Providing Authentic Long-term Archival Access to Complex Relational Data

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(Dated: July 19, 2004)

We discuss long-term preservation of and access to relational databases. The focus is on national archives and science data archives which have to ingest and integrate data from a broad spectrum of vendor-specific relational database management systems (RDBMS). Furthermore, we present our solution SIARD which analyzes and extracts data and data logic from almost any RDBMS. It enables, to a reasonable level of authenticity, complete detachment of databases from their vendor-specific environment. The user can add archival descriptive metadata according to a customizable schema. A SIARD database archive integrates data, data logic, technical metadata, and archival descriptive information in one archival information package, independent of any specific software and hardware, based upon plain text files and the standardized languages SQL and XML. For usage purposes, a SIARD archive can be reloaded into any current or future RDBMS which supports standard SQL. In addition, SIARD contains a client that enables ‘on demand’ reload of archives into a target RDBMS, and multi-user remote access for querying and browsing the data together with its technical and descriptive metadata in one graphical user interface.

Keywords: Long-Term Digital Preservation, Digital Archives, Relational Databases, Value of Information

The urgency of deep-infrastructure solutions for long-term digital preservation and archiving was clearly formulated in the late 90’s of the past century by national archives and libraries \(1\,2\,3\,4\,5\,6\,7\) as well as space agencies and institutions in earth observation, oceanography, and astronomy \(8\,9\). The finding of problem statements and strategies is still in progress and was recently supported by a charta of the United Nations \(10\). Deep and lasting solutions are still not available, and for national archives and libraries (faced with very heterogeneous types of content) it is broadly accepted that digital collections are growing at a rate that outpaces their ability to manage and preserve them \(11\).

There is an ongoing process of recognition that long-term digital preservation poses similar problems in diverse disciplines. Despite of different vocabularies used by different communities, research and development in the field can only be successful in a joint effort. During the past decade, however, decisive progress was achieved in analytical and conceptual work \(12\,13\,14\). Furthermore, the Open Archival Information System (OAIS) reference model became widely accepted in diverse disciplines and covers a full range of archival information preservation functions including ingest, archival storage, data management, access, and dissemination. It has become the international standard ISO 14721:2003 \(15\) and may be applicable to any archive as it does not refer to specific implementations or archival strategies but merely provides a common terminology and functional framework to discuss different implementation approaches.

Many current development projects focus on the archiving of digital images (digitized photographs or paper documents) and sound recordings, while more complex types of digital information have been neglected, even though their relevance for governmental and scientific activities has drastically increased during the past decade. In particular, a recent international workshop on the long-term preservation of databases \(16\) revealed that many archives do have a long-standing practice and experience in ingesting and preserving relational data, but their daily work is constrained to the treatment of rather simply structured data sets, requires extensive manual work by archives personnel, and does not allow for smooth and standardized integration of data and descriptive meta data on a level required to ingest, preserve, and provide access to complex relational databases.

In this paper we present a method and application named “Software-Invariant Archiving of Relational Databases” (SIARD), developed at the Swiss Federal Archives. It completely detaches typed relational data from almost any relational database management system, while still retaining most of the original data logic and integrating data and metadata in one archival information package that is based on text files and standardized technologies. In Section \(\text{III}\) we discuss the technical and intellectual complexity of relational data in modern database systems, the resulting problems for long-term preservation, and its relevance to archives. The objectives in the development of SIARD are described in Section \(\text{IV}\) while Section \(\text{V}\) covers SIARD’s system architecture, workflow, features, and development platform.

I. INTRODUCTION

Relational data is one of the oldest forms of structured information representation, intuitively used already centuries before the “digital age”. With the rise of computer technology, the introduction of mathematical formulations of the relational data model in the mid-20th
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data models, are able to physically store terabytes of
data, cover rich data types (including internal procedural code), enable multi-user transactions, and provide internal data life-cycle management. The definition, represent-

ation, management, and query of relational data was thereby standardized and separated from specific application logic and application software that operates on the database. As a result, RDBMS have become core components of almost any type of digital information system.

It is obvious that this development has decisive impacts on the work of those institutions which are charged to collect or accept digital data from various data sources, to make it broadly accessible, and to preserve it over decades: national archives and libraries, science data archives, or business companies being under special legal regulations for long-term data retention (like, for example, the pharmaceutical sector [14]).

