IMPROVING DATA QUALITY CONTROL IN THE XPLAIN-DBMS

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ABSTRACT

This paper discusses the usability of convertibility, a principle for data quality used by the Xplain-DBMS. Convertibility (uniqueness) of type definitions is a helpful criterion for database design, whereas convertibility of instances is a criterion for the uniqueness of instances (records). However, in many situations with or without generalization/specialization, convertibility appears to be an insufficient criterion for correctness of instances, which is illustrated by many examples. In order to be able to specify more rigorous rules for correctness of instances we propose to use new concepts such as 'identifying property'. These new concepts also facilitate the transformation of relational databases into Xplain databases.

Keywords: Convertibility, Entity correctness, Generalization, Specialization, Transaction, Xplain-DBMS

1 INTRODUCTION

Data Base Management Systems (DBMS) offer sharing of integrated data (reducing data redundancy) and maintenance of entity integrity (correctness) and referential integrity on the basis of a conceptual data model and restrictions complying with organizational structure and information needs (Elmasri & Navathe, 2010; Connolly, Begg, & Strachan, 1995). Databases are the core of many information systems and can contain enormous data collections (terabytes to petabytes) that are vital for many large organizations, such as the U.S. federal government, insurance companies, NASA, UPS, etc.

An essential part of a database is a conceptual data model that defines its logical data structure. For example, in a relational DBMS a project database of some organization can be based on the following data model, specified in terms of relations and attributes (an informal specification without value domains):

relation project (<u>proj#</u>, description, starting_date, final_date);
relation employee (<u>emp#</u>, name, address, town, birth_date, salary);
relation work (<u>work#</u>, *emp#*, *proj#*, date, worked_hours);
relation invoice (<u>inv#</u>, description, date, amount).

Here an underlined attribute is a primary key (its value must be unique), whereas foreign keys are presented in italic type face (their value must exist among the primary key values of the referenced relation). Foreign keys are essential for maintaining referential integrity, which means here that records of the relation "work" must contain foreign key values already existing in a record (tuple) of "employee" (emp#) and a record of "project" (proj#). Moreover, records may not be removed from the database as long as they are referenced by other records. Using the relational language SQL we can define such a model including explicit constraints for primary and foreign keys.

An option is to apply a "NOT NULL" statement, which is mandatory for primary keys, but not for other attributes, including foreign key attributes. In the last case the interpretation of "null" probably is "unknown" or "irrelevant". However, a foreign key having a "null" value is violating referential integrity. Maintaining referential integrity is essential for calculating derivable data such as the sum of worked hours for each project, therefore it makes sense to add a "NOT NULL" rule to the definition of a foreign key such as "work.*proj#*".

Ad hoc data manipulation by experts is supported by a query language (SQL in relational systems). An example is the following query deriving the total of worked hours in projects per employee:

```
SELECT employee.emp#, SUM(worked_hours)
FROM work, employee
WHERE work.emp# = employee.emp#                    /* an equi-join
GROUP BY employee.emp#
UNION
SELECT employee.emp#, 0                            /* sum of worked hours = 0
FROM employee
WHERE employee.emp# NOT IN (SELECT emp# FROM work).
```

This query illustrates that the semantics of SQL, especially the GROUP BY construct, is not simply understandable. The first selection using an equi-join only selects the employees who worked for any project. The second selection (after "UNION") produces data on employees who did not work for any project at all. In other words, the first sub-query without the union produces only a correct result if all employees worked for any project. This first sub query alone is incorrect (incomplete) because a query has to produce correct and complete results irrespective the database contents.

Another source of problems is that SQL allows joining tables that do not have any structural relationship (through a matching pair of a primary and a foreign key). In order to demonstrate this pitfall, the relation "invoice" is part of the example model, which enables us to specify the following query:

```
SELECT work.proj#, work.date, invoice.amount
FROM work, invoice
WHERE work.date = invoice.date;
```

The last query ignores the structure of the data model and can produce a result table where the same amount is coupled to many projects: the well known **connection trap** (Codd, 1970). In order to avoid such semantic problems it is advisable that naive users use standard applications. For further discussions on (dis)advantages of DBMS's we refer to text books (Rolland, 1998; Elmasri & Navathe, 2010; Connolly, Begg, & Strachan, 1995).

Data security in a local database management system can be managed on the basis of user privileges registered in an authorization scheme. However, when a database is accessible via the Internet, other security problems can arise often caused by improperly specified queries (North, 2010). For example, SQL allows joining relations (tables) even without any join condition: a Cartesian product, possibly requiring a very long execution time. This product of two tables contains $N * M$ results if there are N records in a table and M records in the other table. One might wonder whether it makes sense that SQL enables users to generate more data than present in the underlying database.

In order to prevent these problems related to SQL, a first objective of Johan ter Bekke was to design a data language without these problems. Soon he discovered that this also required designing new concepts for data modeling. Inspired by publications of Smith and Smith (1977) on aggregation and generalization as construction principles for data models he developed new concepts for data modeling and data manipulation (ter Bekke, 1980, 1991, 1992). In order to enhance data quality control in the Xplain-DBMS Johan ter Bekke also developed well separated categories of restrictions for data models: inherent and explicit restrictions.

Inherent restrictions (convertibility and referential integrity, Section 1.2) are a logical consequence of a data model. Convertibility means that a type is identified not only by a name, but also by a set of attributes, and reversely, a set of attributes identifies a type. At the implementation level convertibility is a criterion for the uniqueness of instances: instances belonging to the same object type must have a single identifier and a unique collection of attribute values.

Explicit restrictions - such as business rules - are not inherent in an Xplain data model. We can distinguish static restrictions (Section 1.3) and dynamic restrictions (Section 1.4). Section 1.3 also discusses the meta model of Xplain for the data dictionary. Section 1.5 introduces the concept of generalization/specialization, whereas Section 1.6 shows the strict relationship between data structure and data manipulation (also for recursive operations) in Xplain. The next Section gives a motivation for writing the present paper.

1.1 Motivation

Johan ter Bekke briefly wrote in his first Dutch textbook (ter Bekke, 1983) that convertibility is required over the combination of generalization and specialization. In his later textbooks such a remark can no longer be found. Probably he was aware of some unsolved problems and still working on a solution when he suddenly passed away in March 2004.

It is the objective of the present paper to identify these problems and to propose a generic solution for diverse situations with or without generalization/specialization in data models. The present paper will clarify that there are two problems related to convertibility of instances:

1. Convertibility is not always a satisfactory criterion for the correctness of instances, which requires the design of new rules for correctness of instances.
2. Depending on the kind of generalization/specialization it is necessary to specify different rules for the correctness of instances.

Before starting an extensive discussion on problems and solutions we give an overview of the principles for data definition and manipulation of the Xplain-DBMS in Sections 1.2 - 1.6.

1.2 Inherent restrictions

Convertibility or uniqueness of type definitions
In the Xplain-DBMS each type is identified by a name and at the same time also by a set of relevant attributes (ter Bekke, 1980). Reversely, a certain set of attributes identifies a type as well. This is the principle of convertibility of type definitions. To illustrate this we show a part of a project database based on the model in Figure 1. The structure of this model complies with the relational data model in the introduction. Figure 1 shows a graphical representation - an abstraction hierarchy - of composite types (types with attributes) and their relationships, but it does not show base types (types without attributes). A rectangle representing a referenced type is placed below the referencing type and a middle to middle line indicates a 1 : n relationship between a referenced type, for example: “employee” (cardinality: 1) and a referencing type, for example: “work” (cardinality: n, n ≥ 0). There also is a 1 : n relationship between “project” (cardinality: 1) and “work” (cardinality: n). So “work” defines an n : m relationship between “employee” and “project”, which means that every employee may work for each project. Consequently there is no need to show these cardinality ratios in an abstraction hierarchy.

The definition of a composite type is based either on aggregation or generalization. For example, “employee *its* name” is an attribute based on the aggregation of the types “employee” and “name”. This will become clearer after showing the data dictionary, later in the present section. Generalization/specialization will be discussed in Section 1.5.

Attributes may have a prefix indicating a role. An example is “employee *its* birth_date”. A prefix is mandatory if a composite type has two or more attributes based on the aggregation of the same two types. For example, both attributes “project *its* starting_date” and “project *its* final_date” are based on the aggregation of the types “project” and “date” (see the meta model and the attribute table, this section). Value domains (between brackets) will be discussed later in this section.

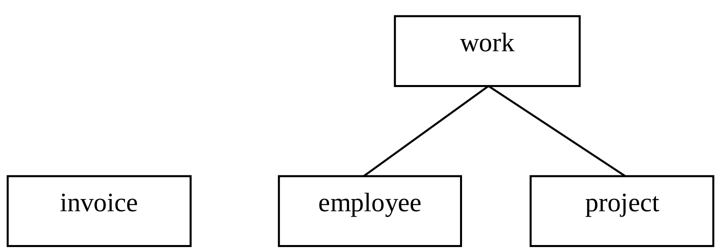


Figure 1. An example of an abstraction hierarchy

Figure 1 is based on the following definitions:

base name (A12). *base* date (D). *base* address (A20). *base* town (A22).
base description (A18). *base* salary (R4,2). *base* hours (I4). *base* amount (R5,2).
type work (I5) = employee, project, date, worked_hours.
type project (I3) = description, starting_date, final_date.
type employee (I3) = name, address, town, birth_date, salary.
type invoice (I3) = description, date, amount.

A consequence of convertibility is that the following definitions may not be part of the previous data model:

type activity (I3) = description, starting_date, final_date. /* already defined set of attributes
type employee (I3) = first_name, last_name, address, town, birth_date, salary. /* "employee": already defined

Based on the model in Figure 1, we can specify a query in the Xplain language deriving the total number of hours worked in projects per employee. In Xplain nested queries and joins may not and cannot be specified, so we start with the derivation of the total worked project hours per employee ("employee *its* project hours"):

extend employee *with* project hours = *total* work *its* worked_hours
per employee. /* "*per*" means: for <u>all</u> instances of "employee"
get employee *its* name, project hours. /* employee identifier is automatically included

In the last *extend* operation the referential path "work *its* employee" is used, which avoids the need of specifying any join operation. Contrary to SQL, Xplain requires to apply a path existing in a data model. In this way the connection trap is avoided (ter Bekke & Bakker, 2001).

Value domains and value restrictions

The following value representations (value domains) are supported by the Xplain-DBMS:

In: integer consisting of at most n decimal digits.
An: alpha-numeric string with at most n characters.
Rn,m: real with at most n decimal digits before and m decimal digits after the decimal point.
B: Boolean variable, its value is either *true* or *false*.
D: dates specified by decimal digits using the format "yyyymmdd".

Xplain also supports value restrictions such as ranges, enumeration and patterns (not shown here). In some later examples we will show assertions containing a value range indicating a value restriction.

Convertibility (uniqueness) of instances

Convertibility of type definitions (conceptual level) implies that convertibility is also required at the implementation level: each instance of a composite type must have a single unmodifiable identifier (unique within that type) and at the same time the set of all its attribute values must be unique. The set of attributes can be considered as a kind of key. It is a modifiable key, so it is better to speak of an identifying property.

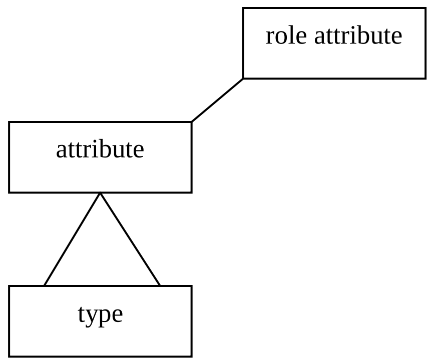
Convertibility of instances is a weak criterion for entity correctness because often uniqueness is required for only some of the attributes. For example, a business rule could be that instances of "project" must have a unique description. This weakness will be discussed further in Sections 2 - 5.

Relatability (referential integrity)

In the data language of Xplain a term - depending on its context - may have different interpretations. For example "employee" indicates a composite type, but "employee" can also be considered as an attribute of the type "work". This example of a kind of object relativity implies an inherent reference from the type "work" to the type "employee" via the referencing attribute "work *its* employee". So there is no need to specify any explicit subset constraint supporting referential integrity, which is a contrast to the explicit foreign key statement of SQL (Connolly, Begg, & Strachan, 1995).

Meta model (model of the data dictionary)
The storage of data definitions in Xplain is based on the meta model in Figure 2. Here types are identified by integers, which implies that a property such as “attribute *its* type” has an integer value. In this way a modification of a type name does not require modifying the value of references such as “attribute *its* type”. Figure 2 does not show the concepts for the registration of value restrictions such as range, enumeration, and pattern (ter Bekke, 1992).

