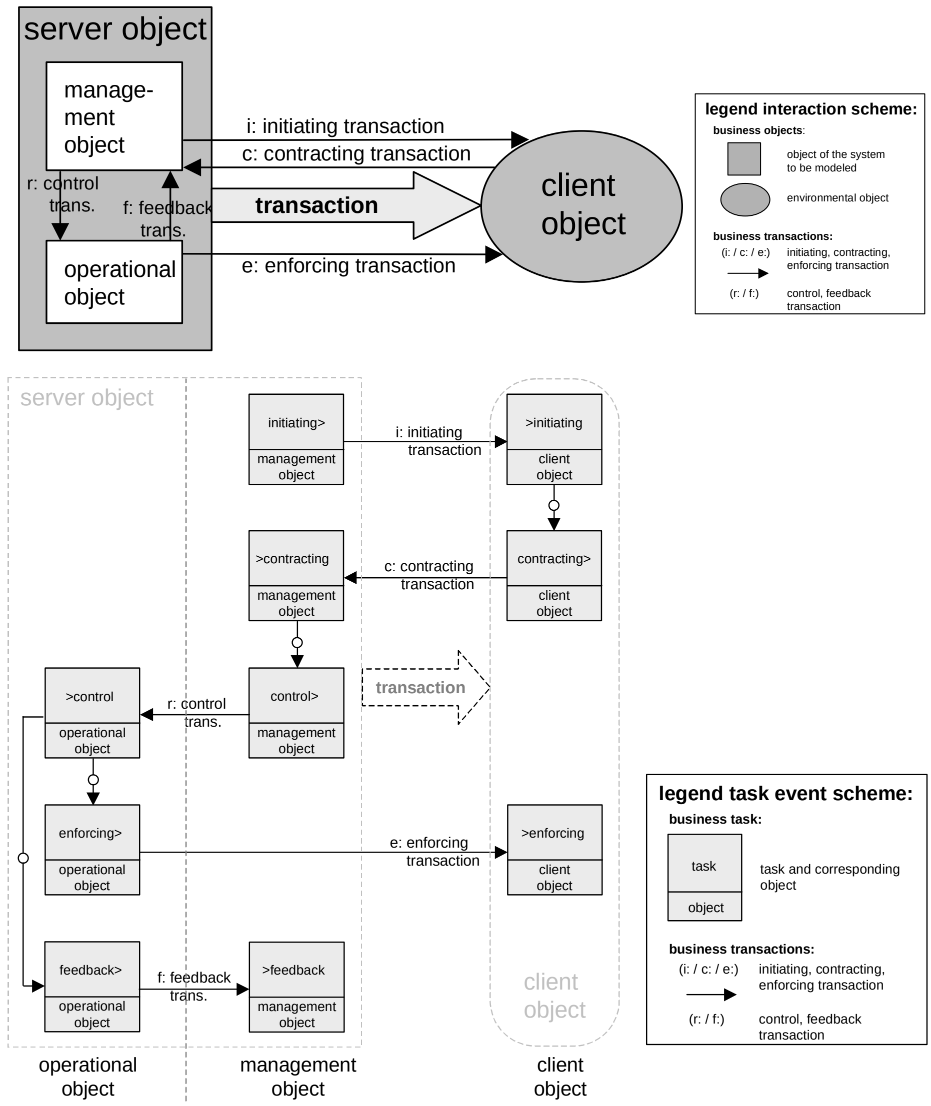

Fig. 2. Interaction schema and corresponding task-event schema (according to [8], [9], [11])

3. Derivation of Initial Data Warehouse Structures from Business Process Models

3.1 Introduction to Study and Higher Education at a German University

We show the application of our approach by a typical business process model of a German university [24]. The model is based on results of the project OptUni (optimization of university processes) ([19], [20]). An university can be understood as a service provider. The services *higher education* and *research* are immaterial in nature because they demand to obtain scientific knowledge. Besides they are not storable and the customer especially the student participates directly in the service. An university is organized by main and service processes (figure 3). Two main processes can be revealed. Each takes care of specific customers of the university. The process *study and higher education* provides the service of *higher education* to *students* and the process *research* provides *research activities* to interested *research partners*. Several service processes like *budgeting*, *staff* and *library* help to fulfil the goals of the main processes by providing special services. In the following we focus on a simplified extract of this whole business process model, the main process *study and higher education,* to describe the basic ideas behind our approach.

