MANAGING DATA DEPENDENCY CONSTRAINTS THROUGH BUSINESS PROCESSES

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Abstract: Business Process Management (BPM) and related tools and systems have generated tremendous advantages for enterprise systems as they provide a clear separation between process, application and data logic. In spite of the abstraction value that BPM provides through explicit articulation of process models, a seamless flow between the data, application and process layers has not been fully realized in mainstream enterprise software, thus often leaving process models disconnected from underlying business semantics captured through data and application logic. The result of this disconnect is disparity (and even conflict) in enforcing various rules and constraints in the different layers. In this paper, we propose to synergise the process and data layers through the introduction of data dependency constraints, that can be modelled at the process level, and enforced at the data level through a (semi) automated translation into DBMS native procedures. The simultaneous and consistent specification ensures that disparity between the process and data logic can be minimized.

1 INTRODUCTION

The evolution of business software solutions has seen a number of architectural generations. For the last several years, business process management (BPM) has secured a leading position in enterprise systems. A process enabled enterprise system will typically have a three-tier architecture consisting of data, application and process layers.

Just as the DBMS provided a means of abstracting application logic from data logic, the business process management systems (BPMS) provided a means of abstracting coordinative process logic from application logic. Every generation has provided additional functionality through supporting systems.

A clear separation of Process, Business, Data, and Presentation aspects of enterprise systems with minimal overlap can be observed in current process-enabled systems.

Furthermore, application components have minimal direct awareness of one another and also have minimal direct awareness of "where and how" they are being utilized in BPM layer. BPM takes the primary responsibility to achieve business objectives through configuration, coordination, collaboration, and integration of application components.

In spite of the abstraction value that BPM provides through explicit articulation of process models, a seamless flow between the data, application and process layers has not been fully realized in mainstream enterprise software, thus often leaving process models disconnected from underlying business semantics captured through data and application logic. The result of this disconnect is disparity (and even conflict) in enforcing various rules and constraints in the different layers.

In this paper, we propose to synergise the process and data layers through the introduction of data dependency constraints. These constraints can be modelled at the process level, thus providing the benefits of abstraction and clarity of business semantics. At the same time, we propose an automated translation of these constraints into DBMS native procedures. The simultaneous and consistent specification ensures that disparity between the process and data logic can be minimized.

The remaining paper is organized as follows: We first present a detailed discussion on related work in section 2, which encompasses data dependency constraints in general as well as managing of data

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dependency and data flow in BPMSs. We will then introduce in section 3, two types of data dependency constraints that characterize certain notions of data dependency in business processes. These are presented within a typical architecture of a BPMS. We will demonstrate that the constraints cannot be easily modelled in current business process modelling languages and will provide a discussion on their properties. We present in section 4, an automated translator of the constraints into DBMS native procedure for constraint enforcement in the data layer, and finally discuss the main contributions and future extensions of this work in section 5.

2 RELATED WORK

Historically, one of the first successes in data integrity control was the invention of referential integrity enforcement in relational database systems (Date 1981). The generality of this solution, based on a formal definition of a class of constraints, made this data management concept uniformly applicable (independently from application domain), thus eliminating large numbers of data integrity errors. Since then, data dependency constraints have been widely studied with many classes of constraints introduced.

In (Fan et al. 2008) the authors proposed a class of integrity constraints for relational databases, referred to as conditional functional dependencies (CFDs), and study their applications in data cleaning. In contrast to traditional functional dependencies (FDs) that were developed mainly for schema design, CFDs aim at improving the consistency of data by enforcing bindings of semantically related values.

In this paper, we aim to extend the data dependency constraints of process enabled systems through the business process model. In general, the process model is a definition of the tasks, ordering, data, resources, and other aspects of the process. Most process models are represented as graphs mainly focussed on the control flow perspective of activity sequencing and coordination, such as Petri nets (Aalst & Hofstede 2000), (OMG/BPMI 2009), (OMG 2009).

