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On Enforcing Existence and Non-Existence Constraints in MatBase

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Abstract

Existence constraints were defined in the Relational Data Model, but, unfortunately, are not provided by any Relational Database Management System, except for their NOT NULL particular case. Our (Elementary) Mathematical Data Model extended them to function products and introduced their dual non-existence constraints. *MatBase*, an intelligent data and knowledge base management system prototype based on both these data models, not only provides existence and non-existence constraints, but also automatically generates code for their enforcement. This paper presents and discusses the algorithms used by *MatBase* to enforce these types of constraints.

Keywords: Existence and Non-Existence Constraints; The (Elementary) Mathematical Data Model; *MatBase*; Database Design; Non-relational Constraint Enforcement

Introduction

Unfortunately, no commercial Relational Database Management System (RDBMS) is providing this constraint type, but only its particularization $\varnothing \mid -g$, which is called *NOT NULL* (or *required values*) *constraint*.

You cannot use the *tuple constraint type* (i.e., constraints of the type $(\forall x \in D)(P(x))$, where P is a first order logic predicate involving only functions defined on D) either for enforcing existence constraints in commercial RDBMSes. For example, MS SQL Server syntactically accepts a check constraint reading "not f is null and not g is null" for a table containing columns f and g accepting nulls (and, e.g., both of type int), but you cannot save it in the schema of that table (e.g., under the name "CK_test"), as it is semantically rejected with the following error message: "Unable to add constraint 'CK_test'. The ALTER TABLE statement conflicted with the CHECK constraint 'CK_test'."

In our (Elementary) Mathematical Data Model ((E)MDM) [4, 5], tables are considered (object) sets and their columns are functions defined on the corresponding sets and taking values in either value (i.e., data type) or object sets. Hence, the NOT NULL constraints are called *total* ones (i.e., corresponding functions are totally defined). Besides \varnothing (i.e., the empty set), (E)MDM also considers the distinguished countable set of *null values* (be them temporarily unknown or inapplicable), denoted *NULLS*. For example, *SSN* • *BirthDate* : *PERSONS* \rightarrow (NAT(9) \cup NULLS) x ([1/1/1900, Today()] \cup NULLS) may be simply declared as *SSN* • *BirthDate* : *PERSONS* \rightarrow NAT(9) x [1/1/1900, *Today*()], as none of these two functions is totally defined (because not everybody is entitled to an SSN).

(E)MDM also extends the existence constraints, by allowing on both sides of the implication sign, computed functions, not only atomic ones. For example, $SSN \mid BirthDate \cdot Sex$ asks that both BirthDate and Sex be not-null whenever SSN is not-null, while $EYear \mid FName \cdot FirstBook$, forces users to also specify the first name for the first author of any book for which there is at least an edition having that book as its first one and for which the edition year is known (see the $Public\ Library\ db\ from\ [3]$). Generally, for any $f \cdot g : D \rightarrow C_f \times C_{g'} f \mid g$, means ($(\forall x \in D)\ (f(x) \notin NULLS) \Rightarrow g(x) \notin NULLS$).

Moreover, (E)MDM also considers a dual of existence constraints: a *non-existence constraint* is denoted $f \neg \vdash f_1 \bullet ... \bullet f_n$ and stands for $(\forall x \in D)(f(x) \notin \text{NULLS} \Rightarrow f_i(x) \in \text{NULLS}, \forall i, 1 \le i \le n)$, where n > 0 is a natural. For example, *TributaryTo* $\neg \vdash Lake \bullet Sea \bullet Ocean \bullet LostInto$ asks that, whenever a river is tributary to another one, its values for *Lake, Sea, Ocean,* and *LostInto* be nulls.

For cases in which at most one function from a product might take a not null value, (E)MDM provides the abbreviation $\neg \vdash f_1 \bullet ... \bullet f_n$, which stands for $(\forall x \in D)(f_j(x) \notin NULLS \Rightarrow f_i(x) \in NULLS, \forall i, 1 \le i \ne j \le n)$, where n > 1 is a natural. For example, $\neg \vdash TributaryTo \bullet Lake \bullet Sea \bullet Ocean \bullet LostInto$ formalizes the constraint that a river may be either tributary to another one or end in a lake, or sea, or ocean, or be lost (e.g., in a desert, cave, etc.), which consolidates five atomic non-existence constraints.