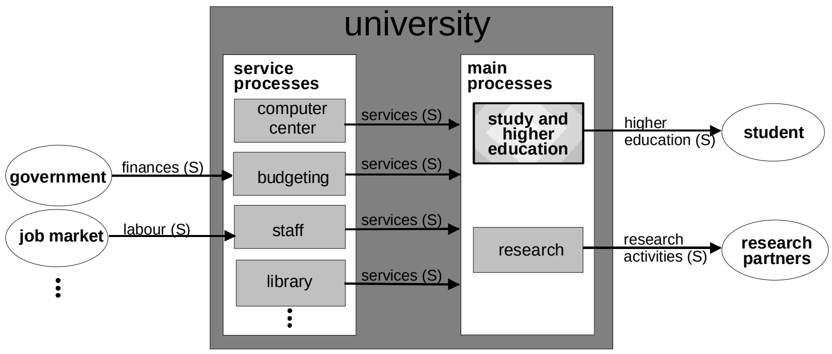

Fig. 3. Business process structure of an university (following [19])

3.2 The Derivation Process

We now introduce a business process oriented model of action to derive initial data warehouse structures. The suggestion is based on the comprehensive business engineering methodology SOM of Ferstl/Sinz ([10],[11]). The approach comprises four major stages (figure 4). While the first three stages correspond to a large extent with the SOM methodology [8] and are specialized to fit the needs of data warehousing, a completely new fourth stage is added which allows a smooth identification of data warehouse structures.

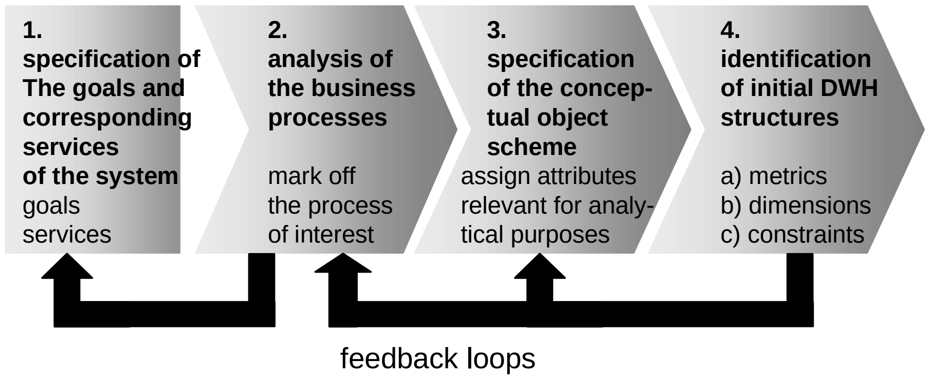

Fig. 4. Main stages in the derivation process

After identifying the goals of the system (stage 1), the network of business processes is analyzed to get a deep understanding of the application domain (stage 2). A business process is marked off for further consideration. Next we derive a so called conceptual object schema (COS) from our marked off business process (stage 3). A COS is a conceptual data schema enriched with object-oriented concepts. It describes all data structures necessary to accomplish the selected business process. To obtain an initial COS we transform as much information of the business process model as possible to the level of the application system. Within the COS we are able to identify initial data warehouse structures (stage 4). They are visualized by star and snowflake schemata. When applying the derivation process we follow the chain of argumentation: goal - business process - service- metric - dimension. In the following section the four stages are described in detail. There are explicit feedback loops between the stages which are also explained in the following.