In addition, some process models (often in scientific rather than business domain) focus on the data flow perspective of the process, i.e. data-centric approaches. The importance of a data-centric view of processes is advocated in (Ailamaki et al. 1998) and (Hull et al. 1999). In (Ailamaki et al. 1998), the authors promote an "object view" of scientific workflows where the data generated and used is the central focus; while (Hull et al. 1999) investigates "attribute-centric" workflows where attributes and modules have states. Further, a mixed approach was proposed by (Medeiros et al. 1995) which can express both control and data flow. (Reijers et al. 2003) and (Aalst et al. 2005) uses a product-driven case handling approach to address some concerns of traditional workflows especially with respect to the treatment of process context or data. (Wang & Kumar 2005) proposed document-driven workflow systems where data dependencies, in addition to control flows, are introduced into process design in order to make more efficient process design. Another approach called the Data-Flow Skeleton Filled with Activities (DFSFA) is proposed in (Du et al. 2008) to construct a workflow process by automatically building a data-flow skeleton and then filling it with activities. The approach of DFSFA uses data dependencies as the core objects without mixing data and activity relations. (Joncheere et al. 2008) propose a conceptual framework for advanced modularization and data flow by describing a workflow language which introduces four language elements: control ports, data ports, data flow, and connectors. Their view of workflow's data flow is specified separate from its control flow by connecting tasks' data ports using a first-class data flow construct. Also worth mentioning is the work on data flow patterns (Russell et al. 2005), in particular the internal data interaction pattern namely Data-Interaction – Task to Task (Pattern 8). It refers to the ability to communicate "data elements" between one task instance and another within the same case, and provides three approaches, namely a) Integrated Control and Data Channels b) Distinct Control and Data Channels c) No Data Passing that uses a global shared repository. (Kunzle & Reichert 2009) studies the activity-centered paradigm of existing WfMS are too inflexible to provide data object-awareness and discussed major requirements needed to enable object-awareness in process management systems.

Despite these contributions from research in modelling data flow perspectives of business process, widely used industry standard such as BPMN will only show the flow of data (messages), and the association of data artefacts to activities, that is, it doesn't express the data flow (logic) below the Data Object level. It can be observed that data artefacts can have interdependencies at a low level of granularity which if not explicitly managed, can compromise the integrity of the process logic as well as corrupt underlying application databases. We propose to use concepts and contributions from research in data integrity management through data dependency constraints to overcome this limitation in business process models. Our work is focussed on a specific class of data dependencies, that have the capacity to not only enrich the process model, but also provide a means of enforcing the constraints across all layers of the process enabled enterprise system, namely process, application and data. The next section details our approach.

3 DATA DEPENDENCY CONSTRAINTS FOR PROCESS MODELS

We present in Figure 1 a reference BPM architecture to provide the background for managing data dependency constraints through BPM. Our aim is to demonstrate the above mentioned layers namely Data logic, Business or Application logic and Process logic within the architecture:

- The Data logic components provide repositories for business and corporate data as well as documents, mails, content management system data, etc.
- The Business logic components provide business application functionalities through various type of application and the coordination of these applications are through the web-based tools provided by the BPM Suite or via custom developed interface with the BPM tools..
- The BPM Suite provides the core BPM functionalities which includes two main parts, Business Modeller and Workflow Application Service.

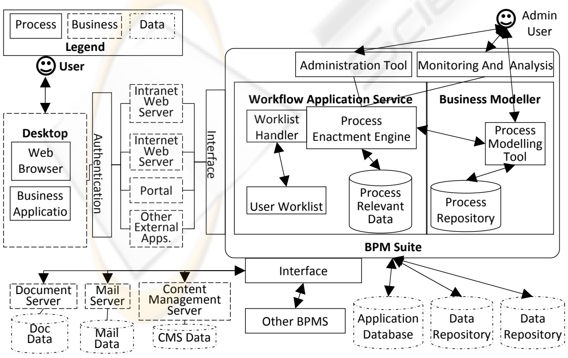
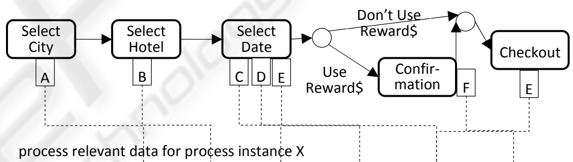


Figure 1: BPM reference architecture.