II. COMPLEXITY AND RELEVANCE

A. Technical Complexity of Relational Data

One consequence of the progress in database technology is that relational data and relational databases become highly complex. They often consist of hundreds of linked tables (i.e. physical representations of relational entities3), which makes it impossible to handle and query table data outside an RDBMS if these links become broken or cannot be managed automatically anymore.

Furthermore, any data item in a RDBMS has a precisely defined data type and domain. (Entire tables or integral parts of them may likewise have types.) Apart from basic data types (for example integer and real numbers, dates, and character strings), low-level types like large binary objects, complex and inheritable user-defined types, and multi-lingual character encodings are widely used in modern databases. As for the linking of tables, the connection between the data and its data types and domain definitions is not preserved when table data is trivially exported to external plain text files.

In addition to those entities and features mentioned above, modern RDBMS include, for example:

- Check constraints and assertions: For a single column of a table or a set of entire tables, assure that changing or entering data does never violate defined data types, quantitative restrictions, or value domains. In particular, it can be assured that data items in a table column will never be empty.
- Views: Assemble selected parts of several tables and operate on them as customized, virtual tables.
- Triggers: Force the RDBMS to initiate timed operations on data when user-specified conditions are met, for example log and audit user activities.
- Functions (basic and user-defined): Perform numerical calculations, conversions, or character operations on data items or sets.
- Stored Procedures: Store and execute programs inside the RDBMS to perform common or critical tasks which are not part of the specific application software outside the RDBMS.
- Foreign Keys: Ensure referential data integrity, i.e., automatically prevent that values can be stored in rows of one table if there are no corresponding values in referencing entries within the database.
- Grants and Roles: Define user profiles and assign or withdraw privileges, for example to create new tables or access certain parts of the database.

For long-term preservation in national archives, relational data is collected from many different database systems and has to be retained and kept processable and accessible for decades. It is therefore essential to store and maintain the databases independent of any specific and short-lived products (or at least transferring them all into one preferred product). In fact, most RDBMS use the same language for the definition of the internal logical organization of data, namely the declarative (i.e. non-procedural) Structured Query Language (SQL). Despite of its name, the scope of SQL also includes the definition of data structure and the manipulative operations on data stored in that structure [14].

The development of SQL started in the 1970’s, leading to the international standard ISO/IEC 9075 in 1987, and evolved in four main stages through SQL-89, SQL-92, SQL:1999, and recently SQL:2003 [20], while the size of the standard has grown from 120 to over 2’000 pages. SQL-2003 and SQL:1999 are fully upward compatible with SQL-92. The standard language keywords are structured in three subsets: Data Definition (DDL), Data Manipulation (DML), and Data Control and user authorization (DCL). To increase acceptance by vendors, the stan-

3 We will not discuss the relational model in this article [14, 15]. It will be sufficient to think of tables which consist of one or more table columns and one or more table rows. The points of intersection of columns and rows contain data items which have a data value and a data type. If (and only if) there never occur duplicate rows in a table, then the table is a relation, and its columns and rows are also called attributes and tuples (or records), respectively. Using relational algebra and calculus, several relational tables can be managed and manipulated jointly.
standard defines three levels of conformance and implementation: entry, intermediate, and full level. The mandatory part of SQL:1999 and later is called the “Core” of SQL and described in Part 2 (Foundation) and Part 11 (Schema) of the standard.

Aside from revisions to all parts of SQL:1999 (e.g., new data types and functions that return entire tables), the 2003 edition contains the new part: “SQL/XML” defines a minimal handling and integration of text-based data structured by the Extensible Markup Language XML. This includes mappings between tables and XML documents, SQL data types and XML Schema data types, and RDBMS implementation-specific character sets to Unicode character encodings. Additionally, the related standard “SQL Multimedia and Application Packages” ISO/IEC 13249:2003 defines a number of packages of generic data types common to various kinds of data used in multimedia and application areas, to enable storage and manipulation of such data in a relational database.

1. Standardized – Really?

SQL is an internationally standardized and comprehensive language for the definition, description, query, and manipulation of relational data and databases. It is widely used since almost 25 years, developed upward compatible, and will probably play a key role for another 25 years. Since most RDBMS are based on SQL (and most vendors claim compliance with the standard) one could assume that relational database definitions are independent of any specific RDBMS product. Unfortunately, this is far from being true. In contrast to standardized programming languages like ISO-C or ANSI-Fortran, SQL-based database layouts and SQL code can rarely be ported between different RDBMS without major modifications and loss of functionality.