3.2.1 Specification of the goals and corresponding services of the system

First we specify the goals and corresponding services the university provides to its customers. We distinguish between two kinds of goals. While one kind specifies the products and services to be provided, the other determines to which extent the goals have to be pursued. Finding goals is a complex and creative process. Therefore we have to consider manifold requirements of different spheres of interest from within and outside the university. The government and the ministry for example prescribe general conditions by law and ordinance. Furthermore the university's goals are influenced by the management of the university, the students as well as the public. In the following we consider only two environmental conditions when we specify the goals of the university. These are two essential laws for Bavarian universities prescribed by the government: the "Hochschulrahmengesetz" (HRG) and the "Bayerisches Hochschulgesetz" (BayHSchG). While specifying the goals, the modeller has to be aware that goals can be connected in different ways. They can be indifferent to, in conflict with or complementary to other goals. Only goals which can be quantified are operable and can easily be decomposed to sub-goals. Without describing these goal relations in further detail we exemplarily show four high granular goals of Bavarian universities. These goals correspond to the already mentioned HRG and the BayHSchG:

1. Providing science related higher education through study and teaching (§21 HRG and section 2 I BayHSchG)
2. Preparation of students for their occupation to apply scientific knowledge and methods (§2 I BayHSchG)
3. Promote international cooperation through study exchange between German and foreign universities (§2 VI HRG and section 2 V BayHSchG)
4. Make councelling centers available (§4 II HRG and section 55 II BayHSchG)

According to our initial business process model in figure 3 the main services of an university are:

1. Higher education for students
2. Research activities and cooperation with research partners

The following now exemplarily focuses on one of the goals mentioned above. Therefore we chose the goal *providing science related higher education* through study and teaching for further consideration. This goal complies with the main service *higher education* for students. By analyzing und detailing the corresponding business process we generally reveal sub-services of a finer granularity which enable us to gain a deeper understanding of the underlying business domain and of candidates for a proper data warehouse structure. When we perform the derivation process we have to keep the following chain of argumentation in mind: : "goal –business process - service – metric". Which services does the university offer to reach its goals and how can this service be measured?

3.2.2 Analysis of the business processes

We now have to examine the business processes and mark off the process of interest. Processes describe a procedure to realize the system of goals and corresponding services of an university. Thus they provide a solution to an university plan. We distinguish main and service processes. While main processes contribute directly to the goals of the university and provide a service (*higher education and research activities*) to the customers (*students* and *research partner*), service processes help to fulfil the services of main processes and make supporting services available. For our example we have to mark off the business process which corresponds to our chosen goal *providing higher education*. The main process *study and higher education* complies with our goal and is selected for further consideration. In order to proceed detailed knowledge about this process, its sub-services and specific characteristics of the application domain is required. Figure 5 shows a more detailed view of the interaction schema of figure 3 describing the process *study and higher education*. The decomposition rules negotiation and feedback control principle from section 2.2 have been applied several times. Analyzing the business process more detailed can often reveal important sub-services within the main service *higher education*. In figure 5 transactions which provide services can be distinguished from the remaining transactions by the letter S in brackets. Now we explain the order of events and transactions (visualized by numbers in brackets) and the participating objects of the business process *study and higher education*. The corresponding task-event schema describing the order of transactions and events in more detail is shown in figure 8 in the appendix.