Currently, such constraints must be manually enforced by software developers of db software applications. Our *MatBase* [4-6], an intelligent data and knowledge base management system prototype based on both (E)MDM, RDM, the Entity-Relationship Data Model [3, 7, 8], and Datalog¬ [2, 5], provides in its (E)MDM interface a Graphic User Interface (GUI) MS Windows form for declaring both existence and non-existence constraints; if they are accepted, *MatBase* is automatically generating code for their enforcement. This paper presents and discusses the corresponding algorithms, which, of course, may also be used by any developer not having access to a copy of *MatBase*.

Literature Review

Existence constraints were defined in the framework of RDM [3, 4, 5, 9]. Non-existence constraints were introduced by us [4, 5]. Generally, existence constraints were very rarely studied.

In the ontology realm, RDM existence constraints are semantically divided into three subtypes (namely, *exclusive*, for not-applicable nulls, *mutual*, when f and g have same applicability domains, and *conditioned*, for the original RDM concept) [10].

As frequently happens, other concepts are also known in the literature under the "existence constraint" name. For example, [11] uses it in the context of dynamic (transactional) integrity constraints; in the NoSQL Memgraph and Neo4j DBMSes, the NOT NULL constraints are called existence constraints [12, 13]; existence constraints are also used with a completely different meaning (i.e., they "assert that for all (medial-level) variable values from a set of infinite cardinality, there must exist (lower-level) variable values from a second set that satisfy an inequality") in the realm of semi-infinite programs [14].

Methodology

Well-formed existence and non-existence constraints

First, please note that only functions which are not totally defined may be involved in existence and non-existence constraints. Indeed, if, for example, f is totally defined, then $f \mid - g$ implies that g must also be totally defined (as f does not ever take null values); dually, if g is totally defined, then $f \mid - g$ is superfluous (as g does not ever take null values). For the dually non-existence constraints

things are similar. Indeed, if, for example, f is totally defined, then $f \neg | - g$ implies that g must always be null, which is absurd: why would you add to a table a column that is allowed to store nothing? Conversely, if g is totally defined, then $f \neg | - g$ is unenforceable, except when f is always taking null values.

In terms of incoherence (i.e., no function image should always be the empty set or a subset of NULLS) and redundancy (i.e., no constraint should be implied by others) of constraint sets, this may be summarized in the following proposition:

Proposition 1.

- (i) $(f | -g \land f \text{ total} \Rightarrow g \text{ total}) \Rightarrow f | -g \text{ redundant}.$
- (ii) $f | -g \wedge g \text{ total } \Rightarrow f | -g \text{ redundant.}$
- (iii) $(f \neg | -g \land f \text{ total} \Rightarrow \forall x, g(x) \in \text{NULLS}) \Rightarrow \{f \neg | -g, f \text{ total}\} \text{ incoherent.}$
- (iv) $(f \neg | -g \land g \text{ total} \Rightarrow \forall x, f(x) \in \text{NULLS}) \Rightarrow \{f \neg | -g, g \text{ total}\} \text{ incoherent.}$

Consequently, any existence or non-existence constraint must not be accepted if at least one of the functions implied is totally defined.

Secondly, which is obvious according to their definitions, both existence and non-existence constraints are subtypes of the tuple constraints.

Consequently, any existence or non-existence constraint must not be accepted if at least one of the functions implied is not defined on a subset of a set that includes the domains of the rest of the implied functions. This restriction includes the existence and non-existence constraints in the subcategory of constraints on function products.

For example, $\neg |$ — *SSN* • *ITIN* (where *ITIN* stands for the Individual Taxpayer Identification Number) is well-formed as both are defined on subsets of the *USResidences* set, a subset of *PERSONS*. On the contrary, *BirthPlace* |— *Country* is not a valid existence constraint, as *BirthPlace* : *PERSONS* \rightarrow *CITIES*, while *Country* : *CITIES* \rightarrow *COUNTRIES*.

To conclude with, a *well-formed existence or non-existence constraint* must be defined over a function product whose components are not totally defined functions.

Figure 1 shows MatBase's pseudocode algorithm for accepting, rejecting, and deleting existence and non-existence constraints.

Enforcing existence and non-existence constraints

First, please note that, obviously, deleting an element from the underlying set of an existence or non-existence constraint, i.e., a line from the corresponding db table, cannot violate any such constraint.