There are two main reasons for severe incompatibilities. First of all: Although the SQL standard today comprises over 2’000 pages, it is far from being fully self-contained. In contrast, SQL:1999 explicitly identifies 381 so-called implementation-defined items and 137 so-called implementation-dependent items. Their implementation is left open for any manufacturer of RDBMS products. As long as a manufacturer completely documents all implementation-defined items, the product can rightly claim to comply with the SQL standard, though it differs from all competing products. (The precision of the SQL integer data type is a simple example of an implementation-defined item.)

The second reason is that most of today’s RDBMS implement only (and sometimes fail to) the core and the entry level of the standard completely, but add plenty of non-standard, product-specific enhancements, leading to different “flavors of SQL”. These include new additions to or modifications of, for example, data types, functions, operators, behavior and syntax of SQL statements. Additionally, almost all RDBMS products use their own procedural programming languages for stored routines (Oracle PL/SQL, Postgres PL/pgSQL, Microsoft T-SQL, PL/Perl etc.) rather than implementing the standard’s procedural language SQL/PSM.

Finally, it is an almost trivial remark that modern RDBMS move the physical storage of the data from the operating system (file level) to the application level (the internal storage of the RDBMS).

2. “SQL for Archiving”?

Considering the imponderables discussed in the previous subsection we can draw the following conclusion with respect to archival institutions: If they have to collect and ingest relational data from various database management products for the purpose of integrating them, to preserve them over long periods of time, and to make them broadly accessible, then these institutions are faced with a Sisyphean task: The data they have to preserve for long is locked up in short-lived obsolescent and complex software products from a vast diversity of manufacturers, making the longevity of the data heavily depend on the availability of the products and their versions, the support by vendors, and the existence of the manufacturers. One lesson learned is that long-term preservation of relational databases is much more than just making backups of export or dump files from database management applications, though IT professionals usually use ‘archiving’ and ‘backup’ as synonyms.

It is a tempting idea to demand a “SQL for Archiving”, defined as a subset of the ISO-9075-SQL standard. It would leave database designers the choice to restrict their databases to layouts suitable for long-term preservation (and transfer of databases among competitive RDBMS products, of course). A similar effort is undertaken by government agencies and industry representatives to define an ISO standard “PDF for Archiving, PDF/A” based on the popular Portable Document Format (PDF) specification 1.4 by Adobe Systems Inc. and the ISO 15930 standard PDF/X. However, the current ISO-9075-SQL standard is probably not suited for a similar attempt; too many important items are left open as implementation-defined and would require adding deep descriptions of implementation details in the standard.

It should be mentioned that since its first edition, ISO-9075 requires SQL implementations to provide a feature called “SQL-Flagger” (feature F812 in SQL:1999) which is able to identify and signal certain kinds of non-standard SQL language extensions used in the specific implementation. The feature is implementation-dependent and its intention is to assist SQL programmers in producing SQL language that is portable among different conforming SQL-implementations. Standard SQL flagging is only required for the entry level of SQL. In fact, most major RDBMS manufacturers have implemented SQL-Flaggers for SQL-92 in their products. The reason is that the U.S. Government implicitly requires conformance with the entry level of SQL-92 for all SQL
products in federal procurements. (Conformance with higher levels may be specified explicitly.) The minimum requirements for conformance with entry-level SQL-92 as well as specific features of the SQL-Flagger are specified in the Federal Information Processing Standard (FIPS) 127 (33).

The purpose of FIPS SQL is “to promote portability and interoperability of database application programs, to facilitate maintenance of database systems among heterogeneous data processing environments, and to allow for the efficient exchange of programmers among different data management projects” (33). Although not explicitly mentioned in FIPS 127, its intention also supports long-term preservation of databases. The U.S. National Institute of Standards and Testing (NIST) used to validate SQL implementations to conform with FIPS-127. Although this procurement specification is still in force nowadays, it was not updated to the 1999 and 2003 editions of SQL, and NIST ceased its product validation in 1997. (A suite of automated validation tests for SQL-92 implementations is still freely available from NIST (33).) To our knowledge, none of the major RDBMS products include SQL-Flaggers for SQL:1999 or SQL:2003 as it would be required by the respective standard editions. Our application SIARD (described in Section IV) has its own, built-in SQL validator. Aside from this, we are aware of only one (third party and commercial) tool which provides such functionality (33).

We conclude from our work, that standard (i.e. generic) SQL may be reasonably exploited for long-term preservation purposes only when data and data logic is actively extracted from database management systems by specialized ingest tools which map different "SQL flavors" to generic SQL, and transparently trace and document those parts which cannot be mapped.