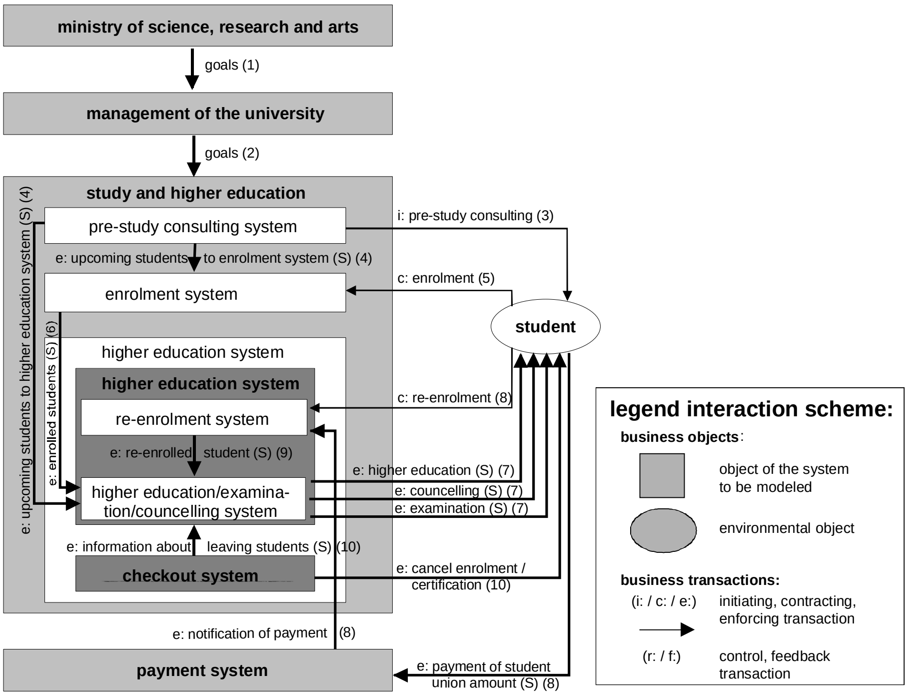

Fig. 5. Interaction schema of the business process *study and higher education* (following [20])

The *ministry of science, research and arts* prescribes the *goals* of the universities in Bavaria (1). These goals are refined and realized by the *management* of each university (2). To provide *higher education* to *students* the business object *study and higher education* has to be decomposed. Decomposing often reveals sub-services within a business process. First the *pre-study consulting system* helps the *student* to become acquainted with the university and its offered subjects (3). It provides the sub-service *information about upcoming students* to *the higher education/examination/councelling system* and the *enrolment system (4)*. The *enrolment system* reports *enrolments* with *students* (5) as the sub-service *enrolment information* to the *higher education/examination/councelling system (6)*. The *higher education system* can be decomposed to an *higher education/examination/councelling system*, *a re-enrolment system* and a *checkout system*. We don't consider a further decomposition of *the higher education/examination/councelling system*. It provides the main services *higher education*, *examination* and *councelling (7)*. Each semester students have to inform the *re-enrolment system* that they want to continue their studies and pay a fee to the *payment system (8)*. The *re-enrolment system* informs the *higher education/examination/councelling systems* about the current number of re-*enrolled students (9)*. *The checkout system* informs the *higher education/examination/councelling system* about *certification* and *cancels of enrolments (11)*. After the short description of the process *study and higher education*, we derive the conceptual object schema (COS) from the interaction and task-event schema in the next step.

3.2.3 Derivation of the Conceptual Object Schema (COS)

Our goal is to transfer as much information as possible from the second layer (business process model) to the third layer (specification of resources) (figure 1). To derive multidimensional data structures only the area of business application systems is of further interest. The specification of organization of personnel and machines or plants is dropped. The area of the business application system is described by a so called conceptual object schema (COS) and a schema of task classes. Data structures are part of the COS. Therefore we transform the information already contained in business process models to data structures conforming to the COS. A COS can be understood as a conceptual data schema in the Structured Entity Relationship Model (SERM)-notation [25] which is enriched by object oriented concepts. The SERM is a comprehensive extension of the Entity Relationship Model (ERM) ([5], [25]). Conceptual entities encapsulate the states of tasks of a business object as well as the states of corresponding transactions and services. A special characteristic of the COS is the visualization of existence dependencies. Independent entities are located on the left hand side of a COS, dependent entities on the right hand side of the schema. This concept leads to a sequential increase in dependence between entities from left to right. For example *enrolment* depends on *pre-study consulting* which depends on *student*.