On the contrary, both adding a new element (line) and modifying an existent one might violate such constraints. Let us consider $f = f_1 \bullet \dots \bullet f_n : D_f \to C_P$, $g = g_1 \bullet \dots \bullet g_m : D_g \to C_P$, $g = g_1 \bullet \dots \bullet g_m : D_g \to C_P$, $g = g_1 \bullet \dots \bullet g_m : D_g \to C_P$, $g = g_1 \bullet \dots \bullet g_m : D_g \to C_P$, and $g \in D$.

According to its definition, the existence constraint $f \mid ---g$ is violated for a $x \in D$ whenever $f_i(x) \notin \text{NULLS}$, $1 \le i \le n$, and there is at least a j in $1 \le j \le m$ such that $g_i(x) \in \text{NULLS}$.

According to its definition, the non-existence constraint $f \neg | -g$ is violated for a $x \in D$ whenever $f_i(x) \notin NULLS$, $1 \le i \le n$, and there is at least a j in $1 \le j \le m$ such that $g_j(x) \notin NULLS$, whereas a consolidated set of non-existence constraints of the type $\neg | -g$ is violated for a $x \in D$ whenever there are at least two values i, j in $1 \le i, j \le m$, $i \ne j$, such that $g_j(x) \notin NULLS$ and $g_j(x) \notin NULLS$.

```
Algorithm A1: adding or deleting existence and non-existence constraints
Input: the current constraint set C, the required operation type ot (true for add or false for delete),
      constraint name cn, constraint type ct (true for existence or false for non-existence), left-side
      function f = f_1 \bullet \dots \bullet f_n : D_f \to C_f, and right-side function g = g_1 \bullet \dots \bullet g_m : D_g \to C_g, n, m
Output: C \longrightarrow \{cn\}, if \neg ct and cn's deletion is confirmed or C \cup \{cn\}, if cn is admissible;
Strategy:
if \neg ct then if cn \in C then if user confirms his/her request to delete cn then C = C - \{cn\}:
            else display "Request rejected: " & cn & " is not a known constraint name!";
else if there is a constraint in C named cn then display "Request rejected: " & cn & " is the name " &
                              "of another constraint! Please choose a unique constraint name instead!";
     else if ct and n = 0 then display "Request rejected: please add to \hat{C} the constraint " & g &
                                 "total instead!";
          else if there is no set D such that D_f \subset D and D_g \subset D then display "Request rejected:" & f
                                 & " and " & g & " do not have compatible domains!";
              else Boolean ok = true; int i = 1;
                while ok and i < n
                   if f_i total then ok = false; display "Request rejected: " & f_i & " is totally defined!";
                   else i = i + 1;
                end while;
                if ok then i = 1;
                  while ok and i \le m
                    if g_i total then ok = false; display "Request rejected: " & g_i & " is totally defined!";
                    else i = i + 1;
                   end while;
                   if ok then if there is x \in D such that cn is violated for it then
                                 display "Request rejected: " & cn & " is violated for " & x & "!";
                             else C = C \cup \{cn\};
                  end if;
          end if;
   end if:
end if;
End Algorithm A1;
```

Figure 1: MatBase algorithm for adding and deleting existence and non-existence constraints.

Consequently, to enforce such constraints the class D of the software application managing the db to which D belongs must contain an event-driven method BeforeUpdate like the one shown in Figure 2 that must be automatically launched whenever the current line from table D (uniquely identified by the value of D's surrogate primary key x) has been modified and the user asks for saving the modifications into the corresponding db. If such a method does not exist, then MatBase automatically generates it the first time that a constraint involving D is added to the db scheme.

```
method BeforeUpdate()
Boolean Cancel = false;
if not Cancel then Cancel = enforce_non-existence_cnstr(nec, f(x), g(x));
if not Cancel then Cancel = enforce_existence_cnstr(ec, f(x), g(x));
if Cancel then reject saving the current line into the db;
end method BeforeUpdate;
```

Figure 2: The event-driven method *BeforeUpdate* of a class *D* associated to a table *D*.

Whenever MatBase accepts an existence constraint $ec: f \mid --g$ over D, it adds to this method a line that reads "if not Cancel then Cancel then Cancel = $enforce_existence_cnstr(ec, f(x), g(x))$;"; whenever MatBase accepts a non-existence constraint $nec: f \neg \mid --g$ over D, it adds a line that reads "if not Cancel then Cancel = $enforce_non-existence_cnstr(nec, f(x), g(x))$;". All lines are added to this method immediately after the line that reads "Boolean Cancel = false;". This is how MatBase implements the $C = C \cup \{cn\}$ statement of the Algorithm A1 from Figure 1.