In Figure 1, it is worth to distinguish the differences between Process Relevant Data and Application Data. Process Relevant Data is used by the Business Process Management System (in addition to other uses) to determine the state transitions of a process instance, for example pre- and post-conditions, transition conditions, etc. Such data may affect the choice of the next activity to be chosen and may be manipulated by related applications as well as by the process engine. On the other hand, the Application Data is application specific and strictly managed by applications supporting the process instance. In terms of the data flow pattern Data-Interaction – Task to Task in (Russell et al. 2005), the Process Relevant Data refers to the third category i.e. the use of a "Global Shared Repository".

In the context of the above architecture, we propose to introduce the modelling and enforcement of two classes of data dependency constraints though the BPMS. We identify these as so-called Change Dependency Constraint and Value Dependency Constraint.

To understand the semantics behind the constraints, consider the following scenario.



	City	Hotel	Date	Discount	Reward $	BookingFee
Time stamp 1	Brisbane				$10	
Time stamp 2	Brisbane	Hilton			$10	
Time stamp 3	Brisbane	Hilton	10/Mar/09	10%	$10	
Time stamp 4	Brisbane	Hilton	10/Mar/09	10%	$5	$5

Figure 2: Example scenario.

Assuming a hotel booking system introduces special booking rates to the process, where 3 specific data elements entered in activity Select City, Select Hotel, Check out are named A, B and C respectively. Suppose we would like to specify a constraint that ensures if A and B are entered in certain values, the value of C would be pre-determined. For example, if Date = "10/Mar/09" and "Hotel" = Hilton, then Discount = 10%. This constraint would guarantee the data quality of the applications associated with the process is synchronized with the process definition, as well as the ability to dynamically modify the "condition values" without changing the process definition. While the values do not dictate the values of every instance, but rather options of the possible combinations, the dashed line implies this weak relationship. Current business process models do not have the feature to support the specification of such "*value dependency*".

Similarly we can observe that changes in data values can also have dependencies. For example, assume the user decides to spend his/her membership reward point for further discount, the system would automatically deduct the amount from the balance at the checkout. This constraints enforces the automatic calculation of Process Relevant Data "Reward $", we term such a constraint as "*change dependency*".

In the following discussion, we will provide a means of specifying the constraints using a well-known notion of data tableaus borrowed from database integrity constraint management. The tableaus allow us to specify constraints in a concrete manner, as well reason with their properties. However, we first need to present some background concepts on process schema and instance, as well as data tableaus.

Definition 1 (Process Schema). A tuple P = (N, C, D, L, K) is called a process schema with:

- *N is a set of finite Nodes. Each node $n \in N$ has a type $T \subseteq E \cup A \cup G$ such that $E \cup A \cup G$, $E \cap A = \phi$, $A \cap G = \phi$, $E \cap G = \phi$, where E denotes the set of Event types (e.g., Start, End, etc.) and A denotes the set of Activity types (e.g. User, Manual, Service, etc.) and G denotes the set of Gateway types (e.g., AND-SPLIT(Fork), XOR-SPLIT(Choice), AND-JOIN(Join), XOR-JOIN(Merge))*
- *C is a set of Connecting objects or Control Flow. Connect Relation $C \subseteq N \times N$ is a precedence relation (note: $n_{src'} \rightarrow n_{dest} \equiv (n_{src'}, n_{dest}) \in C$)*
- *D is a set of process data elements. Each data element $d \in D$ has a type D where D denotes the set of atomic data types (e.g., String, number, etc.)*
- *$L \subseteq N \times D$ is a set of data links between node objects and data elements. For the purpose of this research, we assume the link exists at the point of node completion, i.e. the value of the data elements equals the value stored in database at the end of the activity (node).*
- *For each link $l \in L$, l can be represented by a pair <n, d >*
  - *node[l] or n[l]=n where $n \in N$ represent node of l.*
  - *data[l] or d[l]=d where $d \in D$ represent data element of l.*
- *$K: C \rightarrow TC(D) \cup \phi$ assigns to each control flow an optional transition conditions where TC(D) denotes the set of all valid transition conditions on data elements from D*

Definition 2 (Process Instance). A process instance I is defined by a tuple *(P_I, NS^{P_I}, V^{P_I}) where:*

