Table of Contents

Message from the General Chair ................................................................. ix
Message from the Program Chairs ................................................................. x
Organizing Committee .................................................................................. xii
Steering Committee ...................................................................................... xiii
Program Committee ..................................................................................... xiv
Additional Reviewers ................................................................................... xv

Keynotes
Beyond the Lone Reverse Engineer: Insourcing, Outsourcing and Crowdsourcing ......................................................... 3
Margaret-Anne D. Storey
Legacy and Future of Data Reverse Engineering .............................................. 4
Jean-Luc Hainaut

WCRE 1999 Most Influential Paper
Ten Years Later, Experiments with Clustering as a Software Remodularization Method ........................................................... 7
Nicolas Anquetil and Timothy C. Lethbridge

Session I – Mining Software Repositories
Who are Source Code Contributors and How do they Change? ................................................................. 11
Massimiliano Di Penta and Daniel M. German
A Study of the Time Dependence of Code Changes ......................................................... 21
Omar Alam, Bram Adams, and Ahmed E. Hassan
Relating Identifier Naming Flaws and Code Quality: An Empirical Study ................................................................. 31
Simon Butler, Michel Wermelinger, Yijun Yu, and Helen Sharp
Techniques for Identifying the Country Origin of Mailing List Participants ................................................................. 36
Ran Tang, Ahmed E. Hassan, and Ying Zou
Session II – Dynamic Analysis

NTrace: Function Boundary Tracing for Windows on IA-32 ................................................................. 43
  Johannes Passing, Alexander Schmidt, Martin von Löwis, and Andreas Polze
Recovering Views of Inter-System Interaction Behaviors ................................................................. 53
  Christopher Ackermann, Mikael Lindvall, and Rance Cleaveland
Mining Quantified Temporal Rules: Formalism, Algorithms, and Evaluation ..................................... 62
  David Lo, Ganesan Ramalingam, Venkatesh Prasad Ranganath, and Kapil Vaswani

Session III – Empirical Software Engineering

An Exploratory Study of the Impact of Code Smells on Software Change-proneness ................................ 75
  Foutse Khomh, Massimiliano Di Penta, and Yann-Gaël Guéhéneuc
An Empirical Study on Inconsistent Changes to Code Clones at Release Level ................................... 85
  Nicolas Bettenburg, Weyi Shang, Walid Ibrahim, Bram Adams, Ying Zou, and Ahmed E. Hassan
Lexicon Bad Smells in Software ............................................................................................................ 95
  Surafel Lemma Abebe, Sonia Haiduc, Paolo Tonella, and Andrian Marcus

Session IV – Remodularization and Reengineering

Automatic Package Coupling and Cycle Minimization ......................................................................... 103
  Hani Abdeen, Stéphane Ducasse, Houari Sahraoui, and Ilham Alloui
Identifying Cycle Causes with Enriched Dependency Structural Matrix .............................................. 113
  Jannik Laval, Simon Denier, Stéphane Ducasse, and Alexandre Bergel
The Logical Modularity of Programs ....................................................................................................... 123
  Daniel Ratiu, Radu Marinescu, and Jan Jürjens
On the Use of ADM to Contextualize Data on Legacy Source Code for Software Modernization ........ 128
  Ricardo Pérez-Castillo, Ignacio García-Rodriguez de Guzmán, Orlando Ávila-García,
  and Mario Piattini

Session V - Change and Defect Proneness

On the Relationship Between Change Coupling and Software Defects ............................................. 135
  Marco D’Ambros, Michele Lanza, and Romain Robbes
Tracking Design Smells: Lessons from a Study of God Classes ......................................................... 145
  Stéphane Vaucher, Foutse Khomh, Naouel Moha, and Yann-Gaël Guéhéneuc
Bug-Inducing Language Constructs ....................................................................................................... 155
  Javed Ferzund, Syed Nadeem Ahsan, and Franz Wotawa
Design Patterns and Change Proneness: A Replication Using Proprietary C# Software ..................... 160
  Matt Gatrell, Steve Counsell, and Tracy Hall