The concept of “attribute” is a generalization of the concepts of “attribute” (its properties: “composite_type, type, kind”) and “role attribute” (its properties: “prefix, composite_type, type, kind”). So “role attribute” is a specialization of “attribute”: it is an attribute with an additional property “prefix”. This **is-a** relationship between “role attribute” and “attribute” implies an optional 1 : 1 relationship between “attribute” (cardinality: 1) and “role attribute” (cardinality: 0..1), textually indicated by square brackets and graphically by a corner to corner line.



type role attribute = [attribute], prefix.
type attribute = composite_type, type, kind. /* kind: “A” (aggregation) or “G” (generalization)
type type = name, representation. /* name: must be unique.

Figure 2. Part of the meta model for the data dictionary of Xplain

The data dictionary corresponding with a part of the data model of Figure 1 is presented in the Tables 1-3:
base name (A12). *base* date (D). *base* address (A20). *base* town (A22).
base description(A18). *base* salary (R4,2). *base* hours (I4).
type work (I5) = employee, project, date, worked_hours.
type project (I3) = description, starting_date, final_date.
type employee (I3) = name, address, town, birth_date, salary. /* the type “invoice” is ignored

Table 1. Examples of type definitions

type	name	representation
1	name	A12
2	date	D
3	address	A20
4	town	A22
5	description	A18
6	salary	R4,2
7	hours	I4
8	employee	I3
9	project	I3
10	work	I5

Table 2 shows two attributes with identifiers 7 and 8, based on the same aggregation of the types “project” and “date”. These attributes are not a conflict with the principle of convertibility because each attribute is accompanied by different role attributes (Table 3, identifiers: 2 and 3), and convertibility has to be considered over the combination of generalization (here: “attribute”) and specialization (here: “role attribute”) (ter Bekke, 1983, 1992).

Table 2. Examples of attribute definitions

attribute	composite_type	type	kind
1	8 /* employee	1 /* name	A
2	8	3 /* address	A
3	8	4 /* town	A
4	8	2 /* date	A
5	8	6 /* salary	A
6	9 /* project	5 /* description	A
7	9	2 /* date	A
8	9	2 /* date	A
9	10 /* work	8 /* employee	A
10	10	9 /* project	A
11	10	7 /* hours	A
12	10	2 /* date	A

Table 3. Examples of role attribute definitions

role attribute	[attribute]	prefix
1	4 /* employee *its* birth_date	birth
2	7 /* project *its* starting_date	starting
3	8 /* project *its* final_date	final
4	11 /* work *its* worked_hours	worked

1.3 Static restrictions

In Xplain static restrictions are specified in terms of derived data using assertions, which means that these rules are based on controlled redundancy. An assertion applies to a database state at any time and cannot be specified inherently in a data model. In many cases an assertion complies with a business rule. An example is that a project ends at a later date than the starting date. This can be expressed by a derived attribute "project *its* correctness", its calculation and a value restriction "(*true*)". If the final date is not known yet, a special value as "99991231" should be applied (see Section 1.4).

assert project *its* correctness (*true*) = (final_date > starting_date).

Another requirement is that "work *its* date" complies with the project dates:

assert work *its* date correctness (*true*) = (date >= project *its* starting_date *and* date <= project *its* final_date).

Other examples of applying assertions are related to a model for orders and order lines (without showing value domains). An attribute between slashes is derived by an assertion:

type order line = order, article, price, number, /amount/. /* "amount" is a derived attribute
type order = customer, date, /total amount/, /line number/. /* "total amount", "line number": derived attributes

assert order line *its* amount (0..*) = number * price. /* "price": property of "order line"
assert order *its* total amount (0..*) = *total* order line *its* amount *per* order. /* "*total*": a set function
assert order *its* line number (1..*) = *count* order line *per* order. /* "*count*": another set function

Apparently convertibility is a weak correctness principle: it allows two or more instances of "order line" with the same values for the attribute combination ("order, article, price") but with different values for "number". Such a duplication should not be allowed. Moreover, it leads to an incorrect calculation of the derived attributes "order *its* total amount" and "order *its* line number". A further discussion of similar problems will be presented in Section 2.

1.4 Dynamic restrictions

Dynamic restrictions have to deal with the correctness of database state transitions (insertions and updates). An example of an insert restriction is associated with the following model, a slight modification of the previous model. Now the amount of an order line is calculated automatically at insertion time only using the *init* command. Therefore later updates of “article *its* price” do not affect the earlier registered data on “order line *its* amount”.

type order line = order, article, number, amount.
type order = customer, date, /total amount/, /line number/.
type article = name, price. /* here: a price per article
assert order *its* total amount (0..*) = *total* order line *its* amount *per* order.
assert order *its line* number (1..*) = *count* order line *per* order.
init order line *its* amount = number * article *its* price. /* only valid at insertion time

Errors in order dates can be prevented by using a default value for order dates:
init default order *its* date = *systemdate*. /* only valid at insertion time

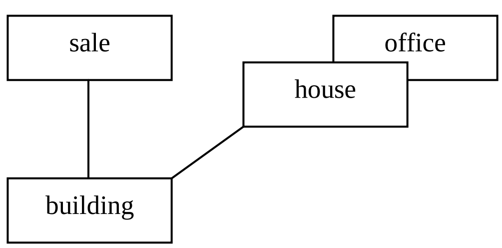
If a final date in the example in Section 1.2 is not known at insertion time, we might apply:
init default project *its* final_date = 99991231.

We do not show how update restrictions (ter Bekke, 1992) are specified. An example is that, at the end of a school year, pupils only may move to a higher class level or leave the school or have to stay at the same level, whereas during a school year a degradation to a lower level is possible. So there is a distinct number of updates (transitions) allowed for the value of an attribute, such as “pupil *its* class_level”.

Explicit delete restrictions make no sense because a deletion is a transition from an existing state to an empty state, whereas implicit delete restrictions are a consequence of inherent rules such as referential integrity or assertions. For example: an order must have at least one order line, therefore a single remaining order line may not be deleted without deleting the involved order.

1.5 Generalization/specialization

Aggregation is not the only constructing principle for data modeling; Xplain also supports generalization/ specialization. This is a useful design concept when almost similar object types, for example “office” and “house”, have the same properties such as “address” and “construction_year”, etc, but differ in terms of other properties. The common properties can be considered to belong to their generalization (here: “building”), whereas distinguishing properties belong to a specialization type. The following definitions mean that a building is a house or an office and is not both at the same time (ter Bekke, 1992). Therefore, an example of a data model for a real estate agency (figure 3) shows an example of disjoint specialization:



type office = [building], office type, floor space.
type house = [building], sort, number of rooms.
type building = address, construction_year, purchase_date, price, owner.
type sale = building, date, price, new owner.

Figure 3. A data model (abstraction hierarchy) with disjoint specialization

The following alternative requires applying two “null” values for each instance of “building’, which is a source of insertion errors because this simpler model does not explain which attributes must have a “null” value in which case:

type building = address, construction_year, purchase_date, price, owner,
office type, floor space, sort, number of rooms.

This application of generalization (Figure 3) avoids this insertion problem and makes it easier to specify retrievals addressing only the common properties of both kinds of buildings. Another advantage is that other types, such as “sale”, may refer to the generalization (e.g. “sale *its* building”), which makes it easier to specify retrievals of sales irrespective the kind of sold object. Without generalization/specialization, we would have to define two partially overlapping building types (“house” and “office”) and two types for sale results: “house sale” and “office sale”. The same applies to retrieving all sale results. Using generalization/specialization, each composite type can be defined in terms of definitive properties (attributes) relevant to **all** instances of that type. Contrary to SQL, there is no need to use a “null” value if an attribute is irrelevant, which is essential for deriving data and referential integrity as well. In relational databases, “null” can also have other interpretations such as “unknown” or “zero” (ter Bekke, 1997).

1.6 Relationship between data structure and data manipulation

Xplain requires a strict relationship between data structure (data model) and data manipulation. Definitive properties (intrinsic or inherited) are always found by using an existing path in a data model. It is not allowed and not possible to join data. For example, the following query retrieves some properties of work data and related data inherited of employees who worked for project 345:

type work = employee, project, date, worked_hours.
type project = description, starting_date, final_date.
type employee = name, address, town, birth_date, salary.

get work *its* employee, employee *its* name, date, worked_hours
where project = 345. /* means the same as “*where* work *its* project = 345”

In the last query we see that the attributes “work *its* employee” (also a reference), “work *its* worked_hours”, and a longer path “work *its* employee *its* name” are specified. If an employee worked on more than one day for project 345, then this query generates many copies of the same employee data. A better query avoids this replication of results and will be shown later.

In SQL there is not such a clear relationship between data structure (defined by a matching pair of primary and foreign keys) and data manipulation. We refer to the example in the introduction of Section 1, where two relational tables (“work” and “invoice”) are joined over two non-key attributes. We already showed in Section 1 that the “GROUP BY” construct of SQL has a meaning other than the “*per*” construct of Xplain.

In cases where derivable data have to be retrieved, Xplain requires starting with an *extend* operation calculating the desired derivable property. For example, the following query retrieves the name and salary of employees who worked for project 345. Now the result does not contain any repetition of the same retrieved data on employees:

extend employee *with* involved = *any* work *where* project = 345 /* deriving “employee *its* involved”
per employee. /* used path: “work *its* employee”
get employee *its* name, salary
where involved. /* using “employee *its* involved”

Also in the case of recursive queries (for example, finding the shortest path (over arcs) between two points (nodes) in a network (graph)) it is essential that data structure is respected. Earlier solutions for recursive problems such as transitive closure (Aho, Hopcroft, & Ullman, 1974; Bailey, 1999; Connolly, Begg, & Strachan, 1995; Dar & Ramakrishnan, 1994; Suciu & Paredaens, 1994; Ullman & Widom, 1997) often create successor lists much larger than the original data set, which leads to time-consuming duplicate elimination and cycle detection (Karayiannis & Loizou, 1978). Moreover, these solutions are specified in languages that are difficult to understand by end users. Another problem is associated with recursive views in SQL3. The syntax of this language (Ullman & Widom, 1997) still allows for procedural operations, such as the join operation. Therefore SQL3 cannot guarantee termination (ter Bekke & Bakker, 2004).

Contrary to these earlier approaches, the new algorithm uses graph reduction (ter Bekke & Bakker, 2003), thus avoiding data expansion. Graph reduction is the basis for recursive data processing as can be specified by the *cascade* command (ter Bekke, 1998) in the Xplain language. As far as we know this is a new approach and it has some important consequences for end user computing:

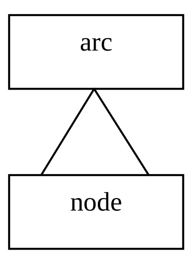
1. Graph reduction processes **all** data defining a directed graph, even in the case of finding a shortest path, where probably not all nodes and arcs are involved. This might seem inefficient, but it also offers an analogue solution for critical path (longest path) problems. In procedural approaches to critical path problems a programmer has to choose start and finish nodes, which is not always possible because there can be many candidates for start and finish. Xplain releases end users of this problem by determining start and finish itself.
2. Graph reduction ends either with an empty graph or with a graph containing one or more cycles (proven by Bang-Jensen & Gutin, 2001). Only for a directed graph without any cycle, graph reduction produces a well-ordered list of arc data, suitable for further serial calculations.
3. Cycle detection is part of the arc ordering process, consequently termination is guaranteed. This is essential for open systems - accessible to millions of unknown users - that cannot be protected by authorization tables (Bakker & ter Bekke, 2001). Appendix II gives examples of graph reduction and cycle detection.
4. The worst case complexity of arc ordering is $O(N^2)$, where N is the number of arcs. This ordering avoids the data expansion associated with other approaches (Bancilhon & Ramakrishnan, 1986; Molluzzo, 1986; Rosenthal, Heder, Dayal, & Manola, 1986; Suciu & Paredaens, 1994). Using the produced list of ordered arc data, further calculations take $O(N)$ time.

The new query language approach to recursive operations in databases has been applied to data sets with an acyclic structure. Examples based on non-recursive data models are related to project planning (ter Bekke & Bakker, Innsbruck, 2002) and production planning (ter Bekke & Bakker, Copenhagen, 2002). However, an acyclic data set can also be based on a recursive data model. For example, a family tree is acyclic, but can be based on the following recursive definition:

type person = name, mother_person, father_person, birth_date.

Now it is possible to specify a recursive query retrieving all ancestors of a person (ter Bekke & Bakker, Banff, 2003).

Even in the case of cyclic geometries, graph reduction is usable, provided the geometric cyclic graph is transformed into an acyclic time-based graph (Bakker & ter Bekke, 2004). The following example shows that the *cascade* command enables us to specify a rather short query retrieving the longest or critical path, using the following data model (Figure 4) for a directed graph (ter Bekke & Bakker, 2003):



type node = description.
type arc = from_node, to_node, length.