Dually, whenever MatBase deletes an existence constraint named ec over D, it deletes from this method the line that starts with "if $not\ Cancel\ then\ Cancel\ enforce_existence_cnstr(ec,";$ whenever MatBase deletes a non-existence constraint named nec over D, it deletes the line that starts with "if $not\ Cancel\ then\ Cancel\ enforce_non-existence_cnstr(nec,".$ This is how MatBase implements the C=C— $\{cn\}$ statement of the Algorithm A1 from Figure 1.

Figures 3 and 4 present the pseudocode of methods *enforce_existence_cnstr* and *enforce_non-existence_cnstr*, respectively, that *Mat-Base* is storing in one of its libraries.

```
Boolean method enforce existence cnstr(ec, f(x), g(x));
// returns true if the values of f(x) and g(x) violate ec and false otherwise
enforce existence cnstr = false;
if x is a new line or f(x) has been modified or g(x) has been modified then
  Boolean null = true; int i = 1;
  while mull and i \le n
     if f_i(x) \notin \text{NULLS then null} = \text{false}; else i = i + 1;
  end while;
  if not null then i = 1;
     while not null and i \le m
       if g_i(x) \in \text{NULLS then null} = true; else i = i + 1;
     if null then enforce_existence_cnstr = true; display "Saving these values is rejected: according"
              & " to existence constraint " & ec & ", column " & g_i & " must have a not null value!"
  end if;
end if;
end method enforce existence cnstr;
```

Figure 3: MatBase algorithm for enforcing existence constraints.

Results and Discussions

Analyzing Algorithm A1, it is easy to prove the following proposition:

Proposition 2: Algorithm A1 from Figure 1 has the following properties:

- (i) It never loops forever.
- (ii) Its complexity is O(n + m).
- (iii) It deletes existence and non-existence constraints, if the corresponding requests are confirmed, without any check, as such a deletion cannot affect either the coherence or the minimality of the remaining constraint set (recall that a set of constraints is *minimal* if and only if it does not include any redundant constraint).
- (iv) It enforces the unicity of the constraint names.
- (v) It rejects all totality constraints, i.e., particular cases of existence constraints of type ∅ |—f.
- (vi) It only adds well-formed existence or non-existence constraints.
- (vii) It adds existence and non-existence constraints only if the current db instance does not violate them.
- (viii) It is optimal, i.e., it performs its tasks with the minimum possible number of statements.

Analyzing method *BeforeUpdate*, it is easy to prove the following proposition:

Proposition 3: Method BeforeUpdate from Figure 2 has the following properties:

- It never loops forever.
- (ii) Its complexity is k = 4.
- (iii) It enforces any valid existence and non-existence constraints.
- (iv) It ends as soon as it discovers that a constraint is violated.
- (v) It is optimal, i.e., it performs its tasks with the minimum possible number of statements.

Analyzing method *enforce_existence_cnstr*, it is easy to prove the following proposition:

Proposition 4: Method *enforce_existence_cnstr* from Figure 3 has the following properties:

- (i) It never loops forever.
- (ii) Its complexity is O(n + m).
- (iii) It returns *true* if the values of f(x) and g(x) violate ec and false otherwise.
- (iv) It does not check *ec* if neither f(x) nor g(x) were updated.
- (v) It does not even check g(x) if f(x) only has null values; otherwise, it ends as soon as it discovers a null value in g(x).
- (vi) Whenever ec is violated, it displays a corresponding error message, also indicating the value that violates it.
- (vii) It is optimal, i.e., it performs its tasks with the minimum possible number of statements.

```
Boolean method enforce non-existence cnstr(nec, f(x), g(x));
// returns true if the values of f(x) and g(x) violate nec and false otherwise
enforce non-existence cnstr = false;
if x is a new line or f(x) has been modified or g(x) has been modified then
  int i = 1;
  if f(x) == \emptyset then // consolidated set of non-existent constraints
     int j = 0;
                       // position of the first not null value in g(x)
     while not enforce non-existence cnstr and i \le m
       if g_i(x) \notin \text{NULLS then}
          if j == 0 then j = i;
          else enforce non-existence cnstr = true;
                display "Saving these values is rejected: according to non-existence constraint " &
                        nec & ", only one of the columns " & gi & " and " & gi & " may have a " &
                        "not null value!";
          end if;
        else i = i + 1:
     end while;
  else
                        // single non-existent constraint
     Boolean \ mull = true;
     while null and i \le n
       if f_i(x) \notin \text{NULLS then null} = false; else i = i + 1;
     end while:
     if not null then i = 1;
        while not null and i \le m
          if g_i(x) \notin \text{NULLS then null} = \text{true}; else i = i + 1;
        end while:
        if null then enforce non-existence cnstr = true;
                display "Saving these values is rejected: according to non-existence constraint " &
                        nec & ", column " & gi & " must have a null value!"
     end if:
  end if;
end if:
end method enforce non-existence cnstr;
```