The initial structure of the schema of conceptual classes is derived from the most detailed level of the interaction schema (figure 5) in conjunction with the task-event schema (figure 8 in the appendix) of the corresponding business process model. We apply the following transformation rules leading to figure 6:

- Business objects are independent and can be visualized as conceptual entities on the left hand side of the diagram. Therefore the business objects *higher education/examination/councelling system*, *pre-study consulting system*, *student*, *enrolment system*, *re-enrolment system*, *checkout system* and *payment system* are shown one below the other on the left hand side of the diagram.
- Transactions depend on corresponding business objects and are visualized as dependent entities on the right hand side of the conceptual entities representing these business objects. Further they are connected by "interacts with" relationships commonly referred to as "edges". The initiating transaction *pre-study consulting* depends on the business objects *student* and *pre-study consulting system*.
- The task-event schema provides an executing order for transactions. Sequences of transactions are gradually transformed into sequences of existence dependencies between conceptual entities. Conceptual entities representing transactions are not connected directly to their corresponding two business objects when there is an

indirect connection with already transformed transactions possible. *Information about upcoming students to enrolment system* depends on the *enrolment and pre-study consulting system*. There is an indirect connection with *pre-study consulting* to the *pre-study consulting system* available. The other transactions are derived analogously.

If required the COS can be further refined ([10], [11]). Sometimes it's helpful to consider the cardinalities of the relations between conceptual entities.
To prepare the fourth step we have to assign attributes to the conceptual entities. To manage complexity you should confine yourself to attributes relevant for analytical purposes only. Interviewing selected executives like the chancellor or the vice chancellor can be decisive for reducing the number of relevant attributes for decision making. We exemplarily mention relevant attributes for the following three object types in the COS: *student*, *pre-study consulting* and *enrolment*. We assign for example attributes like *age*, *nationality* (*city*, *state*, *country*), *gender* to *student*, *date*, duration in hours to *pre-study consulting* and *type of enrolment* (*first* or *new enrolment*), *faculty*, *subjects* to *enrolment*.

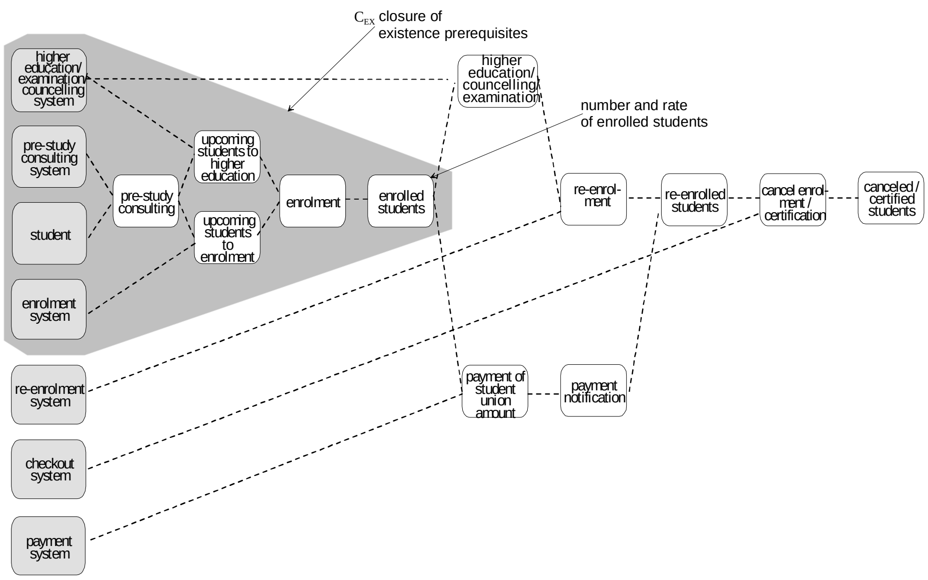

Fig. 6. Conceptual object schema (COS)

3.2.4 Identification of initial data warehouse structures

Next we derive initial data warehouse structures from the conceptual object schema specified in stage 3. Because there is not a generally accepted standard for the conceptual modeling of data warehouse structures yet, we use a common logical modeling technique, the star schema [21], to represent our data warehouse structures.