Figure 4. An abstraction hierarchy for a directed graph

Using these definitions we now can specify a recursive query for a longest path. Here we apply the restriction that names of derived attributes may not contain any underscore:

extend node *with* firstpath = 0. /* Initialize all nodes, now ordering is irrelevant
cascade node *its* firstpath = *max* arc *its* length + from_node *its* firstpath /* from "from_node" to "to_node"
per to_node.
extend node *with* lastpath = 0.
cascade node *its* lastpath = *max* arc *its* length + to_node *its* lastpath /* from "to_node" to "from_node"
per from_node.
value longestpath = *max* node *its* firstpath + lastpath.
extend node *with* relevant = (firstpath + lastpath = longestpath).
get node *its* first_path *where* relevant *per* firstpath. /* Sorting by increasing value of "node *its* firstpath"

After this introduction to the basic principles of the Xplain-DBMS and its language, Section 2 discusses convertibility for situations without generalization/specialization, whereas Section 3 discusses convertibility for disjoint specialization (either optional or mandatory). Section 4 discusses optional non-disjoint specialization and Section 5 discusses two special cases. Section 6 draws some conclusions and proposes a generic solution. In Appendix II we discuss that one of the possible solutions can be supported by checking transactions.

2 CONVERTIBILITY IN THE ABSENCE OF GENERALIZATION

Section 2.1 shows two cases in which convertibility of instances is not a satisfactory criterion for entity correctness, whereas Section 2.2 shows an example where uniqueness over only three of the four attributes is required. Section 2.3 argues that externally defined identifiers should not be accepted to function as identifier in databases of other organizations. Still, externally defined identifiers may be used, but only then as attribute, which complies with the principle that in Xplain an identifier is not the same as an attribute.

2.1 Types with one or more unique attributes

In a company where departments are characterized by properties such as name, floor and extension a composite type as "department" can be defined by its aggregation with respectively three base types: "name", "floor" and "extension" (local telephone number):

base name (A15). *base* floor (I2). *base* extension (I3).
type department (I2) = name, floor, extension.

These definitions mean that each instance of "department" has an unmodifiable single identifier (I2) and also a unique value combination of the attributes ("department *its* name, floor, extension"). However, if the name of a department must be unique, the two instances "1" and "2" of "department" in Table 4 do not comply with this business rule although they are not conflicting with convertibility of instances. A similar problem occurs when each department has a unique extension.

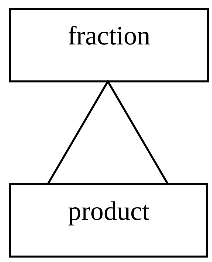
Table 4. Convertibility is not rigorous enough as criterion for entity correctness

department (identifier)	**name**	**floor**	**extension**
1	toys	3	352
2	toys	1	352

Apparently convertibility of instances is not strict enough as a criterion for entity correctness, although it remains a correct criterion for the uniqueness of instances. A solution can be to specify a uniqueness rule for both identifying attributes. An alternative solution for the first attribute is to choose a department name - for example a string (A12) - as value representation for "department". The disadvantage is that identifiers - now department names - may not be modified. In a relational system, this problem can be solved by adding a "UNIQUE (name)" and a "UNIQUE (extension)" SQL-statement (Ullman & Widom, 1997) to the table definition of the following relation:

relation department (<u>dept#</u>, name, floor, extension).

Another example demonstrating that convertibility alone cannot enforce entity correctness is related to the model used for product databases (ter Bekke & Bakker, 2002). In the assemblage of electronic products certain numbers of other products are applied, so “fraction” defines the number of minor products present in a major product (value domains not shown). If a product is part of an intermediate product then it also indirectly is part of (end) products containing such an intermediate product. Thus a product can be part of an intermediate product and part of a finished product as well. Therefore the involved data constitute a hierarchy, but not necessarily a tree, see Figure 5:



type product = name, stock, ordered_quantity. /* “product *its* name” must be unique
type fraction = major_product, minor_product, multiplicity.

Figure 5. An abstraction hierarchy for product compositions

The following query creates production information related to basic products (products without parts). Ordered quantities of finished or intermediate products can have consequences for orders of basic products, taking into account the stock of ordered products. The following recursive query determines the needed basic components and quantities needed to produce the ordered products:

extend product *with* need = ordered_quantity - stock.
extend product *with* induced = 0.
cascade product *its* induced = *total* fraction *its* multiplicity * (major_product *its* need + major_product *its* induced)
per minor_ product.
extend product *with* basic = *nil* fraction *per* major_product. /* basic products have no parts
update product *its* need = need + induced.
get product *its* name, need *where* basic *and* need > 0.

The previous *cascade* operation can produce incorrect total needs of basic products if the uniqueness of “product *its* name” is not enforced. Again we perceive that the rule of convertibility of instances is not strict enough for correctness of instances.

2.2 A type with a unique combination of attributes

Another example demonstrating the weakness of the principle of convertibility of instances is based on the following data model:

type work = <u>employee, project, date</u>, worked_hours.
type project = description, starting_date, final_date.
type employee = name, address, town, birth_date, salary.

Here the combination of underlined attributes must be unique. Otherwise it is possible to register many times worked hours for the same value combination of (“employee, project, date”) provided the diverse values of “worked_hours” are differing. This could result in a wrong calculation of the total worked hours per project using the following query:

extend project *with* hours = *total* work *its* worked_hours
per project.
get project *its* description, hours.

In a relational system based on the data definition: *relation* work (work#, *emp#*, *proj#*, date, worked_hours), this problem can be solved by using the SQL statement "UNIQUE (emp#, proj#, date)" in the table definition. Another solution is to define a composite primary key consisting of three attributes (underlined), including two foreign keys (in italic type face):

relation work (*emp#*, *proj#*, date, worked_hours).

2.3 Convertibility and externally controlled identifiers

The examples in Sections 2.1 and 2.2 discussed identifying attributes with values controllable by a private organization. Another problem emerges if a commercial organization uses an externally controlled identifier as identifier. This is illustrated by the following model in which "employee *its* sofi number" is a unique social security/fiscal number assigned by the Dutch government to persons (today called "BSN": "Burger Service Number"). This number facilitates the work of governmental organizations such as tax offices and passport offices:

type employee = name, address, town, birth_date, sofi number. /* uniqueness over the underlined attributes
type work = description, employee, first_date, last_date.

In order to avoid a conflict with the convertibility of instances, a database designer could choose this sofi number as an identifier for instances of "employee", which would result in the following definition in which "sofi number" is not visible anymore as an attribute:

type employee = name, address, town, birth_date.

However, this identifier (the value of an instance of "employee" equals a sofi number) is controlled by the Dutch government, and it cannot be excluded that some future government might wish to modify all sofi numbers. This would create a lot of work in governmental and private databases using sofi numbers as identifiers, especially when "employee" also functions in a referring attribute such as "work *its* employee". In order to avoid this, a sofi number has to be specified as an identifying property (attribute). The combination of the other attributes ("name, address, town, birth_date") constitutes a second identifying property. Now we want to be able to specify the following two identifying properties: ("employee *its* sofi number") and ("employee *its* name, address, town, birth_date").

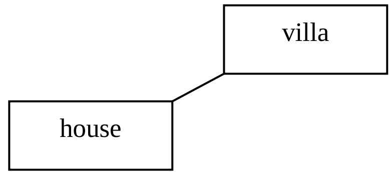
We see that also in the case of an externally controlled identifying attribute, convertibility of instances is not a usable criterion for entity correctness, and in this example we have to specify two identifying properties.

3 CONVERTIBILITY AND DISJOINT SPECIALIZATION

Disjoint specialization occurs when a generalization has two or more non-overlapping specializations (see Section 3.2). These specializations are different in terms of some properties, but their common properties define a generalization. It is also possible that a generalization is accompanied by only one specialization (Section 3.1). In theory we might distinguish optional (Sections 3.1 and 3.2) and mandatory specialization (Section 3.3). However, mandatory single specialization makes no sense: a better design is to merge the definitions of generalization and specialization type into a single type.

3.1 Optional single specialization

An example of optional single specialization (Figure 6) is related to a building firm offering different standard houses with or without a dormer. In this firm a house is called a villa if it has a dormer and its number of floors is larger than two. Now we consider "dormer_width" as property of the specialization "villa". Both types have in common the properties included in the definition of the generalization "house". Table 5 shows some instances of "house" and "villa".



type villa = [house], dormer_width. /* Cardinality ratio's: "house" (1) and "villa" (0 .. 1).
type house = price, length, width, number of floors, number of rooms.
assert villa *its* correctness (*true*) = (house *its* number of floors > 2).

Figure 6. An example of optional single specialization

Table 5. Some combinations of generalization and specialization instances

house (ident.)	**length**	**width**	**number of floors**	**number of rooms**	**villa** (ident.)	**[house]** (reference)	**dormer_width**
5	8	10	3	4	**2**	5	3.30
6	8	10	3	4			
8	8	10	3	4	**4**	8	3.90

If the registration of house "5" (Table 5) is accompanied by the registration of the associated instance of "villa" within the same transaction, then there is no conflict with convertibility if later house "6" without a dormer is registered. However, the reverse order of insertions creates a problem because the generalization instance house "5" alone is conflicting with the then already registered house "6". This conclusion is incorrect if an associated instance of "villa" has to be registered together with house "5". Then convertibility should apply to the combination of a generalization instance and the associated specialization instance. In order to avoid this problem and to support completeness of insert transactions, a solution is to extend the definition of "house" with a special case attribute with either the allowed value *"nil"* or "villa". In this way a DBMS can derive from the value of a case attribute whether or not an associated instance of "villa" also has to be inserted.

It is essential that only case attributes may have a *"nil"* value. Otherwise we get the same problems as in relational databases where it is possible that attributes - even foreign key attributes - have a "null" value. Our proposal extends the scope of case attributes - originally restricted to mandatory specialization (ter Bekke, 1992) - to optional specialization, which leads to the following modified definition of "house":

type house = length, width, number of floors, number of rooms, *case.*

If the case attribute has the value "villa" then one associated instance of "villa" must be inserted together with an instance of "house" and convertibility must be evaluated over the following attribute combination of both generalization and specialization, expressed in terms of intrinsic and inherited attributes of "villa" (inherited from the generalization): ("villa *its* dormer_width, villa *its* house *its* length, villa *its* house *its* width, villa *its* house *its* number of floors, villa *its* house *its* number of rooms"). If the case attribute is *"nil"* then the following combination of attributes belonging to only the generalization "house" has to be evaluated for convertibility: ("house *its* length, house *its* width, house *its* number of floors, house *its* number of rooms, house *its case"*). This approach allows for the instances in Table 6. Now we see that two villas are different, although they have some common properties inherited from different instances of "house" ("5" and "8") with different identifiers.

Table 6. Combinations of generalization (with case attribute) and specialization instances

house (ident.)	**length**	**width**	**number of floors**	**number of rooms**	***case***	**villa** (ident.)	**[house]** (reference)	**dormer_width**
5	8	10	3	4	villa	**2**	5	3.30
6	8	10	3	4	*nil*			
8	8	10	3	4	villa	**4**	8	3.90

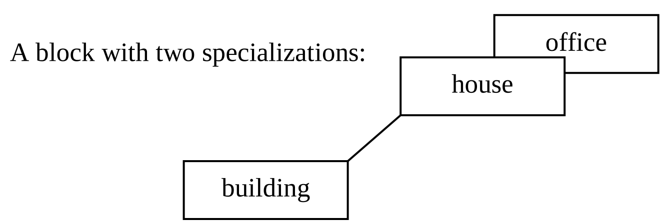
Now a case attribute must be involved in the assertions dealing with the completeness of insertions of instances of “house”. The evaluation order of interdependent assertions can be derived from the position or role of a derivable variable in an assertion (Bakker &ter Bekke, 2001). This is demonstrated by the following assertions dealing with the completeness of instances of “house”: the derivable attribute “house *its* has a dormer” has to be specified before it can be applied in the second assertion:

assert house *its* has a dormer = *any* villa *per* house.
assert house *its* completeness (*true*) = (*case = “nil” and not* has a dormer *or case* = “villa” *and* has a dormer).

If necessary, the DBMS must inform the involved user about the violation of the last rule and advise the user what to do. Deletion completeness is supported by maintaining referential integrity: a generalization instance may only be removed after removing all the (specialization) instances referring to that generalization instance. Contrary to this example with “house” and “villa”, the following sections will show again that convertibility of instances is not always rigorous enough as a criterion for entity correctness.

3.2 Optional multiple disjoint specialization

A generalization may be accompanied by two or more non-overlapping specializations and each generalization instance is accompanied by at most one instance of one of the specializations. This means an optional 1 : 1 relationship between an instance of the generalization and an associated instance of one of the specializations. Therefore the related abstraction hierarchy only shows one line from a block of specializations to the rectangle representing the generalization. An example is the following data model (Figure 7) for a real estate agency offering different kinds of buildings for rent (ter Bekke, 1992). We assume that the destination of a building (house or office) is not predestined. Therefore the specialization of “building” into “house” or “office” is optional.



type office = [building], office type, floor space.
type house = [building], sort, number of rooms.
type building = address, construction_year, purchase_date, price, owner, *case*.