- *$P_I := (N_I, C_I, D_I, L_I)$ denotes the process schema of I which is determined during runtime, where N_I denotes the node set and C_I denotes the control flow set and D_I denotes the data element set and L_I denotes the data elements link set.*
- *NS^{P_I} describes node states of I: $NS^{P_I} : N_I \rightarrow$* {Initial, Scheduled, Commenced, Completed }
- *V^{P_I} denotes a function on D_I, formally: $V^{P_I} : D_I \rightarrow Dom_{DI} \cup$* {Undefined}. *This means for each data element $d \in D_I$ has a value either from domain Dom_{DI} or an* Undefined *value which has not been stored yet.*
- *In particular, we denote $V[L_I]^{P_I}$ as the values of data elements link sets of Process Instance P_I, which is a function on L_I, formally: $V[L_I]^{P_I}$: $D_I \rightarrow Dom_{DI} \cup$* {Undefined} *and $L_I = N_I \times D_I$*

Definition 3 Data Tableau. A data tableau $T_{L'}$ is a tableau with all attributes in L', referred to as the value pattern tableau of L' or V[L'], where for each l in L' and each tuple $t \in T_{L'}$, t[l] is either a constant in the domain Dom(d) of l, or an unnamed variable '_'.

- $L' \subseteq L$, therefore the maximum number of attributes in $T_{L'}$ equals |L|.
- t[l] = '_' means that the value can be anything within $Dom_d \cup$ {Undefined}
- For example: a tableau can be presented as the following

Tableau for Definition 3

<n_1,d_1>	*<n_2,d_1>*	*<n_3,d_1>*
-	-	-
10	10	10

This tableau implies that the value of d1 can be anything within the Dom(d_1) throughout n_1 to n_3, but if <n_1,d_1> = 10, then the values of d_1 at n_2 and n_3 must remain consistent.

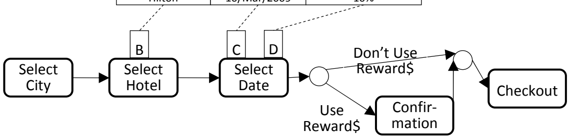
3.1 Constraint Specification

Using the notion of data tableaus from above, we can specify value and change dependency constraints as below in Figure 3 and 4 respectively.

In Figure 3 a data dependency is defined through the value relationship between multiple data items. The Tableau T represents the conditional values Hotel, Date and Discount at Task SelectHotel, SelectDate and Checkout respectively. The Tableau suggests a conditional rule such that if Hotel equals to Hilton and Date equals to 10/Mar/2009, then the Discount will be 10%. Otherwise the data will not be accepted. In this example, instance 1 does not satisfy this rule therefore the data is invalid.

Tableau T

SelectHotel, Hotel	SelectDate, Date	Checkout, Discount
Hilton	10/Mar/2009	10%



Execution Data

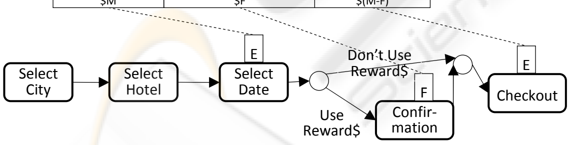
	SelectHotel, Hotel	SelectDate, Date	CheckOut, Discount	
Instance 1	Hilton	10/Mar/2009	20%	Invalid
Instance 2	Hilton	10/Mar/2009	10%	Valid
Instance 3	Hilton	18/Mar/2009	0%	Valid
Instance 4	Sheraton	10/Mar/2009	0%	Valid

Figure 3: Value dependency.

In Figure 4 another type of data dependency is given, which defines the conditions under which a data value can be changed. The example below defines the conditional values of Reward$ at "SelectDate", "Use Reward$", "Don't Use Reward$" and "Checkout" respectively. Since the Tableau suggests a conditional rule such that if Reward$ at SelectDate equals to $M and if the path "Use Reward$" is taken and BookingFee$ equals to $F then the Reward$ at Checkout would equal to $(M-F). In this example, instance 4 does not satisfy this rule therefore the data is invalid.