Session VI – Static Analysis and Security

Automatic Static Unpacking of Malware Binaries ............................................................................. 167
  Kevin Coogan, Saumya Debray, Tasneem Kaochar, and Gregg Townsend
Computing the Structural Difference between State-Based Models ................................................... 177
  Kirill Bogdanov and Neil Walkinshaw
Extraction of Inter-procedural Simple Role Privilege Models from PHP Code ................................... 187
  Dominic Letarte and Ettore Merlo
Session VII – Traceability

Traceability Recovery Using Numerical Analysis ............................................................................................................. 195
Giovanni Capobianco, Andrea De Lucia, Rocco Oliveto, Annibale Panichella, and Sebastiano Panichella

Benchmarking Lightweight Techniques to Link E-Mails and Source Code ........................................................................ 205
Alberto Bacchelli, Marco D’Ambros, Michele Lanza, and Romain Robbes

Domain Feature Model Recovery from Multiple Applications Using Data Access Semantics and Formal Concept Analysis ......................................................................................................................................... 215
Yiming Yang, Xin Peng, and Wenyun Zhao

Session VIII - Program Comprehension

Characterizing Evolutionary Clusters ....................................................................................................................................... 227
Adam Vanya, Steven Klusener, Nico van Rooijen, and Hans van Vliet

Autumn Leaves: Curing the Window Plague in IDEs ............................................................................................................. 237
David Roethlisberger, Oscar Nierstrasz, and Stéphane Ducasse

Constructing a Resource Usage View of a Large and Complex Software-Intensive System .................................................. 247
Trosky Boris Callo Arias, Pierre America, and Paris Aygeriou

Session IX – Static Analysis

Static Detection of Disassembly Errors ............................................................................................................................. 259
Nithya Krishnamoorthy, Saumya Debray, and Keith Fligg

Reverse Engineering Sequence Diagrams for Enterprise JavaBeans with Business Method Interceptors ............................................ 269
Alexander Serebrenik, Serguei Roubtsov, Ella Roubtsova, and Mark van den Brand

Computing Structural Types of Clone Syntactic Blocks ..................................................................................................... 274
Ettore Merlo and Thierry Lavoie

Reverse Engineering Existing Web Service Applications .................................................................................................. 279
Houda El Bouhissi and Mimoun Malki

PhD Forum

Supporting Feature-Level Software Maintenance .............................................................................................................. 287
Meghan Revelle

Enabling the Evolution of J2EE Applications through Reverse Engineering and Quality Assurance .......................................................... 291
Fabrizio Perin

Approximate Graph Matching in Software Engineering ..................................................................................................... 295
Sègla Kpodjedo

Evolving Software Systems Towards Adaptability .............................................................................................................. 299
Mehdi Amoui

SQUAD: Software Quality Understanding through the Analysis of Design ............................................................................. 303
Foutse Khomh
Tool Demonstrations

PRECISO: A Reverse Engineering Tool to Discover Web Services from Relational Databases .................................................. 309
   Ricardo Pérez-Castillo, Ignacio García-Rodríguez de Guzmán, Ismael Caballero, Macario Polo,
   and Mario Piattini
Recovering Class Models Stereotyped with Crosscutting Concerns .......................................................... 311
   Heitor Augustus Xavier Costa, Paulo Afonso Parreira Júnior, Valter Vieira de Camargo,
   and Rosângela Aparecida Dellosso Penteado
SHINOBi: A Tool for Automatic Code Clone Detection in the IDE .............................................................. 313
   Shinji Kawaguchi, Takanobu Yamashina, Hidetake Uwano, Kyohei Fushida, Yasutaka Kamei,
   Masataka Nagura, and Hajimu Iida
Enhancing Quality of Code Clone Detection with Program Dependency Graph ........................................ 315
   Yoshiki Higo and Shinji Kusumoto
JavaCompExt: Extracting Architectural Elements from Java Source Code ..................................................... 317
   Nicolas Anquetil, Jean-Claude Royer, Pascal André, Gilles Ardourel, Petr Hnětynka,
   Tomáš Poch, Dragos Petrașcu, and Vladiela Petrașcu
ConAn: A Tool for the Identification of Crosscutting Concerns in Object Oriented Systems
   Based on Type Hierarchy Analysis ................................................................. 319
   Mario Luca Bernardi and Giuseppe Antonio Di Lucca