Figure 7. An example of an abstraction hierarchy for optional multiple disjoint specialization

Disjoint specializations have the same (possibly empty) prefix in the attribute referring to the generalization. These specializations are not overlapping: they belong to the same block of specializations.

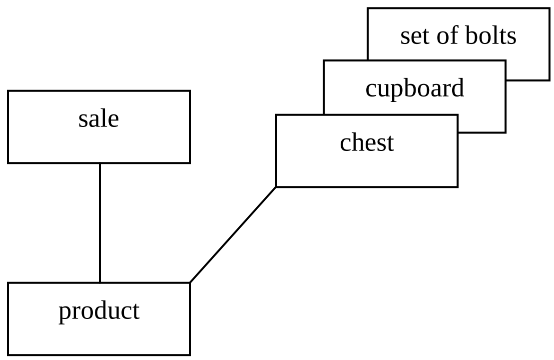
Now “building *its case*” must be either *“nil”*, “house”, or “office”. Depending on the actual value, a DBMS has to decide which kind of instance(s) must be registered within one insert transaction and over which instance(s) convertibility must be checked. However, a stricter rule for entity correctness has to be specified here because the following combination of attributes (“building *its* address, building *its* construction_year”) must be unique: this combination is an identifying property of “building” and also is an inherited identifying property of both specializations (via “office *its* building” or “house *its* building”). For example, the identifying property of “house” can be specified as: (“house *its* building *its* address, house *its* building *its* construction_year”). Completeness of building registrations can be enforced by using the following assertions:

assert building *its* is office = *any* office *per* building. /* Definition and calculation of a derived attribute.
assert building *its* is house = *any* house *per* building. /* Idem.
assert building *its* completeness (*true*) = (*case* = “*nil*” *and not* is office *and not* is house
or case = “house” *and* is house *or case* = “office” *and* is office).

3.3 Mandatory disjoint specialization

The following model (Figure 8) is used by a manufacturer producing different kinds of furniture, construction materials and parts of furniture. The common characteristics of these products are "description", "weight" and "production_cost". Many products have these three properties but are different in terms of other properties. Therefore it makes sense to apply mandatory disjoint specialization. This is expressed by "product *its case*" with a value that must be equal to the name of one of the specializations, either "chest", "cupboard" or "set of bolts". Here the case attribute may not be *"nil".* We do not show other specializations such as "shelf", "chair" or "table".

Now we want to distinguish mandatory specialization and optional specialization (see also Section 6.2) by using brackets for mandatory specialization, whereas square brackets from now on indicate optional specialization. This modification of the language must be expressed in the data dictionary: from now on the value of "attribute *its* kind" must be either "O" (optional specialization), "M" (mandatory specialization), or "A" (aggregation). Appendix I. explains that we need this modification in order to be able to specify additional rules.



type sale = product, number, amount, customer, date.
type set of bolts = {product}, number, diameter, length, kind of metal.
type cupboard = {product}, number of doors, depth, width, height, kind of wood.
type chest = {product}, number of drawers, depth, width, height, kind of wood.
type product = description, weight, production_cost, *case.*

Figure 8. An example of an abstraction hierarchy with mandatory disjoint specialization

Without applying generalization we would have to define a separate type for each kind of product and also different kinds of "sale", such as "cupboard sale", for each kind of product. Consequently, an overview of all sales in a year would require specifying a retrieval for each kind of product. Then calculations, such as the average profit per product in 2011, would become more complex than the following transaction:

extend product *with* yield = *total* sale *its* amount *where yearf* (date) = 2011
per product.
extend product *with* number = *total* sale *its* number *where yearf* (date) = 2011
per product. /* *"yearf"*: function producing the year of a date.
extend product *with* average yield = 0.
update product *its* average yield = yield/number *where* number > 0.
extend product *with* average profit = average yield - production_cost.
get product *its* description, *case*, average yield, production_cost, average profit.

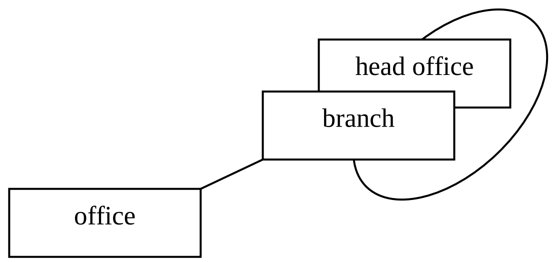
Depending on the value of the case attribute, the DBMS has to require convertibility over the combination of the following intrinsic and inherited attributes:

("chest *its* number of drawers, chest *its* length, chest *its* depth, chest *its* width, chest *its* height, chest *its* kind of wood, chest *its* product *its* description, chest *its* product *its* weight, chest *its* product *its* production_cost")
or over:

("cupboard *its* number of doors, cupboard *its* depth, cupboard *its* width, cupboard *its* height, cupboard *its* kind of wood, cupboard *its* product *its* description, cupboard *its* product *its* weight, cupboard *its* product *its* production_cost")
or over:

("set of bolts *its* number, set of bolts *its* diameter, set of bolts *its* length, set of bolts *its* kind of metal, set of bolts *its* product *its* description, set of bolts *its* product *its* weight, set of bolts *its* product *its* production_cost").

Each of these attribute combinations is suitable as identifying property for the involved specialization. Now the generalization "product" does not need to have any identifying property. However, this is not a general rule for all cases with mandatory specialization. This is demonstrated by the data model in Figure 9, a slight modification of an example in the textbook (ter Bekke, 1992). It is related to a banking organization with regional head offices and branches, each branch reporting to a head office. This organization requires that an office is either a branch or a head office: therefore the value of "office *its case*" must be either "head office" or "branch".



type head office = [office], region.
type branch = [office], head office.
type office = <u>address, town</u>, <u>telephone number</u>, *case.*

Figure 9. Another example of mandatory disjoint specialization

Two attributes of the generalization ("office *its* address" and "office *its* town") constitute an identifying property and "office *its* telephone number" is another identifying property. It makes sense that the specializations inherit the identifying properties of their generalization. For example, the identifying properties of "branch" are defined by ("branch *its* office *its* address, branch *its* office *its* town") and ("branch *its* office *its* telephone number").

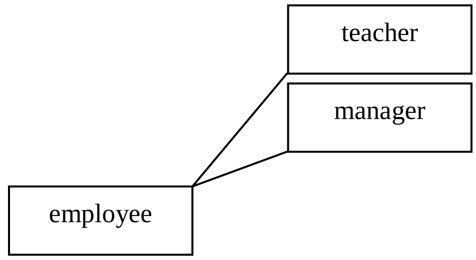
In the case of mandatory specialization there is no need to specify any identifying property for the generalization. Even if attributes of a generalization alone or together with attributes of an associated specialization are participating in an identifying property of a specialization, the specialization and not the generalization must have at least one identifying property, possibly containing an attribute inherited from the generalization. Another choice is possible, but a generic solution requires applying a standard approach to all cases with mandatory specialization. Section 6.2 will show that this is essential for checking correctness of specifications.

4 CONVERTIBILITY AND NON-DISJOINT SPECIALIZATION

In the case of non-disjoint or overlapping specialization there are at least two specialization blocks and each block consists of at least one specialization. Then each instance of a generalization may be accompanied by many specialization instances if these instances belong to different blocks. Each block must be identified by a unique prefix in the attribute referring from a specialization to a generalization. Two variants of non-disjoint specialization are possible: optional and mandatory. However, the last kind is superfluous because a more usable design is to merge the attributes of the specializations with the attributes of the generalization into a single composite type.

4.1 Optional non-disjoint specialization

An example (Figure 10) of optional non-disjoint specialization is related to a school with three categories of employees: common employees without any specific characteristics, or employees with specific characteristics: teachers and/or managers. We assume that in this school a teacher may also be a manager at the same time:



type manager = [managing_employee], function.
type teacher = [teaching_employee], qualification.
type employee = name, address, town, birth_date, starting_date, salary, teaching_*case*, managing_*case*.

Figure 10. An example of optional non-disjoint specialization with two specialization blocks

Here are two case attributes and two non-disjoint specialization blocks each consisting of one specialization. The correspondence between a block and a case attribute can be derived from the prefix of a case attribute that must be equal to the prefix in the attribute of a specialization referring to the generalization. The allowed value of "employee *its* teaching_case" is either *"nil"* or "teacher", whereas the other case attribute must be either *"nil"* or "manager".

Now five (underlined) attributes of the generalization "employee" constitute a composite identifying property: ("employee *its* name, address, town, birth_date, starting_date"). The specialization types "teacher" and "manager" inherit this identifying property from "employee". Further, in order to support completeness of insert transactions, we need to specify the following assertions:

assert employee *its* is a manager = *any* manager *per* managing_employee.
assert employee *its* is a teacher = *any* teacher *per* teaching_employee.
assert employee *its* completeness (*true*) =
((managing_*case* = "manager" *and* is a manager *or* managing_*case* = "*nil*" *and not* is a manager)
and (teaching_*case* = "teacher" *and* is a teacher *or* teaching_case = "*nil*" *and not* is a teacher)).

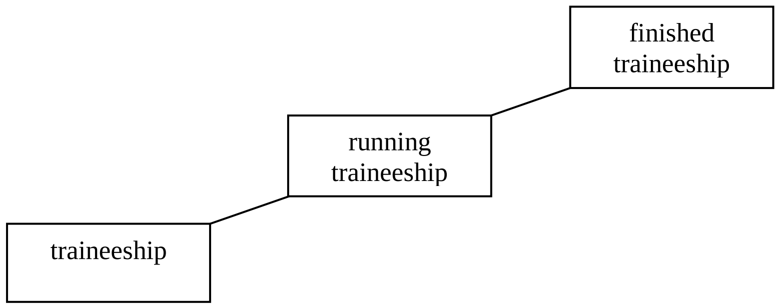
Conclusion: in the case of optional non-disjoint specialization with N specialization blocks we have to apply N case attributes. Then it is possible to derive from the value of the case attributes whether or not and which specialization(s) is (are) involved in an insertion. It is possible that some generalization instances do not have any associated specialization instance. Therefore it is necessary that both generalization and specializations have at least one identifying property, even if the specializations inherit the identifying property of its generalization.

5 CONVERTIBILITY IN EXTRAORDINARY CASES

We also have to consider some rarely occurring situations with generalization/specialization. Otherwise we cannot develop a generic solution for the specification of identifying properties. Section 5.1 shows a specialization that also is a generalization, whereas Section 5.2 shows that a specialization can also have an aggregation relationship with its generalization.

5.1 Coinciding specialization and generalization

A specialization type can also be a generalization type at the same time. An example of such a situation (ter Bekke, 1993) is related to an institute for higher education, where a special office is organizing trainee ships for third year students in industry. After contacting some organizations, this office registers data on potential trainee ships. Once a student has started a trainee ship, data on a running trainee ship are registered. When a student has finished the trainee-ship including the required report, the data on the finished trainee-ship are registered. The data model in Figure 11 supports such a sequence. Furthermore this design avoids that users have to specify a "nil" value for normal attributes (unlike the case attribute).



type finished traineeship = [running traineeship], report_title, final_date, mark, reviewer.
type running traineeship = [traineeship], start_date, planned final_date, *case*.
type traineeship = organization, contact person, telephone, subject, desired start_date, desired final_date, *case*.

Figure 11. A data model for the registration of traineeships
Further, some additional restrictions are essential:

init default traineeship *its case* = "*nil*". /* update *case* when inserting an instance of "running traineeship"
init default running traineeship *its case* = "*nil*". /* update *case* when inserting an instance of "finished traineeship"

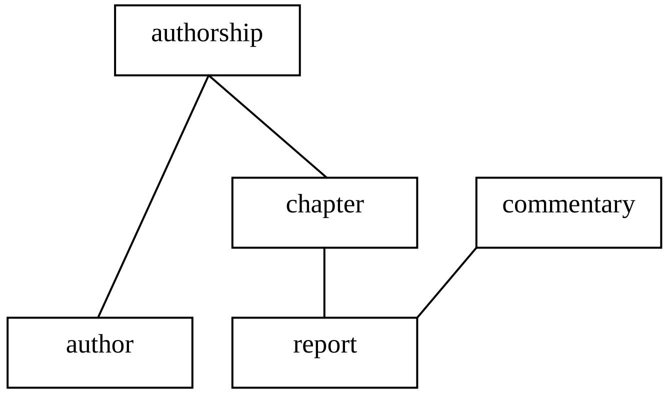
assert running traineeship *its* is finished = *any* finished traineeship
per running traineeship.
assert traineeship *its* is running = *any* running traineeship *where not* is finished
per traineeship.
assert traineeship *its* completeness (*true*) = (*case = "nil" and not* is running
or case = "running traineeship" *and* is running).
assert running traineeship *its* completeness (*true*) = (*case ="nil" and not* is finished
or case = "finished traineeship" *and* is finished).