Figure 4: MatBase algorithm for enforcing non-existence constraints.

Analyzing method *enforce_non-existence_cnstr*, it is easy to prove the following proposition: *Proposition* 5: Method *enforce_non-existence_cnstr* from Figure 4 has the following properties:

- (i) It never loops forever.
- (ii) Its complexity is O(n + m).
- (iii) It returns *true* if the values of f(x) and g(x) violate *nec* and *false* otherwise.
- (iv) It does not check *nec* if neither f(x) nor g(x) were updated.
- (v) It correctly distinguishes between single non-existent constraints and consolidated set of such constraints.
- (vi) For any consolidated set of non-existent constraints, it ends as soon as it discovers a second not null value in g(x).
- (vii) For single non-existent constraints, it does not even check g(x) if f(x) only has null values; otherwise, it ends as soon as it discovers a not null value in g(x).
- (viii) Whenever nec is violated, it displays a corresponding error message, also indicating the value that violates it.
- (ix) It is optimal, i.e., it performs its tasks with the minimum possible number of statements.

For example, let us consider D = PERSONS, $ec: SSN \bullet ITIN \mid _$ BirthDate $\bullet Sex$, and $nec: \neg \mid _SSN \bullet ITIN$;

- 1. Obviously, both *ec* and *nec* are accepted by Algorithm *A*1, so that the *BeforeUpdate* method of class *PERSONS* would look exactly as in Figure 5.
- 2. Any attempt to save to the db a line $\{(SSN \bullet ITIN)(x) = <123456789, >, (BirthDate \bullet Sex)(x) = <, "F">\}$ is rejected with the error message "Saving these values is rejected: according to existence constraint ec, column BirthDate must have a not null value!".
- 3. Any attempt to save to the db a line $\{(SSN \bullet ITIN)(x) = <123456789, >, (BirthDate \bullet Sex)(x) = <"1/1/1990", >\}$ is rejected with the error message "Saving these values is rejected: according to existence constraint ec, column Sex must have a not null value!".
- 4. Any attempt to save to the db a line $\{ , (SSN \bullet ITIN)(x) = <123456789, 987654321 > \}$ is rejected with the error message "Saving these values is rejected: according to non-existence constraint *nec*, column *ITIN* must have a null value!".

```
method BeforeUpdate()
Boolean Cancel = false;
if not Cancel then Cancel = enforce_non-existence_cnstr(nec, , (SSN \bullet ITIN)(x));
if not Cancel then Cancel = enforce_existence_cnstr(ec, (SSN \bullet ITIN)(x), (BirthDate \bullet Sex)(x));
if Cancel then reject saving the current line into the db;
end method BeforeUpdate;
```

Figure 5: The event-driven method BeforeUpdate of class PERSONS associated to table PERSONS.

Conclusion

To guarantee data plausibility, the highest possible quality standard in db software applications, all business rules governing corresponding subuniverses of interest must be formalized as constraints and enforced either by the underlying DBMSes or/and by the software applications. Existence constraints abound in any such subuniverse and were formalized in the RDM framework. However, commercial RDBMSes only provide their NOT NULL particular case, leaving the enforcement of the general case to software developers.

The (E)MDM includes existence constraints in its mathematical db schemes, along with their duals, the non-existence ones. *MatBase*, an intelligent data and knowledge management system prototype, provides users with a GUI form to declare them, and, if and only if they are well-formed and not violated by the db instance, not only stores them in the corresponding db schemes, but also automatically generates code for their enforcement.

This paper presents and discusses corresponding *MatBase* algorithms, which may also be used by software developers without access to a *MatBase* copy.

As *MatBase* is automatically generating code for constraint enforcement (and not only), it is also a modelware tool [6, 15] and (E) MDM is also a programming language of the 5th generation [15, 16].

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions

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