Workshops

R.E.M. 2009 - International Workshop on Reverse Engineering Models from Software Artifacts ............... 323
   Leon Moonen and Tarja Systä
FAMOOSr 2009 - Workshop on FAMIX and Moose in Software Reengineering ........................................ 325
   Simon Denier and Tudor Gîrba

Author Index .................................................................................................................................................. 327
On the use of ADM to Contextualize Data on Legacy Source Code for Software Modernization

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Abstract—Legacy systems are usually made of two kind of artifacts: source code and databases. Typically, the maintenance of those systems is carried out through re-engineering processes. Although both artifacts can be independently maintained, for a more effective re-engineering of the whole system both should be analyzed and evolved jointly. This is mainly due to the fact that the knowledge expected to be extracted by analyzing both kind of artifacts at the same time is greater and richer than the one recovered by just looking at the system partly, and thus ROI and lifespan of the system are expected to improve. This paper proposes the Data Contextualization for recovering code-to-data linkages in legacy systems. This technique is framed in the ADM (Architecture-Driven Modernization) approach to modernization of legacy systems, considering all involved artifacts as models. This paper also presents a tool to support that technique throughout a real-life case study.

Keywords—Data Contextualization, Modernization, Model Transformations, ADM and KDM.

I. INTRODUCTION

At the present time, the majority of organizations have large legacy systems supported by relational databases. These systems are not immune to software ageing. The erosion not only affects to the source code, but databases as well. Age gradually. For instance, in order to adapt the system to new requirements, new tables and/or columns are added to the database; other tables are modified and even discarded without erasing them from the database. These changes over time generate problems related to inconsistency, redundancy and integrity among others.

Therefore, organizations must address maintenance processes taking into account legacy source code and databases together. In those maintenances, the entire replacement of the legacy system would have a great technological, strategical and economical impact for the organization [10]. In addition, according to [2], the 78% of maintenance changes are corrective or behaviour-preserving. Indeed, maintenances based on evolutionary reengineering processes are typically carried out.

The starting point in that reengineering process is the conceptual representation of the legacy system through reverse engineering [1]. At this stage, the legacy source code as well as the legacy database must be represented in order to consider these two artefacts jointly. Nevertheless, a challenge appears in this scenario: finding out what fragments of the database are used by each piece of legacy source code. This knowledge is essential in later stages of the reengineering process, such as restructuring and forward engineering, where the new and improved systems are built [10]. Since the improved system will probably use the same data, it turns out to be very important to keep track of the use the data in the context of the source code of the legacy system. That is to say, it is important to contextualize the data in the representation of the legacy software when we are reversing it.

This paper proposes the Data Contextualization technique and a tool that supports it. This is a novel reverse engineering technique developed in the context of the MARBLE framework to modernize legacy systems [9]. This technique recovers code-to-data links in legacy systems based on relational databases and allows representing and managing these linkages throughout entire reengineering processes. In order to obtain these linkages two main knowledge sources are considered: (i) database schemas and (ii) the sentences embedded in source code. Moreover, the proposal follows ADM (Architecture-Driven Modernization) approach for developing this technique [6]. This approach advocates modelling all artefacts involved in the reengineering process as models and it transforms the models between different abstraction levels according to MDA (Model-Driven Architecture) principles [5].

The remainder of this paper is organized as follows. Section 2 presents the background of this work. Section 3 shows the proposed Data Contextualization technique. Section 4 presents the developed tool. Section 5 presents a case study of a real-life modernization project. Finally, section 6 addresses the conclusions and the future work.

II. BACKGROUND

A. Related work

The inspection of source code and recovery of specific knowledge is a common challenge in reengineering and maintenance processes. Nevertheless, the linkage between code and used data has not been widely studied. Zou developed a framework based on a set of heuristic rules for
extracting business processes following a MDA approach [11]. Those works took into account legacy source code and program data in order to link pieces of code together and to obtain workflows. However, they do not link source code and external data such as databases. Some works such as [3] propose frameworks to align and develop business rules by means of collecting information about how and where these business rules are implemented within the source code. But data and code are not mapped together. Marinescu proposes in [4] an approach for determining the correlation between foreign keys extracted from the database schema and the way the data are used in the source code. Finally, there have been research in database reengineering follows the MDA way the data are used in the source code. Finally, there have been research in database reengineering follows the MDA approach [9], but source code is not considered jointly. In spite of these works, in any case the code-to-data linkage is carried out following the ADM approach.