The following attribute combination of "traineeship" constitutes an identifying property: ("organization, subject, desired start_date"). The types "running traineeship" and "finished traineeship" inherit this identifying property.

The first specialization inherits this identifying property via the path "running traineeship *its* traineeship", whereas the second specialization inherits this identifying property via "finished traineeship *its* running traineeship *its* traineeship". For example, one of the inherited attributes can be specified as "finished traineeship *its* running traineeship *its* traineeship *its* subject". In this case both generalization and specializations must have at least one identifying property because it is possible that an instance of a generalization ("traineeship" or "running traineeship") is not accompanied by any following specialization instance.

5.2 Simultaneous aggregation and specialization of a same type

The situation mentioned in the previous title occurs in the database of a library in a large governmental organization where data on reports have to be stored and must be accessible via an index. There are reports commenting on another report. Now "commentary" is an optional specialization of "report", but at the same time it is also based on an aggregation with the same type "report" because it comments on a previous report. Further, at least one author is responsible for a chapter of a report. Figure 12 shows an abstraction hierarchy for this index. The definition of the composite type "department" is not shown because its attributes are irrelevant for the present discussion.



type authorship = author, chapter.
type chapter = title, report.
type commentary = [report], commented_report. /* “commentary *its* report” defines “report” as a generalization
type author = name, room_number, telephone, department.
type report = title, category, date, responsible_department, *case*.

Figure 12. An abstraction hierarchy for an index on reports

In addition to the previous type definitions some explicit restrictions are necessary:
assert report *its* is a commentary = *any* commentary *per* report.
assert report *its* correctness (*true*) = (is a commentary *and case* = *“commentary”*
or not is a commentary *and case* = *“nil”*).
assert report *its* number of chapters (1..*) = *count* chapter *per* report.
assert chapter *its* number of authors (1..*) = *count* authorship *per* chapter.
assert commentary *its* correctness (*true*) = (report *its* date > commented_report *its* date
and not report = commented_report).

We assume that in this organization a report title must be unique, so “report *its* title” is an identifying property. Then this is also an inherited identifying property of “commentary”. Now there are two possible attribute paths between “commentary” and “report” that can be used to inherit an identifying property of “report” by “commentary”: “commentary *its* report *its* title” and “commentary *its* commented_report *its* title”.

Because of the **is-a** relationship between “commentary” and “report”, as defined by the attribute “commentary *its* report” (attribute *its* kind = “O”; thus optional specialization), it is obvious that the inherited attribute involved in the specification of the identifying property of “commentary” is “commentary *its* report *its* title”.

In many cases it can be derived from a data model which inheritance path or referential path is involved because in those cases there is only one path of attributes between a specialization and an attribute belonging to its generalization. However, the previous example demonstrates why it is necessary, that the path involved in inheriting an attribute of a generalization type must be represented in the new concepts to be designed for the specification of identifying properties and their constituting elements (attributes). For a generic approach we need a standard solution that is able to deal with all allowed situations. Therefore, a first idea is that elements (attributes) belonging to an identifying property may have a preceding element (attribute) in some cases. The data model in Section 5.1 demonstrates that longer inheritance paths can exist.

6 A POSSIBLE SOLUTION

We summarize our observations and preliminary conclusions in Section 6.1. In Section 6.2 we propose a solution for the management of entity correctness based on the introduction of new concepts supporting the specification of identifying properties in the data dictionary of the Xplain-DBMS.

6.1 Rules for entity correctness

The discussions in Sections 2-5 lead us to the following conclusions:

1. Each instance of a composite type must have a unique single valued identifier that may not be modified, which complies with the original concepts of Xplain.
2. According to the original concepts of Xplain convertibility of instances should be checked over the combination of a generalization instance and the associated specialization instance(s).
3. If a type is neither generalization nor specialization then convertibility of instances is required for that type.
4. However, rule 2 and rule 3 must be ignored if stricter uniqueness rules for entity correctness are required.
   <u>If a type is neither generalization nor specialization</u> then uniqueness should be specified over some of its attributes. An example is the composite type “department” with two identifying properties (Section 2).
   <u>For situations with optional specialization</u> it is necessary to define for both the generalization and its specializations at least one identifying property because the case attribute may be *“nil”,* indicating there is not any specialization instance. A specialization may inherit this identifying property from its generalization (for example, in Section 3.2 “house” and “office” inherit from “building”), or a specialization may have its own identifying property defined over its intrinsic and inherited attributes (for example, “villa” in Section 3.1).
   <u>In situations with mandatory specialization</u> only the specializations must have at least one identifying property because an instance of a generalization with mandatory specialization may not exist without any associated specialization instance. Still it is possible that specializations inherit an identifying property of their generalization (for example: “branch” and “head office” inherit from their generalization “office”).
5. In order to support database transactions for the insertion of a generalization instance together with the possibly associated specialization instance(s), we propose to apply case attributes for mandatory and optional specialization as well. The value of a case attribute may be “*nil*” or equal to the name of an associated specialization type in the case of optimal specialization. However, in the case of mandatory specialization, this value must be equal to the name of the associated specialization type.

The actually required rules must be dealt with by the diverse subsystems of the Xplain-DBMS such as query interpreter and application generator. For example, the generator supports the design of correctly nested structures consisting of visible window fields for a generalization instance together with window fields for associated specialization instance(s) (ter Bekke, 1994, 1995). This application generator is also able to support the presentation of warnings about involved rules and other information.

6.2 Concepts for the specification of identifying properties

We demonstrated that convertibility of instances is not always rigorous enough a criterion for entity correctness. In order to design a generic solution for this weakness we require that identifying properties must always be specified explicitly, even when convertibility of instances is a satisfactory correctness requirement. Furthermore, each composite type must have at least one identifying property, except that generalizations with mandatory specialization do not need to have any identifying property. In the last case only the specializations must have at least one identifying property. An identifying property of a specialization type may be based on its intrinsic attributes and attributes inherited from its generalization.

In order to be able to register identifying properties and their constituting elements in a data dictionary we have to design new concepts such as “identifying property” and “element” in addition to the modeling concepts “type”, “attribute” and “role attribute”. An identifying property has to refer to a composite type without mandatory specialization and also must have a unique name because more than one identifying property per type is possible. Further, an identifying property must be based on at least one attribute (an element of the identifying property). Because it is possible that an identifying property is based on many attributes an element must refer to an identifying property and to an intrinsic attribute or an attribute inherited from its generalization. So there is a 1 : n cardinality ratio ($n > 0$) between “identifying property” and “element”.

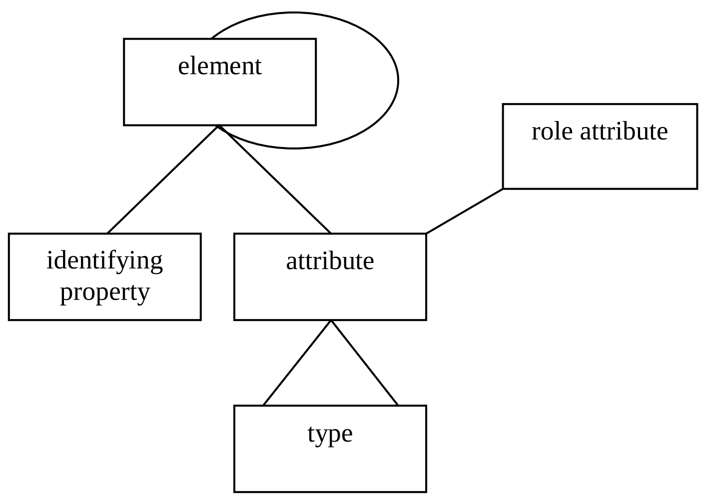
It is possible that a specialization has two references to its generalization (see the example in Section 5.2 with the types “commentary” and “report”) and inherits the identifying property of its generalization. Therefore it is necessary for a generic solution that an inheritance path via a series of elements can be specified. This leads to the following definition of new concepts for a data dictionary:

type identifying property = name, involved_type. /* unique name
type element = attribute, preceding_element, identifying property.

The concept of "element" refers to itself via "element *its* preceding_element". Similar recursive structures are also an essential part of meta models for data distribution and parallel input/output in database management systems (Bakker, 1994, 1998, 2000).

The original concepts of Xplain required that the value of "attribute *its* kind" must be either "A" (aggregation) or "G" (generalization/specialization). Then it was possible to derive from the value "G" and the simultaneous presence of a case attribute that mandatory specialization was meant. However, since we extended the scope of case attributes to optional specialization in order to support completeness of insert transactions, this derivation can no longer be applied. In order to solve this problem, we introduced in Section 3.3 two different values "O" and "M" for "attribute *its* kind" indicating either optional ("O") or mandatory specialization ("M").

In the case of "O" the generalization must have at least one identifying property, whereas "M" implies that the generalization needs not to have any identifying property. In this way it becomes possible to specify a generic rule indicating which types must have at least one identifying property. Examples with optional specialization are the generalizations "house" (specialization: "villa"), "building" (specializations: "house" and "office") and "employee" (specializations: "manager" and "teacher"). This consideration leads us to the extended meta model for the data dictionary of Xplain, shown in Figure 13.



type element = attribute, preceding_element, identifying property.
type identifying property = name, involved_type. /* unique name
type role attribute = [attribute], prefix.
type attribute = composite_type, type, kind.
type type = name, representation. /* unique name

Figure 13. Extended meta model for the Xplain data dictionary

The following assertions are needed for later discussed transactions checking correctness of a data model. They cannot interfere with the insertion of any instance because these assertions do not contain any value restriction:

assert type *its* composite = *any* attribute
per composite_type.
assert type *its* has optional specialization = *any* attribute *where* kind = "O"

per type.
assert type *its* has mandatory specialization = *any* attribute *where* kind = “M”
per type.
assert type *its* is a generalization = (has optional specialization *or* has mandatory specialization).
assert type *its* is a specialization = *any* attribute *where* kind = “O” *or* kind = “M”
per composite_type.
assert type *its* number of case attributes = *count* attribute *where* type *its* name = *“case”*
per composite_type.
assert type *its* has optional non-disjoint specialization = (number of case attributes > 1).
assert attribute *its* prefix = *some* role attribute *its* prefix
per attribute.

The *some* function produces a single random result (an empty result is specified as “*void”*). However, in this case this single result can only be a prefix or “void” because there is at most one role attribute per attribute.

Many correctness checks are required because not all required rules are inherent in the meta model. These checks can be specified in terms of assertions, but then some assertions will be triggered during the specification of types and attributes. For example, the following assertion for “type *its* correctness”, dealing with the required minimal number of identifying properties per type, is triggered by the insertion of a new type and could require some additional insertions in the case of some composite types:

assert type *its* number = *count* identifying property
per involved_type.
assert type *its* correct (*true*) = (composite *and* (*not* is a generalization *and not* is a specialization *and* number ≥ 1
or has optional specialization *and* number ≥ 1 *or* has mandatory specialization *and* number = 0
or is a specialization *and* number ≥ 1) *or not* composite *and* number = 0).

In order to prevent this interference during the specification of a data model it is better to separate concerns, thus to use checking transactions that must be executed by a database administrator after completing the registration of all types, attributes and role attributes. We can distinguish four main tasks for such checking transactions:

1. Checking the correctness of a data model.
   For example, in the case of generalization/specialization each specialization block is identified by the prefix in the attribute referring from a specialization to the generalization. It is required that the same prefix is applied in the involved case attribute.
2. Checking the required minimal number of identifying properties.
   Each composite type must have at least one identifying property, but in the case of mandatory specialization the generalization needs not to have any identifying property.
3. Checking the required minimal number of elements.
   Each identifying property must have at least one element (based on an attribute) referring to that identifying property.
4. Checking the correctness of elements.
   The recursive definition of the concept “element” as such does not enforce that a sequence of elements is correctly specified, so a check for correctness is necessary.

We can specify the required checks in the language of Xplain or we describe them. Because of the structure of the extended meta model it makes sense to register meta data and check their correctness in the following order:

1. Data model (types, attributes and role attributes),
2. Identifying properties (they refer to a composite type) and
3. Elements (they refer to an identifying property).

The required checking transactions will be discussed extensively in Appendix I.

7 DISCUSSION

One principle in Xplain databases remains unchanged: each instance of a composite type has a single, unmodifiable identifier. This is an essential difference with the relational language SQL that allows for a composite primary key even when consisting of modifiable attributes (Connolly, Begg, & Strachan, 1995). A modification of such a key can lead to time consuming consequences for data management, especially when a modifiable primary key is referenced by a foreign key in another relation.