Further it is rather indifficult to transform a star schema to a snowflake schema or a variant of both techniques if required.

Identification of metrics

The importance of business processes can be evaluated according to their contribution to the services and goals of the university. We have to find appropriate metrics to rate these processes. Now let us start from the data structure of the COS. We first specify metrics by following the chain of argumentation: "goal - business process - service - metric".
In our example we considered the goal *providing higher education* to students for further consideration (stage 1, confer section 3.2.1). In stage 2 (confer section 3.2.2) we analyzed the corresponding business process *study and higher education* and its main service *higher education* in detail. While decomposing the business process we revealed many new sub-services which also correspond to our selected goal. It is essential to consider that enforcing transactions transfer services to find metrics. There are enforcing transactions for *information about upcoming students to the enrolment system or the higher education system, enrolled students, re-enrolled students, information about leaving students and higher education/ examination/councelling*. Although we can find appropriate metrics for each of these sub-services we will only concentrate on the sub-service *enrolled students* (enrolment service) in the following. As a prerequisite for the identification of data warehouse structures we derived the inital COS of this process and assigned relevant attributes in stage 3 (confer section 3.2.3). Now we look for metrics and corresponding dimensions to rate the chosen service of this business process according to its specified goals in stage 4.

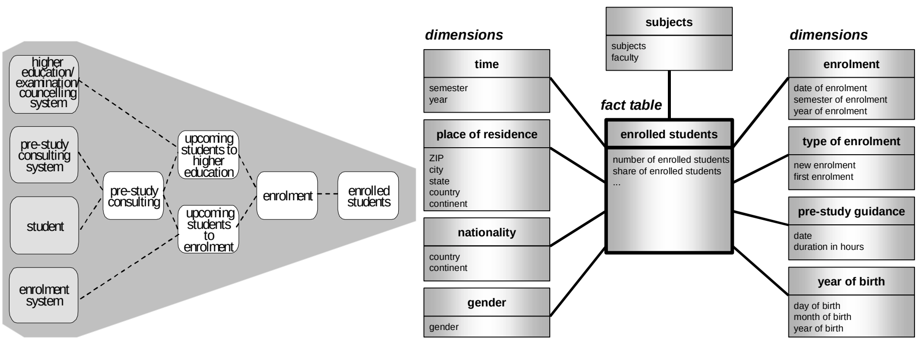

Fig. 7. COS and corresponding star schema

How can the offered service be measured? Service performance and achievement of the set goal should be evaluated through adequate quantitative metrics. The enrolment can be measured for example by the two metrics: number and rate of enrolled students. We distinguish between basic and derived measures. With additional information about the number of actual students we can compute the rate of enrolled students from the number of enrolled students and the number of actual students. Now we assign the metrics to the conceptual entity *enrolled student* representing the corresponding enforcing transaction (figure 6). Transaction based conceptual entities represent “transactional data” and are therefore located on the right hand side of the diagram, because they depend on rather structural entities located on the left hand side. Each metric forms an attribute in the center of a star schema (figure 7). Because there are often many sub-services within a business processes, several metrics can be specified. Several metrics can also be specified for a single service if required. To find further metrics the described process has to be repeated for other sub-services.

Identification of dimensions and dimension hierarchies

The visualization of existence dependencies in the COS helps to identify potential dimensions and dimension hierarchies. In the following we only consider these object types of the COS which contain information about potential dimensions and dimension hierarchies. All conceptual entities which are existence prerequisites of the conceptual entity representing the metrics are of interest for dimensions or dimension hierarchies. Therefore we determine the closure of existence prerequisites C_{ex} (gray shaded in figure 6). Starting with the conceptual entity of the metrics we follow the edges from right to left and gradually enclose all conceptual entities which are directly and indirectly existence prerequisites of the starting entity.