B. Architecture-Driven Modernization

Reengineering and MDA have converged on ADM, another OMG initiative. ADM is the concept of modernizing existing systems with a focus on all aspects of the current systems architecture and the ability to transform current architectures to target architectures [6].

The increasing cost of maintaining legacy systems together with the need to preserve business knowledge has turn modernization of legacy systems into an important research field. ADM provides several benefits such as ROI improvement on existing information systems, reducing development and maintenance cost, extending life cycle of the legacy systems, and easy integration with other systems.

ADM Task Force in OMG has led to several standards. The cornerstone within this set of standards is KDM (Knowledge Discovery Meta). KDM allows standardized representation of knowledge extracted from legacy systems by means of reverse engineering [8]. KDM provides a common repository structure that makes possible the exchange of information about existing software assets in legacy systems. This information is currently represented and stored independently by heterogeneous tools focused on different software assets. KDM can be compared with the UML (Unified Modeling Language) standard: UML is used to generate new code in a top-down manner. In contrast, a process involving KDM (as Data Contextualization) starts from the existing code and builds a higher level model in a bottom-up manner.

ADM and KDM advocate representing any artefact as models according to the MDA approach. Transformations among these models are modelled by means of QVT (Queries / Views / Transformations) [7].

III. DATA CONTEXTUALIZATION

The proposed Data Contextualization is a technique that can be used in modernization processes when the reverse engineering stage is being carried out [9]. This technique recovers the linkages between pieces of legacy source code and the fragments of database schemas used for that pieces. In addition, this knowledge is represented in a KDM Code Model. Therefore, in the modernization processes, this new knowledge is essential when a new version of a legacy systems is being developed after the reverse engineering stage. Perhaps, the modernized system does not require all functionalities of the legacy system. In this case, it is important to be able to identify the fragments of legacy database that are used by the reused pieces of legacy code. As a consequence, the knowledge obtained in the Data Contextualization could be used to obtain a new database schema that is minimal and fits for the modernized system.

In order to obtain the code-to-data linkages this technique considers two knowledge sources: database schemas and the sentences embedded in source code. Thus, the process showed in Figure 1 is divided into three steps: (i) the static analysis of source code (ii) the static analysis of SQL code; and (iii) the model transformations.

A. Static analysis of source code

This activity analyzes the legacy source code in order to obtain a KDM Code Model, an abstract conceptual representation of code. This model is represented according to the Code Package of the KDM metamodel. The SQL queries embedded in the source code are also represented in the KDM Code Model. Nevertheless, this information is not supported by KDM Code metamodel. For this reason, a specific extension of KDM metamodel according to the extension mechanisms defined in the KDM standard [8] is proposed. Therefore, all generated KDM Code Models attach an ExtensionFamily.

The ExtensionFamily defines three stereotypes: (i) <<SQLStatement>> depicts the SQL code of the queries that is recovered in this activity, (ii) <<SQLModel>> represents the model of each SQL query that is built in the second activity, and (iii) <<DatabaseModel>> represents

Figure 1. Overview of Data Contextualization: activities, task and artefacts involved in the technique.
the model of the a specific database schema fragment obtained from an SQL model in third activity. In addition, each stereotype has a TagDefinition to keep the needed information: the code of the query for <<SQLStatement>>, and the path of the model for <<SQLModel>> and <<DatabaseModel>>. Then, when the static parser finds out an SQL query in legacy code, it adds a new CodeElement with the stereotype <<SQLStatement>> and it puts the SQL code in an associated TagValue element. Thus, the query comes represented into the KDM code model.

B. Static analysis of SQL code

After static analysis of source code, there are several points in KDM Code Model where the SQL queries were recognized. Thus, this second activity carries out a static analysis of each SQL sentences in the KDM Code Model in order to generate several models representing the SQL Sentences. For such an end, a specific metamodel has been developed to represent the embedded SQL sentences. This metamodel represents the Data Manipulation Language (DML) of SQL-92: to model the Insert, Select, Update and Delete SQL operations. These operations are generalized in a SQL Statement meta-element. A set of Statements comprise a DML model. In this point, the KDM Code Model knows the SQL Sentence Models that it contains in the legacy system, and in turn, the data requirements for each fragment of source code of the legacy system.