Although convertibility of instances is not an incorrect criterion for uniqueness of instances, it is not always a satisfactory correctness criterion for instances. In Section 2.2 the example based on Figure 1 showed that incorrect instances can lead to derivations producing wrong results. The same problem can occur in the case of recursive calculations (Section 2.1). Aiming at a generic standard solution, stricter rules for correctness of instances should be specified in terms of identifying properties, even if convertibility of instances happens to be a satisfactory criterion for correctness of instances. Therefore we introduced new concepts supporting the specification of identifying properties and their constituting elements. Correctness of these data can be supported by checking transactions if the following standard solution is applied:

Each composite type must have at least one identifying property. The only exception is that a mandatory generalization need not have any identifying property (examples: the furniture case with “product” and the bank case with “office”, both in Section 3.3). In this standard solution it is even possible (see the bank case) that a specialization inherits an identifying property from its generalization. However, if a composite type has more than one identifying property, it is the responsibility of a database designer to specify all required identifying properties.

An alternative is to use the same proposed meta model without applying the proposed standard solution. In many cases it is sufficient to specify an identifying property for only a generalization. For example, if we specify an identifying property for the generalization “building” (specializations: “house” and “office”), then there is no need to specify any identifying property for the specializations. However, such ad hoc choices cannot be checked for correctness by predefined transactions because they do not comply with the described standard solution. Allowing such ad hoc decisions would imply a heavier burden for a database designer.

Berend de Boer and Johan ter Bekke (2001) showed that data definitions and queries in Xplain can be transformed into correct SQL specifications (ter Bekke, 1994, 1995, 1999). Contrary to this conversion, the present paper opens the possibility for a reverse transformation, which is very important considering the large number of existing relational databases. The Xplain-DBMS has a facility to import records from other databases (ter Bekke, 1998). If the relational data have a composite primary key, then Xplain can automatically generate the single identifier for each instance to be inserted. However, it probably is better to execute other modifications (corrections) in the relational database itself, in particular because of the need to check for referential integrity. Possible complications are: foreign keys with a “null” value or foreign keys consisting of many attributes, to be replaced by a single foreign key. The advantage obtained by such a transformation is that the Xplain language can be used. This language is more suitable for end user computing than SQL because in Xplain join operations and nested queries need not and cannot be specified, which is also important for database security. For example, in many cases security holes can be attributed to improperly formed SQL queries (North, 2010). We have demonstrated (ter Bekke, 1997; Bakker & ter Bekke, 2001) that the Xplain language is better and simpler structured than SQL, which makes it easier to prevent improperly specified queries. This is extremely important in open systems accessible via the Internet.

Unfortunately, the extension of Xplain with recursive operations was the last main improvement Johan ter Bekke was able to implement. Considering the strict dependency between data manipulation and data structure in the Xplain-DBMS - also in the case of recursive operations - we may consider his work as an essential contribution to the field of database management systems but also to end user computing. Moreover, his work also demonstrates that query-functionality is limited by data structure as defined by a data model. The present paper has shown that in many cases - with or without generalization/specialization - convertibility of instances is not a satisfactory requirement for correctness of instances and that additional uniqueness rules - using identifying properties - have to be applied in order to guarantee that (recursive) calculations in queries produce correct results.

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9 REFERENCES

Aho, A.V., Hopcroft, J.E., & Ullman, J.D. (1974) *The Design and Analysis of Computer Algorithms*, Addison-Wesley, Reading (MA), p. 208.

Bailey, D.A. (1999) *Java structures: Data structures in JAVA for the principled programmer*, MacGraw-Hill, Boston, USA.

Bakker, J.A. (1994) A semantic approach to enforce correctness of data distribution schemes, *The Computer Journal 37 (7)*, pp. 561-575.

Bakker, J.A. (1998) An extended meta model for conditional fragmentation, *Proceedings 9th International Conference on Database and Expert Systems Applications DEXA'98,* Vienna, Austria, Eds. Quirchmayr, G., Schweighofer, E. & Bench-Capon, T.J.M., Lecture Notes in Computer Science 1460, pp. 702-715.

Bakker, J.A. (2000) A semantic framework for the design of data distribution schemes, *Proceedings 11th International Workshop on Database and Expert Systems Applications,* Greenwich, London, UK, Eds. Tjoa, A.M., Wagner, R.R. & Al-Zobaidie, A., pp. 653-660.

Bakker, J.A. (2000) Semantic partitioning as a basis for parallel I/O in database management systems, *Parallel Computing 26*, pp. 1491-1513.

Bakker, J.A. & Bekke, J.H. ter (2001) Maintaining derived information using dynamic rule ordering, *Proceedings International Conference on Intelligent Systems and Control (ICSC 2001),* Clearwater, Florida, Ed. Hamza, M.H., pp. 253-260.

Bakker, Bert & Bekke, J. H. ter (2001) Foolproof query access to search engines, *Proceedings Third International Conference on Information Integration and Web-based Applications & Services (IIWAS 2001)*, Linz, Austria, Eds. Winiwarter, W., St. Bressan, St. & Ibrahim, I.K., pp. 389 - 394.

Bakker, J.A. & Bekke, J.H. ter (2002) Efficient maintenance of derived information in active databases, *Proceedings 6th International Conference on Artificial Intelligence and Soft Computing,* Bannf, Canada, Ed. Leung, H., pp. 118-122.

Bakker, J.A. & Bekke, J.H. ter (2004) A query language solution for fastest flight connections, *Proceedings IASTED International Conference on Databases and Applications*, Innsbruck, Austria, Ed. Hamza, M.H., pp. 197-202.

Bakker, J.A. & Bekke, J.H. ter (2004) A query language solution for shortest path problems in cyclic geometries, *Proceedings IASTED International Conference on Databases and Applications*, Innsbruck, Austria, Ed. Hamza, M.H., pp. 203-207.

Bancilhon, F. & Ramakrishnan, R. (1986) An amateur's introduction to recursive query processing strategies, *Proceedings 1986 ACM SIGMOD International Conference on Management of Data*, Washington D.C., USA, pp. 16-52.

Bang-Jensen, J. & Gutin, G. (2001) *Digraphs: Theory, Algorithms and Applications*, Springer-Verlag, London, UK.

Bekke, J.H. ter (1980) Convertibility in databases, *Information Processing Letters 11*, number 4/5 (December 12), pp. 168-171.

Bekke, J.H. ter (1983) *Database Ontwerp,* Stenfert Kroese, Leiden, the Netherlands (in Dutch).

Bekke, J.H. ter (1991) *Semantic data modeling in relational environments*, doctoral thesis, Delft University of Technology, Delft, the Netherlands.

Bekke, J.H. ter (1992) *Semantic Data Modeling*, Prentice Hall International, Hemel Hempstead, UK.

Bekke, J.H. (1993) *Database Ontwerp,* Kluwer Bedrijfswetenschappen, Deventer, the Netherlands (in Dutch).

Bekke, J.H. ter (1994) Complex values in databases, *Proceedings International Conference on Data and Knowledge Systems for Manufacturing and Engineering,* Hong Kong, Ed. Chen, N., pp. 449-455.

Bekke, J.H. ter (1995) Meta modeling for end user computing, *Proceedings Workshop on Database and Expert Systems Applications DEXA 1995,* London, UK, Eds. Revell, N. & Tjoa, A. M., pp. 267-273.

Bekke, J.H. ter (1997) Can we rely on SQL?, *Proceedings 8th International DEXA Workshop,* Toulouse, France, Ed. Wagner, R.R., IEEE Computer Society, pp. 378-383.

Bekke, J.H. ter (1997), Advantages of a compact semantic meta model, *Proceedings 2nd IEEE Metadata Conference*, Silver Spring, USA. Retrieved from the World Wide Web, February 11, 2012: http://www.computer.org/conferen/proceed/meta97/papers/jterbekke/jterbekke.html

Bekke, J.H. ter (1998) *Xplain manual* (in Dutch), version 5.4, Delft University of Technology, Delft, the Netherlands (in Dutch).

Bekke, J.H. ter (1999) Semantic requirements for databases in casual environments, *Electronic Proceedings of SAICSIT '99: Prepare for the New Millennium,* Johannesburg, South Africa, Ed. P. Machanick, pp.1-10.

Bekke, J.H. ter & Bakker, J.A. (2001) Limitations of relationships constructed from coinciding data, *Proceedings International Conference on Intelligent Systems and Control (ICSC 2001)*, Clearwater, Florida, USA, Ed. Hamza, M.H., pp. 247 - 252.

Bekke, J.H. ter & Bakker, J.A. (2002) Content-driven Specifications for Recursive Project Planning Applications, *Proceedings IASTED International Conference on Applied Informatics*, Innsbruck, Austria, Ed. Hamza, M.H., pp. 448-452.

Bekke, J.H. ter & Bakker, J.A. (2002) Recursive queries in product database, *Proceedings 5th International Conference on Flexible Query Answering Systems (FQAS 2002)*, Copenhagen, Denmark, October 27-29, Lecture Notes in Computer Science (Subseries LNAI) Volume 2522, Eds. Andreasen, T., Motro, A., Christiansen, H. & Legind Larsen, H., Springer-Verlag, Berlin-Heidelberg, pp. 44-55.

Bekke, J.H. ter & Bakker, J.A. (2003) Modeling and Querying Recursive Data Structures I: Introduction, *Proceedings 7th International Conference on Artificial Intelligence and Soft Computing,* Banff , Canada, Ed. Leung, H., pp. 278-282.

Bekke, J.H. ter & Bakker, J.A. (2003) Modeling and Querying Recursive data Structures II: A Semantic Approach, *Proceedings 7th International Conference on Artificial Intelligence and Soft Computing*, Banff, Canada, Ed. Leung, H., pp. 283-289.

Bekke, J.H. ter & Bakker, J.A. (2003) Fast recursive data processing in graphs using reduction, *Proceedings IASTED International Conference on Applied Informatics*, Innsbruck, Austria, Ed. Hamza, M.H., pp. 490-494.

Boer, Berend de & Bekke, J.H. ter (2001) Applying semantic database principles in a relational environment, *Proceedings International Symposium Applied Informatics (AI2001),* Innsbruck, Austria, Ed. Hamza, M.H., pp. 400-405.

Codd, E.F. (1970) A relational model of data for large shared data banks, *Communications of the ACM 13*, pp. 377-387.

Connolly, T., Begg, C., & Strachan, A. (1995) *Database Systems, A practical approach to design, implementation and management*, 6th ed., Addison-Wesley, Reading (MA).

Dar, S. & Ramakrishnan, R. (1994) A performance study of transitive closure algorithms, *ACM SIGMOD Record, 23*, pp. 454-465.

Elmasri, R. & Navathe, S.B. (2010) *Fundamentals of Database Systems*, 6th ed., Addison-Wesley.

Karayiannis, A. & Loizou, G. (1978) Cycle detection in critical path networks, *Information Processing Letters, 7,* pp. 15-19.

Molluzzo, J.C. (1986) *A first course in discrete mathematics*, Wadsforth, Belmont CA.

North, K. (2010) Terabytes to Petabytes: Reflections 1999-2009, *Dr. Dobb's*, January 4. Retrieved from the World Wide Web, February 13, 2012: http://drdobbs.com/blogs/architecture-and-design/228701466

Rolland, F. (1998) *The essence of databases*, Prentice Hall, Hemel Hempstead, UK.

Rosenthal, A., Heder, S., Dayal, U. & Manola, F. (1986), Traversal Recursion: A Practical Approach to Supporting Recursive Applications, *Proceedings ACM SIGMOD International Conference on Management of Data*, Washington D.C., USA, pp. 166-176.

Smith, J.M & Smith, D.C.P. (1977) Database abstractions: aggregation, *Communications of the ACM 20*, pp. 405-413.

Smith, J.M. & Smith, D.C.P. (1977) Database abstractions: aggregation and generalization, *ACM Transactions on Database Systems 2*, pp. 105-133.

Suciu, D. & Paredaens, J. (1994) Any algorithm in the complex object algebra with power set needs exponential space to compute transitive closure, *Proceedings ACM SIGACT-SIGMOD-SIGART Symposium on Principles of Database Systems*, Minneapolis, Minnesota, USA, pp. 201-209.

Ullman, J.D. & Widom, J. (1997) *A first course in Database Systems*, Prentice Hall, Hemel Hempstead.

Many of these publications and related work can be found via http://www.jhterbekke.net/publications.html

APPENDIX I

I.1 Checking the correctness of a data model

Some of the required rules (assertions) are already mentioned in relation to Figure 10. It makes sense to check the underlying data model for correctness. For example, the prefix of a case attribute must be equal to the prefix in an attribute referring from a specialization to a generalization. Further, for each composite type the number of case attributes must be equal to the number of specialization blocks. In the case of disjoint specialization the block number must be one. If a type is not a specialization and also not a generalization then its block number must be zero. In the case of optional non-disjoint specialization there must be two or more blocks (for example, "employee" has overlapping specializations "teacher" and "manager").

extend type *with* block number = *count* attribute *its* prefix *where* kind = "O" *or* kind = "M"
per type.
extend type *with* correct = (number of case attributes = block number

and has optional specialization *and* block number = 1 *or* has mandatory specialization *and* block number = 1
or has optional non-disjoint specialization *and* block number > 1
or not is a generalization *and not* is a specialization *and* block number = 0)).

get type *its* name, number of case attributes, block number *where* composite *and not* correct.