C_{ex}= {*enrolled student*, *enrolment*, *information about upcoming students to the enrolment system*, *information about upcoming students to the higher education system*, *pre-study consulting system*, *higher education/ examination/ councelling system*, *pre-study consulting system*, *enrolment system*}

Defining dimensions and dimension hierarchies requires creativity and considerable knowledge of the application domain and cannot be described by a formal algorithm. A detailed description with commonly applied rules is provided in ([3], [4]). Information about dimension candidates can either be derived by examining object types and their relations or by considering the attributes of the object types. In the following we focus only on examining attributes, especially those we assigned in section 3.2.3. Rules for deriving dimensions from object types and their relation can be found in ([3], [4]).
Therefore we examine the attributes of the conceptual entities of C_{ex}. We choose those attributes which are appropriate candidates for dimensions or dimension hierarchies. Discovered dimensions or dimension hierarchies are added to the star schema when they fulfil analytical purposes. The conceptual entity *enrolment* can contain attributes like *new enrolment*, *first enrolment*, *subject*, *faculty*, *date of enrolment*, *semester* and *year of enrolment*. This leads to the dimensions *enrolment*, *type of enrolment* and *subject*. The conceptual entity *pre-study consulting* contains attributes about *date* and *duration* of pre-study consulting which leads to a dimension of the same name. *Year of birth*, *place of residence* and *gender* are examples of dimensions concerning the conceptual entity *student*.
Besides often heuristic information can be helpful to add additional dimensions, for example standard dimensions of the application domain or a time dimension. Here we add a time dimension with the granularity of semester to the star schema to provide a historical context.

The logical star schema can easily be transformed to physical tables. On the physical layer you additionally have to consider indexing, partitioning and materializing aggregates (so called materialized views) which is beyond the scope of this paper.

Identification of constraints

When considering complex schemata one will come across shared dimensions between metrics. These shared dimensions should always contain the same information within a business process. Don’t use two different time dimensions within a business process for example.
Besides we have to consider aggregation functions along the dimension hierarchies. The elements of a lower hierarchical level are summarized to a higher hierarchical level. This consolidation rules can not be represented in standard star and snowflake schemata. Metrics can be classified as additive, semi-additive and non-additive based on these aggregation functions according to their dimensions [16]. The metric *number of enrolled students* is non-additive according to the time dimension in figure 7. Summarizing enrolled students over several semester provides meaningless results. Besides aggregation functions are not always as simple as summarization. Median, average, variance and standard deviation are often used as well and must explicitly be specified.
The described model of action contains explicit feedback loops to previous stages which help to refine the model or actively react on changes (figure 4). Between the stages 2, 3 and 4 a direct feedback relationship can be identified. If we measure goals we always have to reconsider the corresponding services. Therefore there is only a transitive relationship between stage 3 or 4 and stage 1. Changes can be triggered by the university or its environment. It is also necessary to pass through the same stages again when changes on goals and services occur because new metrics or dimensions need to be defined. Constructing data warehouse structures is a recurring and evolving process. Before building the data warehouse the results of our approach has to be compared with the information offered by the operational data sources. Therefore deviations of information offerings from information demands could lead to an extension of the operational sources.

7. Summary and Outlook

In this paper we presented a new business process oriented approach to the development of data warehouse structures. We suggested a comprehensive modeling technique which does not only focus on a certain aspect of the business. We use business process models instead of operational data models to derive initial data warehouse structures. Metrics specified in our model help to measure the efficiency of business processes according to the services and goals of the business. The chain of argumentation: "goals - busines process - services - metrics" ensures a consequent orientation on the system of goals. This leads to metrics and dimensions which are of major importance for executives. Before building the real warehouse the result of our approach has to be compared with the *actual* information offered by the operational data sources.

Empirical background of our approach is the CEUS^{HB} project (Computerbasiertes Entscheidungsunterstützungssystem für die Hochschulen in Bayern - Computerbased Decision Support System for the Universities of Bavaria). In this project we are developing a hierarchic distributed data warehouse system for the Bavarian universities. We have shown a short extract of our work using the example of the business process of *study and higher education*. The derivation process is continuously refined and applied on the service processes *staff* and *budgeting*.
Because star schemata are based on relational database management systems, they seem to be not suitable to represent data warehouse structures on a conceptual level. Further research should involve developing a conceptual modeling technique to visualize the information demands of the user adequately. Futhermore we plan to integrate our model of action in the existing SOM tool [12].