C. Model transformations

Finally, in the third activity a database schema model is obtained from the SQL sentence models by means of a set of QVT transformations according to a database schema metamodel. The database schema metamodel has been developed to represent the database in the Data Contextualization process. This metamodel enables the representation of Tables, Constraints related to these tables, and so on.

Figure 2 shows the set of QVT relations established between the meta-elements of the SQL DML Metamodel (left side) and the meta-elements of the Database Schema Metamodel (right side). For instance, the tables that appears in any SQL sentence (insert, select, update or delete) as well as in source and target clauses (such as from, set, into, and so on) will be created as tables elements in induced database schema. Also, the columns that are selected, added, deleted or updated in SQL sentences will be created in the corresponding tables. In addition, the Select sentences organized in join mode suggests potential primary keys and foreign keys in target database schema.

After the QVT transformation, the URL of the obtained database model is put into the Tag Value of the KDM Code Model. Therefore, the final result is a Code Model that has a point for each embedded SQL sentence where it links the associate SQL Sentence and Database Schema Models. Thus, each piece of source code is related to the database schema fragment that it use.

IV. A TOOL FOR DATA CONTEXTUALIZATION

The Data Contextualization technique is aided by an ad hoc tool developed for JAVA-based legacy systems. The tool is structured in three modules corresponding to the three activities of the Data Contextualization technique. In order to support the first and second activity, two tool modules to carry out static analysis was developed. Those modules were developed through JavaCC from the EBNF grammar of Java 1.5 and PL/SQL. The first one takes a Java file as input and generates an XMI file as output that represents the KDM Code model. The second one takes the previous XMI file and generates several XMI files corresponding to the SQL sentence models. Moreover, this module updates the KDM Code model, since it puts the URL of the obtained SQL Sentence models in each embedded query.

The third module executes the QVT transformation using the Medini QVT framework. This module obtain an XMI file for each XMI file correspondig to the SQL Sentences models. In addition, the ECORE version of the three proposed metamodels was developed. Indeed, three graphical editors were obtained from them by means of EMF (Eclipse Modelling Framework) tools.

V. CASE STUDY

The case study addresses a modernization project that is currently being carried out. The subject legacy system of this project is the intranet of Computer Faculty of University of Castilla-La Mancha. This Java-based intranet was developed five years ago by several people. The intranet consists of five well differentiated modules: Main, Administration, Old Students, Management and Quality. The intranet consists of 18.5 KLOC divided into 75 source files. Also, the legacy database schema consists of 140 tables and 7 columns per table on average.

In order to analyze the obtained results, the following research questions are established:

Q1. Are the Database Schema Models complete?

Q2. What is the gain of the Database Schema Models?

Finally, the Q1 question is related to the completeness of the obtained database schema fragments. A specific schema is complete when: (i) any table has primary key; (ii) there are not tables without columns; and (iii) there are not
duplicated elements. Secondly, the Q2 question takes into account the minimization of the database schema. In order to measure the gain between the previous and current size, it uses two variables: the gain related to the number of tables $G_T$ (1) and related to the number of columns in each table $G_C$ (2). In these formulas, $T_{LIS}$ is the number of tables in the legacy database schema and $C_{LIS(T_i)}$ represents the number of columns of the table $i$ in the legacy database. $T$ is the number of tables in the improved database schema and $C_{(T_i)}$ is the number of columns of the table $i$ in the obtained database.

$$G_T = \frac{T_{LIS} - T}{T_{LIS}}$$  \hspace{1cm} (1)

$$G_C(T_i) = \frac{C_{LIS(T_i)} - C(T_i)}{C_{LIS(T_i)}}$$  \hspace{1cm} (2)

The case study is focused particularly on modelling the three kinds of models involved in the Data Contextualization. Due to space limitations, this section shows the models obtained through the tool for a specific Java file of the main module: '_Consultar__Preinscripcion2'.