Tableau T

SelectDate, Reward$	Confirmation, BookingFee$	Check out, Reward$
$M	$F	$(M-F)



Execution Data

	SelectDate, Reward$	Confirmation, BookingFee$	Check out, Reward$	
Instance 1	$10	N/A	$10	Valid
Instance 2	$10	$5	$5	Valid
Instance 3	$20	$5	$15	Valid
Instance 4	$20	$5	$20	Invalid

Figure 4: Change dependency.

Together, the above two examples demonstrate a new type of constraint which we collectively refer to as "Conditional Data Dependency". We define a Conditional Data Dependency as below:

Definition 4 (Conditional Data Dependency or CDD). A conditional data dependency φ is a pair (F:X$\rightarrow$Y, T), where

- *X, Y are sets of links X,Y∈L,*
- F:X$\rightarrow$Y *is a standard Data Link Dependency,* $F \subseteq L \times L$ *is a precedence relation (note:* $l_{from} \rightarrow l_{to} \equiv (l_{from}, l_{to}) \in F$ *)*
- alternatively, we can represent a data link dependency f as $<n_i, d_p> \rightarrow <n_j, d_q>$, where $node[l_{from}] = n_i$, $data[l_{from}] = d_p$, $node[l_{to}]=n_j$, $data[l_{to}]=d_q$.
- *T is a tableau with all attributes in X and Y, referred to as the pattern tableau of* φ. Where for each *l* in X or Y and each tuple t∈ T, t[*l*] is either a constant in the domain Dom(d) of *l*, or an unnamed variable '_'.
  In particular, we define:

Definition 5 (Value Dependency Constraint). A Value Dependency Constraint φ is a pair (F:X$\rightarrow$Y, T), where

For all $<n_i, d_p>$, … $<n_j, d_q>$ in X and Y, $n_i \neq n_j$ implies $d_p \neq d_q$

This means, the Tableau T defines the relationships of value of **multiple** data elements

Definition 6 (Change Dependency Constraint). A Change Dependency Constraint φ is a pair (F:X$\rightarrow$Y, T), where

For all $<n_i,d_p>$, … $<n_j, d_q>$ in X and Y, $n_i \neq n_j$ implies $d_p = d_q$

This means, the Tableau T defines the changes of value of the **same** data element

3.2 Constraint Analysis

We observe that the constraint specification exhibits certain properties namely Subset, Transitivity, Union, Decomposition and Pseudo transitivity. Understanding the properties is essential to provide a non-redundant and conflict-free specification. Although it is not the aim of this paper to present a detailed analysis of the constraints or verification algorithms, we present below a summary of the properties in order to, better understand the semantics of the constraint specification.

Subset. One Conditional Data Dependency can subsume another. Given two CDDs, F_1:[$X_1 \rightarrow Y_1$],T_1 and F_2: [$X_2 \rightarrow Y_2$],T_2, $F_1 \supseteq F_2$ iff $X_1 \supseteq X_2$ and $Y_1 \supseteq Y_2$, and ∀ tuples $t_2 \in T_2$, ∃tuple $t_1 \in T_1$ such that $t_1 \supseteq t_2$

Transitivity. Given two CDDs, F_1:[$X \rightarrow Y$],T_1 and

F_2: $[Y \rightarrow Z],T_2$, We can derive a $F_3:[X \rightarrow Z],T_3$ such that $\forall$ tuples $t_2 \in T_2$ $\exists$tuple $t_1 \in T_1$ such that $t_1[Y] = t_2[Y]$

Therefore, from the property of CDD Transitivity, we can define a new operator $\oplus$ which merges two CDDs into one.