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Appendix

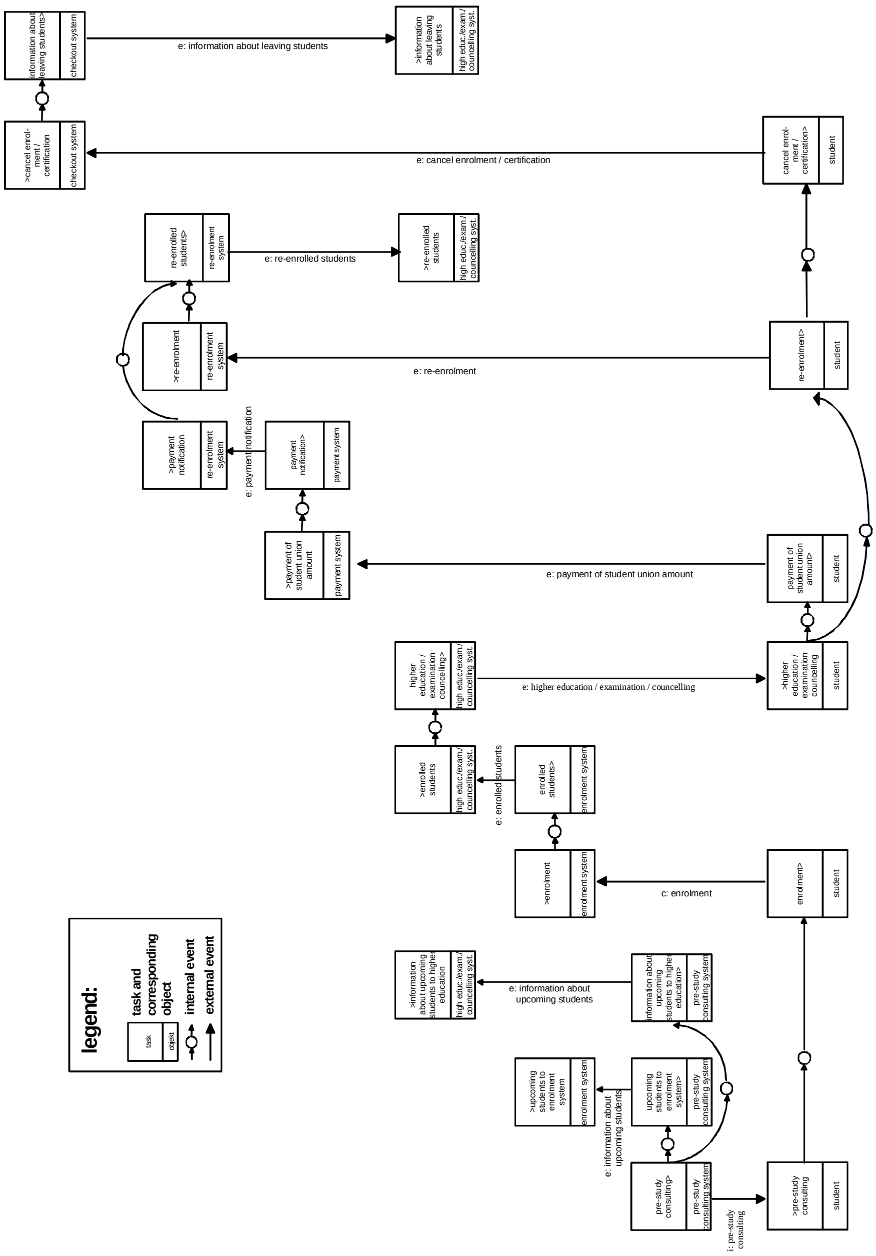

Fig. 8. Task-event schema of the business process study and higher education