Figure 3 (A) shows through the tree model editor the KDM Code model obtained after the static analysis of the Java file. Also, it shows two embedded SQL sentences that were discovered. These two points were updated later with the paths of the SQL Sentence Models and the Database Schema Models. After that, the Data Contextualization tool executes the static analysis of the previous KDM Code model and generates two SQL Sentence Models for each SQL sentence in the first model.

Figure 3 (B) shows the model related to the second SQL sentence. Finally, the tool executes the QVT relations and generates also two Database Schema Models related to the previous models. Figure 3 (C) shows the model related to the second SQL sentence model. In this example, the tables 'MATRICULASCEP' and 'ALUMNOSCEP' of a join select sentence as well as the columns related to these tables were built in the output model.

<table>
<thead>
<tr>
<th>Module</th>
<th>Legacy System</th>
<th>Database Schema</th>
<th>Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N. of source files</td>
<td>LOC (mean per file)</td>
<td>N. of Queries (mean per file)</td>
</tr>
<tr>
<td>Main</td>
<td>18</td>
<td>323.7</td>
<td>1.8</td>
</tr>
<tr>
<td>Administration</td>
<td>8</td>
<td>132.5</td>
<td>1.6</td>
</tr>
<tr>
<td>Quality</td>
<td>44</td>
<td>242.0</td>
<td>1.4</td>
</tr>
<tr>
<td>Old Students</td>
<td>4</td>
<td>141.8</td>
<td>1.0</td>
</tr>
<tr>
<td>Management</td>
<td>1</td>
<td>318.0</td>
<td>1.0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>75</td>
<td>18578</td>
<td>1.5</td>
</tr>
</tbody>
</table>

After the execution of the parser and the QVT transformation, a set of output models of the database fragments was obtained. TABLE I summarizes the obtained results; it shows (i) the source files, LOCs and NOQs for each module; (ii) the primary/foreign keys and tables obtained for each obtained database schema; and (iii) the gain obtained with respect to the source database.

**TABLE I. THE RESULTS OBTAINED IN THE CASE STUDY.**

![Figure 3](image-url)  
Figure 3. An example of the models involved in the Data Contextualization.
The analysis of results obtained for these models reports several conclusions that should be considered to answer the Q2 question:

- The tables are usually obtained without primary keys unless a primary key is attached. This problem was solved with a simple matching between the legacy database and the modernized one.
- Achieving tables without columns is not usual, because any column that appears in a SQL statement is normally associated to its table.
- In this case study, since the only QVT-implemented mechanism for inferring foreign keys is the QVT Relation based on the \textit{join select} sentences, the QVT relations do not infer enough foreign keys. Indeed, the source code of intranet has only two join select sentences due to bad design of the legacy database.

In order to respond the Q2 question, the gain of obtained database schema was also assessed. 25 out of 140 tables were recovered (18%) and the $G_T$ value (1) was 82%. With respect to the columns, the mean per table of the $G_C$ values (2) was 30%, although in some modules this mean was higher. In this study, the $G_C$ mean is lower than the $G_T$. However, the total gain related to the size minimization of the new database schema is significant.

VI. CONCLUSIONS AND FUTURE WORK

The Data Contextualization, a modernization technique based on KDM, has been proposed in this paper. The objective of this technique is the modernization of legacy source code together with the legacy relational database. For this reason, this proposal recovers the code-to-data linkages and obtains three kinds of models according to the ADM approach: (i) The KDM Code Model, which represents the inventory of legacy source code. It has also the points that link the SQL Sentence Models and Database Schema Models. (ii) The SQL Sentence Model for modelling a certain SQL query that was embedded in legacy source code. (iii) The Database Schema Model, which represents the specific database fragment derived by an SQL Sentence Model.

The Data Contextualization technique has been validated by means of a case study in a real-life modernization project of a legacy intranet. The case study reports the many advantages and some limitations of the proposed solution. Firstly, the completeness of the database schema model was higher with respect to table and column elements. Nevertheless, the completeness was lower regarding to the constraint elements. Secondly, the gain of the obtained Database Schema Models was important: the size minimization was around the 30\% and the 80\% for columns and tables respectively.

The work-in-progress focuses on improving the completeness of the output models by means of more patterns related to foreign keys. Furthermore, the future extensions of this research will address the integration of this technique with following stages of the modernization process such as restructuring or forward engineering.

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