$\oplus$ **Merge.** Given two CDDs, $F_1:[X_1 \rightarrow Y_1],T_1$ and F_2: $[X_2 \rightarrow Y_2],T_2$, $F_1 \oplus F_2$ = F3: $[X_3 \rightarrow Y_3]$, T_3 iff $X_3 = X_1 \cup X_2$ and $Y_3 = Y_2$ and $\forall$ tuples $t_3 \in T_3$ $\exists$tuple $t_1 \in T_1$ and $t_2 \in T_2$ such that $t_3[X_3] = t_1[X_1]$ and $t_1[Y_1] = t_2[Y_2]$ and $t_3[Y_3] = t_2[Y_2]$

Union. Given two CDDs, $F_1:[X \rightarrow Y],T_1$ and F_2: $[X \rightarrow Z],T_2$, We can derive a $F_3:[X \rightarrow YZ],T_3$ such that $\forall$ tuples $t_3 \in T_3$ $\exists$tuple $t_1 \in T_1$ and $t_2 \in T_2$ such that $t_1[X] = t_2[X] = t_3[X]$ and $t_3[YZ] = t_1[Y] \cup t_2[Z]$

Therefore, from the property of CDD Union, we can define a new operator $\uplus$ which merges two CDDs into one.

$\uplus$ **Join.** Given two CDDs, $F_1:[X_1 \rightarrow Y_1],T_1$ and F_2: $[X_2 \rightarrow Y_2],T_2$, $F_1 \uplus F_2$ = F3: $[X_3 \rightarrow Y_3]$, T_3 iff $X_1 = X_2 = X_3$ and $Y_3 = Y_1 \cup Y_2$ and $\forall$ tuples $t_3 \in T_3$ $\exists$ tuple $t_1 \in T_1$ and $t_2 \in T_2$ such that $t_1[X_1] = t_2[X_2] = t_3[X_3]$ and $t_3[Y_3] = t_1[Y_1] \cup t_2[Y_2]$

3.3 Summary

To summarize the above, we are proposing a new type of data dependency constraint to model dependencies within process relevant data. We call such constraint a "Conditional Data Dependency". The CDD extends the current process modelling specification by introducing a tableau to specify the data dependency. Such constraint allows us to define business rules to ensure data integrity through the process layer to data layer.

While the specification of the CDDs allows us to specify additional data constraints, the correctness of the specification is also important. A number of conflicts may emerge into the constraint specification namely a) Invalid Data Link Attributes, b) Conflict between Data Link Dependency with Control Flow, c) Conflict between the tuples within the Tableau, d) Conflict between Data flow and Control Flow, etc.

For example, Consider a CDD $\psi 1$ = (<Select Date, Date> $\rightarrow$ <Checkout, Discount>, T_1), where T_1 consists of two pattern tuples (10/Mar/2009, 10%) and (10/Mar/2009, 20%). Then there is no instance Pi can possibly satisfy $\psi 1$. Indeed, for any tuple t in Pi, the first pattern requires if the date equals to 10/Mar/2009, the discount will be 10%, which is contradictory to the second pattern value 20%. Such conflict is a typical conflict between the tuples within the Tableau. Since it is not the scope of this paper to discuss the methods for detecting and resolving these constraint conflict problems, we refer the works in (Sun et al. 2006) (Fan et al. 2008) which can be used as a road map for implementation of the verification algorithms. Design of specific verification algorithms for the proposed constraints is also part of our future work.

In the remaining paper we assume that a non-redundant and conflict-free constraint specification is available to the BPM system in the form of a data tableau.

4 IMPLEMENTATION AND EVALUATION

In this section we would like to demonstrate how a proof of concept can be built for the above approach. The objective is to demonstrate the specification of the constraints at the process level, and enforcement at the data level. We present the proof of concept through a light weight implementation of a workflow engine Chameleon built using MS Windows Workflow Foundation (WWF). Figure 5 shows an overview of the Chameleon 3 architecture.

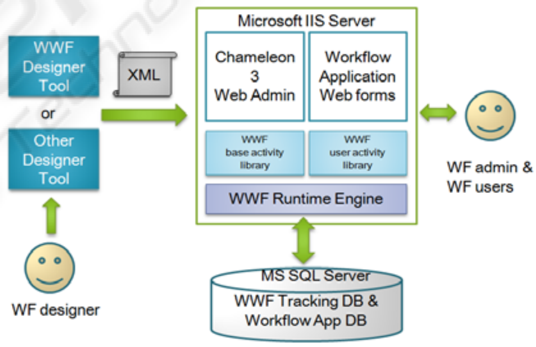


Figure 5: Chameleon 3 architecture.