The prefix in a case attribute must be equal to the prefix in the attribute referring from a specialization to a generalization:

extend type *with* block name 1 = *some* attribute *its* prefix *where* kind = "O" *or* kind = "M"
per type.
extend type *with* block name 2 = *some* attribute *its* prefix
where kind = "O" *or* kind = "M" *and not* prefix = type *its* block name 1
per type.
extend attribute *with* correct prefix = (type *its* name = *"case" and* (prefix = composite_type *its* block name 1
or prefix = composite_type *its* block name 2) *or not* type its name = *"case*".

get attribute *its* composite_type *its* name *where* type *its* name = *"case" and not* correct prefix.

In a similar way more block names can be copied into derived attributes of a generalization.

I.2 Checking the required minimal number of identifying properties

An identifying property must have a unique name and must be specified through a set of (possibly inherited) elements. Further, "identifying property *its* involved_type" must be a composite type. Incorrectly specified identifying properties are retrieved by:

get identifying property *its* name, involved_type *its* name *where not* involved_type *its* composite.

It is also required that almost each composite type has at least one identifying property. Only a generalization with mandatory specialization needs not to have any identifying property:

extend type *with* number = *count* identifying property
per involved_type.
extend type *with* correct = (*not* is a generalization *and not* is a specialization *and* number > 0
or has optional specialization *and* number > 0 *or* has mandatory specialization *and* number = 0
or is a specialization *and* number > 0 *or not* composite *and* number = 0).
get type *its* name, number of identifying properties *where* composite *and no*t correct.

However, the number of identifying properties a type must have cannot be derived from a data model. This remains the responsibility of the involved database designer. An example of a composite type with two identifying properties is "department" (Section 2, Table 4).

I.3 Checking the required minimal number of elements

The number of elements per identifying property must be at least one:

extend identifying property *with* number of elements = *count* element
per identifying property.
get identifying property *its* name, involved_type *its* name, number of elements
where number of elements = 0.

I.4 Checking the correctness of elements

Elements in a path belong to the same identifying property. Therefore "element *its* identifying property" must be equal to "element *its* preceding_element *its* identifying property". This rule does not apply if an element is not preceded by another element (it is a first or 'lowest' element in a path). Then it is necessary to apply a special value such as "0" for "element *its* preceding_element". For example, the element participating in the identifying property of "chest", based on the attribute "product *its* description" (Section 4.3) is not preceded by any element.

For a really existing preceding element, "element *its* attribute *its* type" must be equal to "element i*ts* preceding_element *its* attribute *its* composite_type". An example is "chest *its* product *its* weight" participating in the identifying property of "chest". Here "chest *its* **product**" corresponds with a last path element ('highest' in a path) preceded by an element based on the attribute "**product** *its* weight". An element not referenced by another element has the last position in a path, and therefore this "element *its* attribute *its* composite_type" must be equal to "element *its* identifying property *its* involved_type". An example is the last element in the path "branch *its* office *its* town", which corresponds with "branch *its* office", an attribute of the type "branch". Other examples are last elements without a preceding element. They are based on an intrinsic attribute, for example elements based on attributes of the generalization "house" (Section 4.1).

extend element *its* has last position = *nil* element
per preceding_element.
extend element *with* correct position = (has last position
and attribute *its* composite_type = identifying property *its* involved_type
or not has last position *and not* attribute *its* composite_type =
identifying property *its* involved_type).
extend element *with* correct = (correct position *and* (preceding_element = 0
or attribute *its* type = preceding_element *its* attribute *its* composite_type
and identifying property = preceding_element *its* identifying property)).

get element *its* identifying property *its* name, preceding_element *its* identifying property *its* name,
attribute *its* type *its* name, preceding_element *its* attribute *its* type *its* name, correct position
where not correct.

An identifying property can be specified in the Xplain language by a correctly ordered list of (inherited) attributes after the name of an identifying property. In this way the problem of redundancy in the last element can be avoided because the first attribute mentioned after "*identifying property* <name> = " corresponds with the last element in a path and belongs to the composite type for which the identifying property is specified. For example, we can design a language syntax that allows us to specify the identifying property of "chest" as:

identifying property chest idprop =
chest *its* number of drawers, chest *its* depth, chest *its* width, chest *its* height, chest *its* kind of wood,
chest *its* product *its* description, chest *its* product *its* weight, chest *its* product *its* production_cost.

The DBMS can derive that the definition of this identifying property includes the involved type "chest" and five elements without a preceding element (preceding_element = 0) and three different last elements based on the same referencing attribute "chest *its* product" but with different preceding elements based on different attributes of the type "product".

APPENDIX II

In this appendix we describe cycle detection, graph reduction and the ordering of data to be processed. Together they are the basis for safe recursive operations by end users. Graphs can be based on the following data definitions:

type node (A2) = description (A30). /* nodes identified by one or two characters
type arc (I2) = from_node (A2), to_node (A2), length (R3,1). /* arcs identified by an integer

II.1 Cycle detection

In Figure 14 we show a directed graph containing a cycle (BDEB):

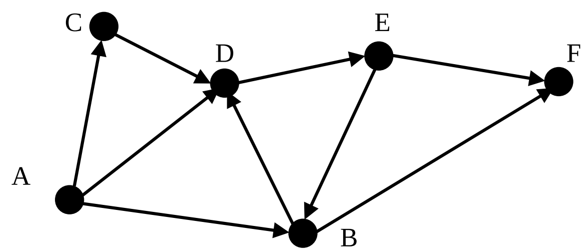


Figure 14. An example of a directed graph with a cycle

The following steps constitute the first reduction step:
1. Find the nodes without any incoming arc (here: node A).
2. Remove the arcs starting in the nodes without any incoming arc (here: arcs (AC), (AD) and (AB)).
3. Remove the nodes not connected with any other node (here: node A).

The result is shown in the following Figure 15:

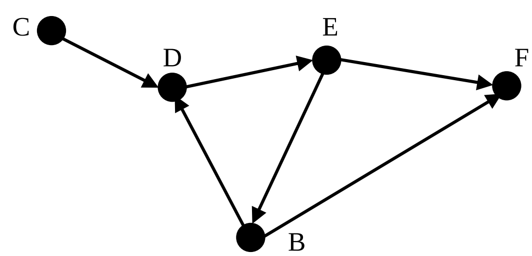


Figure 15. Result of the first reduction step

The next reduction step produces the graph in Figure 16:

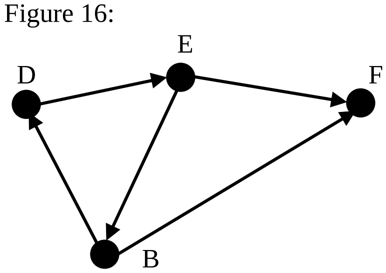


Figure 16. Result of the second reduction step

Now there are no more nodes without any incoming arc and the reduction process continues with finding the nodes without any outgoing arc (here: F): this is reverse reduction. Now the arcs ending in these nodes have to be removed. Figure 17 shows the result:

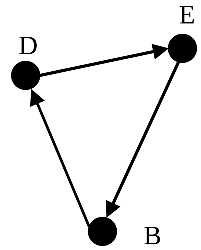


Figure 17. Result of the first reverse reduction

Further reduction is impossible because of the cycle (Bang-Jensen & Gutin, 2001). Xplain informs the user on the arcs and nodes in a cycle. In Xplain cycle detection is an integral part of the algorithm translating a cascading update command into a well ordered processing of the data in arcs. The following section shows an example of ordering and data processing.

II.2 Ordering and data processing

The following example shows that ordering occurs during graph reduction. Table 7 presents the data on arcs and nodes, whereas Figure 18 shows the corresponding directed acyclic graph including the length of arcs and the initial value of the derivable attribute "node *its* firstdist" for each node. Their meaning will become clear after reading the following query specifying a solution for finding the shortest distance between a start node and a finish node. The kind of processing depends on the function used by the cascade command. The query approach determines for each node the distance to the start node (node *its* firstdist) using reduction and the distance (node *its* seconddist) to the finish node using reverse reduction. As an initialization the first extend operation assigns a value for the distance between a node and the start node that is larger than the longest possible path, which occurs if the graph is a linear sequence of arcs. This distance must be updated for the start and finish nodes. The first six commands have to deal with user interaction, so that at run time start and finish node can be entered:

value start = input (a1) "Enter the start node (a letter): ".
value finish = input (a1) "Enter the finish node (a letter): ".
value text1 = "start: ". /* Assigning a value to text1.
value text1. *value* start. /* Two print commands.
value text2 = "finish: ".
value text2. *value* finish.
newline.
value maximum = *total* arc *its* length. /* A path cannot be longer than "maximum" (here 409).
extend node *with* firstdist = maximum. /* Initialization of "node *its* firstdist".
update node start *its* firstdist = 0. /* This value is not affected by the cascading update.
cascade node *its* firstdist = *min* arc *its* length + from_node *its* firstdist
per to_node. /* Calculate the shortest distance to the start node.

In order to be able to find the arcs and nodes lying on a shortest route we also have to apply reverse reduction in order to calculate the distance to the finish node ("node *its* seconddist"). Then the minimum value of "node *its* firstdist + node *its* seconddist" can be calculated, then the minimal value of this sum and finally the nodes participating in the shortest route(s) between start and finish are determined. There can be zero or more shortest routes between start and finish.

extend node *with* seconddist = maximum. /* Second initialization
update node finish *its* seconddist = 0. /* Initialization for the finish node.
cascade node *its* seconddist = *min* arc *its* length + to_node *its* seconddist

per from_node. /* Calculate the shortest distance to the finish node.

Now we can determine the nodes lying on a shortest route between start and finish:

extend node *with* distance = firstdist + seconddist. /* Distance to start + distance to finish.
value minimum = *min* node *its* distance. /* minimum: length of a shortest route.
extend node *with* OK = (distance = minimum *and* minimum < maximum). /* OK: node lies on a shortest route.

Because there can be more than one shortest route between two nodes it makes sense to include the relative position of nodes to the position of the starting node:

value highest = *count* arc. /* If the graph is a sequence of arcs.
extend node *with* position = highest + 1. /* Initialization with the highest possible value.

update node start *its* position = 1. /* Initialization for the start node.
cascade node *its* position = *min* arc *its* from_node *its* position + 1
per to_node.
value comment1 = “The number of shortest routes from start to finish node is:”. *value* comment1.
get count arc *where* from_node *its* OK *and* to_node *its* OK *and* from_node = start.
newline.
value comment2 = “Nodes lying on a shortest route from start to finish node:”. *value* comment2.
newline.
value comment3 = “node id., position, firstdist, seconddist, distance”. *value* comment3.

get node *its* position, “ “, firstdist, “ “, seconddist, “ “, distance *where* OK
per firstdist. /* node identification is automatically included.

In the last retrieval the empty strings are included to create the desired presentation distance between the values to be presented. The presentation order of nodes is by increasing value of the distance (*per* firstdist) to the start node.

If “B” is the start node and “K” the finish node then the query result is:

```
start:
B
finish:
K

The number of shortest routes from start to finish node is:
Count = 1

Nodes lying on a shortest route from start to finish node:

node id. position  firstdist  seconddist  distance
B           1           0        102        102
D           2          18         84        102
F           3          39         63        102
G           4          63         39        102
H           5          83         19        102
K           6         102          0        102
```

If “K” is the start node and “B” the finish node then the result of the query is that there is not a shortest path KB:

```
start:
K
finish:
B

The number of shortest routes from start to finish node is:
Count = 0

Nodes lying on a shortest route from start to finish node:

node id. position  firstdist  seconddist  distance
```

If “C” is the start node and “G” the finish node then the result of the query is:

```
start:
C
finish:
G

The number of shortest routes from start to finish node is:
Count = 2

Nodes lying on a shortest route from start to finish node:

node id. position  firstdist  seconddist  distance
C           1          0         71         71
D           2         26         45         71
E           2         32         39         71
F           3         47         24         71
G           3         71          0         71
```

In the case of only one shortest route we can retrieve the nodes on that route in a well ordered manner: ordered by the distance to the starting point. However, inherent in the described solution for the shortest path problem is that we cannot specify the shortest routes separately if there is more than one shortest route. In the case of a shortest route from “C” to “G” the user must be aware that there are two shortest routes and that arc EF is not part of a shortest route because both “F” and “G” have the same relative position: 3. Each of these nodes lies on a different shortest route from “C” to ”G”. Moreover, if CEFG would be a shortest route then the relative position of “G” must be one higher than the relative position of “F”. Table 7 shows the data used for the construction of our example of an acyclic directed graph.