It can be observed that the architecture is derived from the reference BPM Suite we mentioned previously in section 3. The Chameleon 3 Process Modelling Tool is built based on the Windows Workflow Foundation Designer Tools with extended functionality. One of the most useful features of Windows Workflow Foundation technology is that it allows us to implement customized User Activity types which enable us to implement the activities to include extra properties and functionalities; such extension allows us to access the underlying Application Data and Process Relevant Data at the modelling level. At design time, the WWF GUI process designer tool has the access to any pre-built

User Activity library we implement. We then use the designer tool to create the process model and export the process definition to an XML like language called XOML. This process definition will then be imported into the Chameleon Suite by using the Web Admin tool hosted by Microsoft IIS Server. The WWF services interpret the XML process definition and stores the model as a process template by a Process Repository database hosted by Microsoft SQL Server. At runtime, the Admin User creates and manages instances which the engine provides supporting scheduling services for persisting a workflow's state, handling transactions and also provides other services, such as mechanisms for communicating with software outside the workflow. The Workflow Users then use the web interfaced Chameleon Workflow Application and perform tasks on the Application or Web forms corresponding to the work items on their worklists.

In order to support the specification and implementation of the proposed Conditional Data Dependency, we developed the following enhancement to Chameleon 3 architecture.

1. A Conditional Data Dependency Designer Tool that uses an intuitive user interface for specifying the constraint. This tool is an Add-On to the existing WWF Designer that can capture the constraints as tableaus as shown in the previous section and then exported to the required XML format.
2. An automatic translator to convert the specified CDDs into rules in XML format and subsequently insert the WWF built-in "Policy Activity" into the XML file before importing the model to the Chameleon Suite.
3. We present a simple procedure to translate the CDD constraint to WWF native rule set as follows:

```
begin
For each tuple in Tableau T
   Writeln(If )
   For each data value in X
      Writeln(dp = Vp)
      If not last value in X
         Writelin( and)
      End If
   End For
   Writeln(Then )
   For each data value in Y
      Writeln(dq = Vq)
      If not last value in Y
         Writelin( and)
      End If
   End For
End For
End.
```

4. The above procedure generates a WWF native rule which can be processed by the WWF service. This service automatically generates the underlying data validation codes; hence the data integrity is enforced at runtime as intended.

Figure 6 shows an example of the translation of the Value Dependency described in Figure 3 which generates a rule set for native WWF "Policy Activity". A policy activity is simply a programmatic check for "If" condition "Then" executes a specified "Action".

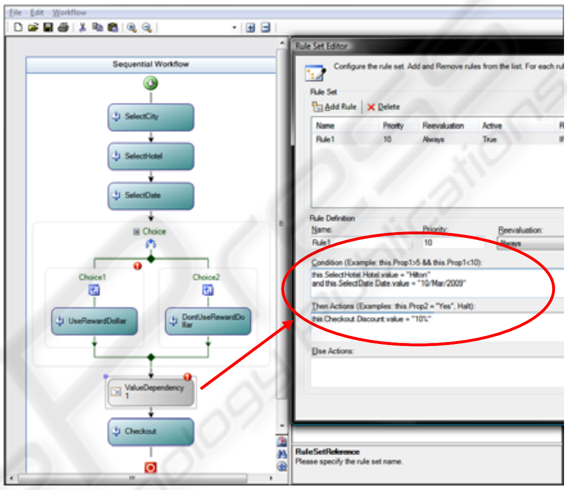


Figure 6: WWF Rule Set for Value Dependency.

5 CONCLUSIONS

One of the biggest challenges in current large scale enterprise systems is overcoming the growing disconnect and consequent disparity in various parts of the system. In this paper, we have attempted to address the disparity in data integrity constraints that may arise due to a disconnect between business process models and underlying databases and related applications. We have provided a means of specifying two types of data dependency constraints on process relevant data. Further we have provided a proof of concept on how the constraint specification can be utilized simultaneously at the process as well as data level thus minimizing the opportunity for disparity between them.

Although we briefly mentioned in this paper the importance of the analysis and verification of the constraints, ensuring correctness of the specification (i.e. non-redundant and conflict-free) remains an interesting and challenging extension of this work.

We also envisage further extension of the prototype implementation, namely Chameleon 3, to include a smart CDD builder.

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