Table 7. Data on arcs present in the graph of figure 18

arc	from_node	to_node	length
1	A	B	29
2	A	C	22
3	C	B	24
4	B	D	18
5	C	D	26
6	C	E	32
7	D	F	21
8	E	F	26
9	E	G	39
10	E	K	61
11	E	H	48
12	F	G	24
13	G	H	20
14	H	K	19

Figure 18 shows the corresponding network. The length of arcs is presented and the values of "node *its* firstdist" are placed between square brackets. Initially all these values are the same: 409. Arcs are identified by their start and finish nodes. We describe graph reduction and the well ordered data processing required for finding the shortest path(s) from node "C" to node "G".

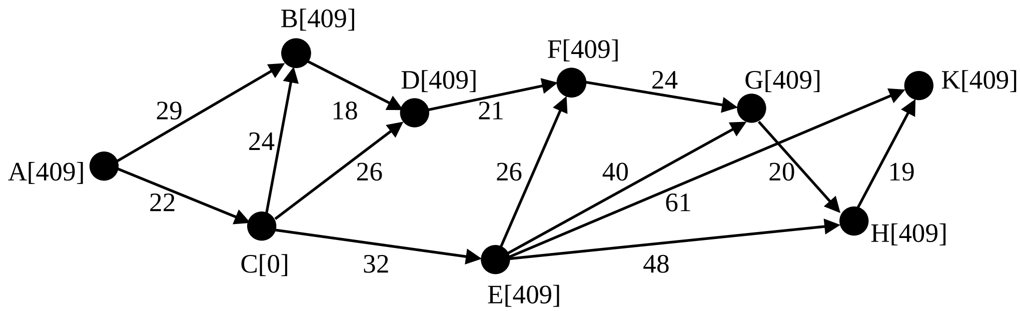
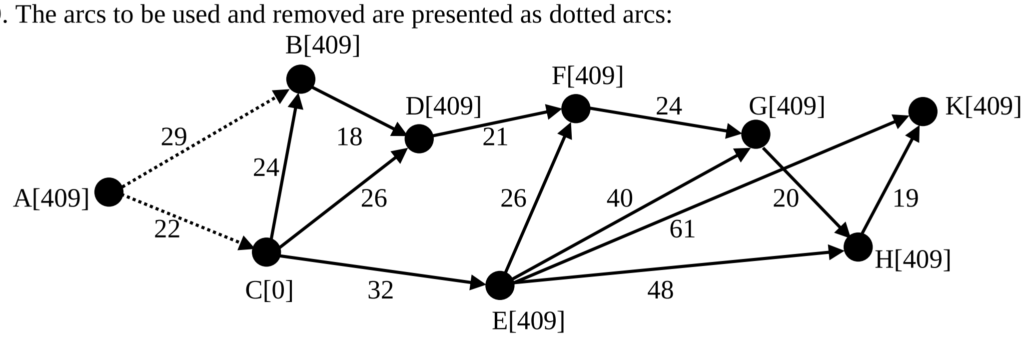


Figure 18. A directed graph without any cycle after initialization of "node *its* firstdist"

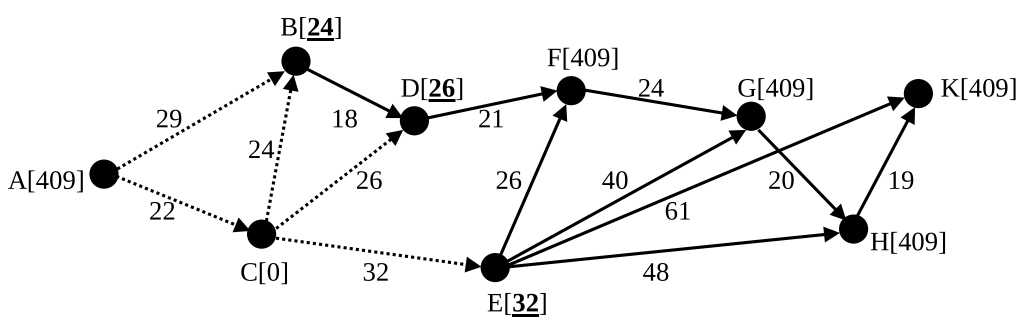
The first reduction step produces a reduced graph and a first group of arcs [(AB) and (AC)] to be processed, see figure 19. The arcs to be used and removed are presented as dotted arcs:



Group 1: arcs (AB) and (AC).

Figure 19. Remaining graph after the first reduction step

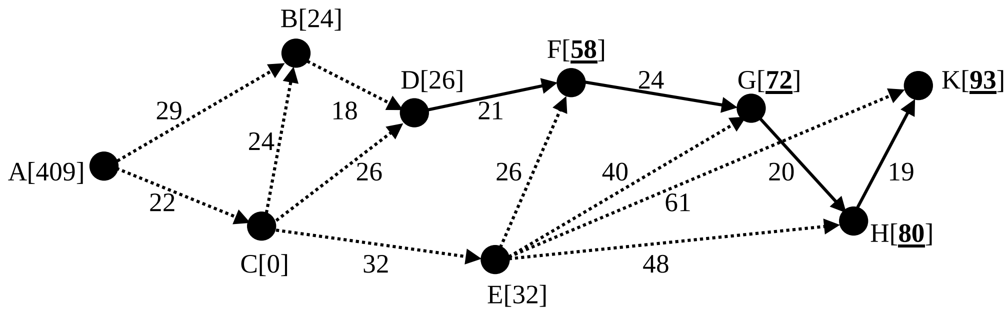
Group 1 contains the arcs [(AB), (AC)]. The length of an arc plus the value of "arc *its* from_node *its* firstdist" is used by cascade commands for the recalculation of the value of "node *its* firstdist" belonging to the destination nodes "B" and "C". In this case, because of the "*min*" set function, these values need not to be modified. In the second reduction step the arcs (CB), (CD) and (CE) have to be used and removed, see figure 20. Modified values produced after a reduction step are presented in a bold type face and are also underlined.



Group 1: arcs (AB) and (AC).
Group 2: arcs (CB), (CD), and (CE).

Figure 20. Remaining graph after the second reduction step

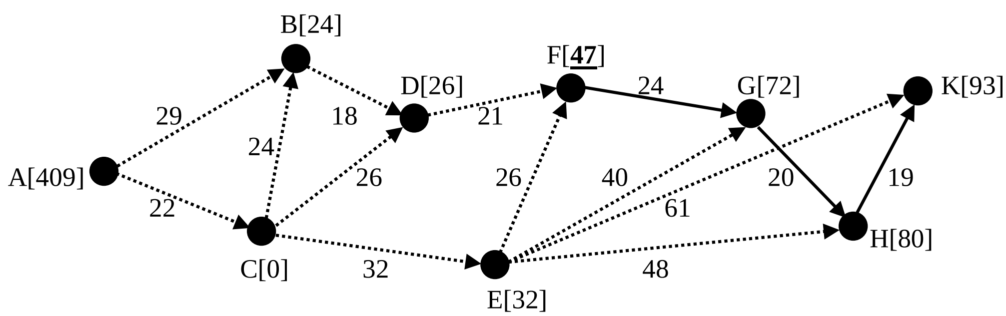
The third reduction step produces a further reduced graph and a third group of removed arcs (figure 21):



Group 1: arcs (AB) and (AC).
Group 2: arcs (CB), (CD) and (CE).
Group 3: arcs (BD), (EF), (EG), (EK) and (EH).
Arc (DF) is not in group 3, so its length is irrelevant for updating "node "F" *its* firstdist" at this time.

Figure 21. Remaining graph after the third reduction step

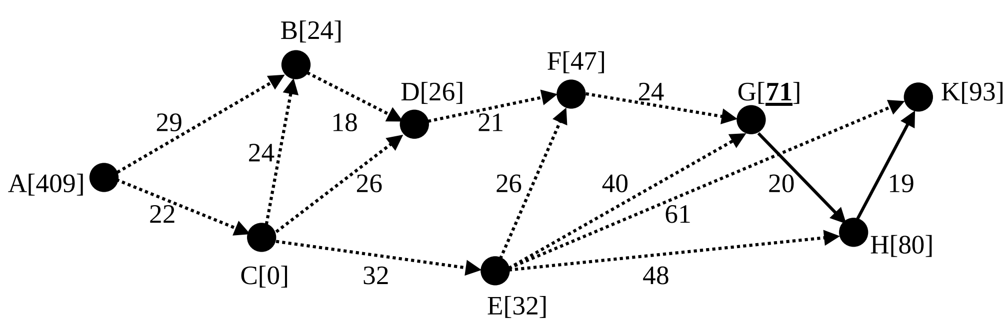
Now the remaining graph is a sequence (DFGHK), so the fourth reduction steps leads to the data shown in Figure 22.



Group 1: arcs (AB) and (AC).
Group 2: arcs (CB), (CD) and (CE).
Group 3: arcs (BD), (EF), (EG), (EK) and (EH). Group 4: arc (DF). Now "node "F" *its* firstdist" is updated.

Figure 22. Remaining graph after the fourth reduction step

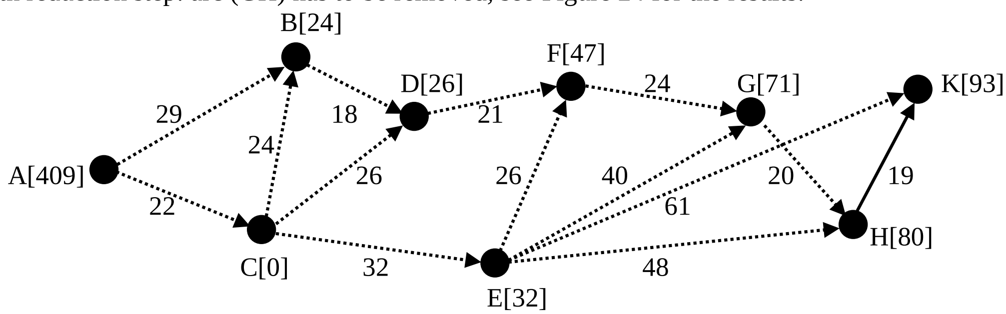
Figure 23 shows the results after removing the arc (FG):



Group 1: the arcs (AB) and (AC).
Group 2: the arcs (CB), (CD) and (CE).
Group 3: the arcs (BD), (EF), (EG), (EK) and (EH). Group 4: arc (DF).
Group 5: arc (FG). Now “node “G” *its* firstdist” is updated.

Figure 23. Remaining graph after the fifth reduction step

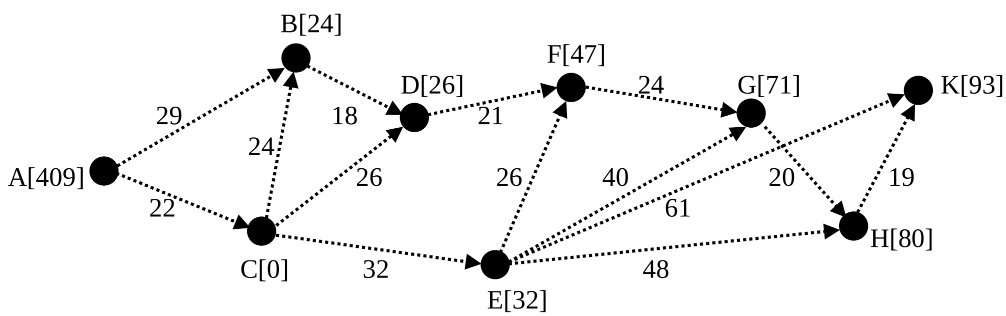
In the sixth reduction step: arc (GH) has to be removed, see Figure 24 for the results:



Group 1: arcs 1(AB), 2(AC.
Group 2: arcs 3(CB), 5(CD), 6(CE).
Group 3: arcs 4(BD), 8(EF), 9(EG), 10(EK), 11(EH). Group 4: arc 7(DF).
Group 5: arc 12(FG). Group 6: arc 13(GH). Now “node “H” *its* firstdist” remains unchanged.

Figure 24. Remaining graph after the sixth reduction step

Figure 25 shows the results after the seventh reduction step, the removal of arc (HK):



Group 1: arcs (AB) and (AC).
Group 2: arcs (CB), (CD) and (CE).
Group 3: arcs (BD), (EF), (EG), (EK) and (EH).
Group 4: arc (DF).
Group 5: arc (FG).
Group 6: arc (GH).
Group 7: arc (HK). Now “node “K” *its* firstdist” remains the same.

Figure 25. Remaining graph after the seventh reduction step

Irrespective the kind of operation used by a cascade command the properties (intrinsic or derived) of the arcs are used in the following order: group 1, group 2, group 3, group 4, group 5, group 6, group 7. Within each group the processing order is irrelevant.

In a similar way the reverse graph reduction is executed for the calculation of “node *its* seconddist”. Further processing and presenting the results has been described in the query.

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