B. Intellectual Complexity and Access

Aside from the technical aspects discussed so far, a successful long-term preservation of databases is only possible if the intelligibility and comprehensibility of the database and its data can be preserved as well. To keep data understandable and meaningful it is indispensable to collect enough technical as well as non-technical metadata and handle it as an integral part of a database archive. Otherwise, there will be a rare chance to understand the meaning and value of the database’s content decades after it was archived.

However, most of the meta-data necessary to enable long-term intellectual access to the data is not deposited in the database but is provided to the archives on separate (and often paper-bound and hard to grasp) documents. On the one hand, this includes precise and complete data dictionaries, code lists, narrative descriptions of the naming, meaning and usage of single database objects. On the other hand, it is descriptive and archival metadata about the context, creation, purpose, usage, or chain of custody of the original database and the RDBMS used to operate it.

The problem of descriptive metadata that supports intellectual accessibility has to be considered in a broader context of trusted digital repositories (35): Any serious long-term preservation strategy for any kind of digital content aims to guarantee continuous

- **Integrity**: protection of the data from unintended and intended harm;
- **Intelligibility**: understandability and comprehensibility of the data;
- **Authenticity**: authentication (of authorship and provenance) and reliability; (of evidence)
- **Originality**: data structure and functionality “as close to the original as possible”;
- **Accessibility**: technical readability and usability.

However, due to overall technical obsolescence in a digital environment, these are competitive and conflicting goals. Each archival institution will therefore have to establish its own measures and priorities among the five above-mentioned criteria. The measures will be primarily ruled by metadata, and many authors address the interplay between obsolescent technical infrastructures and continuing guidance of metadata (36 37).

Moreover, since long-term preservation is a costly and laborious task, effective appraisal methods are increasingly important instruments. The value of information and evidence contained in databases is often determinable only through the purpose, design, and context of usage of the original database application. Again, these criteria are measured by means of metadata provided by the data producers.

Another level of intellectual complexity is introduced by an increasing amount of interlinked, federated and temporal database systems which makes it difficult to determine the correct spatial and temporal scope for extracting data for long-term preservation: A database that is selected for archiving may refer to time-dependent master data in another database, or a database does not overwrite or delete any outdated data but rather records all data modifications, using timestamps as multiple primary key components (e.g. valid-time state tables, tracking logs, backlogs, etc.). It will be a challenge for archives to keep such spatial and chronological dependencies and interrelations understandable and traceable, particularly across sequential accessions from the same database.

C. Current practices

Relational data kept by national archives usually consists of plain text files that contain tabulated data with fixed-length or delimited columns (16). Very often, these files are only derivatives of the original database, produced by denormalization of the original data model to reduce the number of single tables. The data files are
usually accompanied by paper documents or microfiches that provide data dictionaries and other descriptive information necessary to understand the content, provenance, and context of the data. At the time when the data was originally transferred to the archives, it has been scrutinized to reveal any inconsistency with the paper-bound documentation.

In typical archival environments, the descriptive documents are kept separately in cardboard boxes which are stored in air-conditioned shelves, while the electronic data files are stored on labeled magnetic tapes or cartridges. Tapes and cartridges are recopied every 5 to 10 years to prevent data loss from degradation of the magnetic media by physical and chemical processes.

One reason for the deficiency in providing long-term physical and intellectual access to data from archived databases is a high heterogeneity of data formats and the fragmentation of data sets into isolated data files, which are hard to handle in bulk. But primarily it is the habitual bipartite treatment of digital data in most archives: While the data itself is accessible and processible by electronic systems, the metadata necessary to understand the data’s content, provenance, and context, is bound to paper documents and often incomplete, erroneous, outdated, not standardized, and hard to grasp. That’s why even a small data collection requires cumbersome and expensive manual work to overcome this divide between electronic and paper documents.

It can be easily concluded from the discussion of the previous sections that the situation will become even more critical in the future: The advance in information technology puts more and more obstacles on the path that digital information has to pass on its way from producers to the archives. Proprietary, closed data formats and technologies quickly become obsolete, heterogeneous and complex data structures further impede comprehensive data integration in the archives.

Today’s archives become aware that digital information in their custody becomes increasingly volatile rather than persistent. This is particularly true for relational databases since the development of new preservation techniques has mainly focused on other forms of digital content such as images or sound recordings which are easier to handle and more attractive to a broad audience. In contrast, methods for the long-term preservation of data from modern database management systems with increasing complexity and data in the order of terabytes has been neglected.

D. Relevance to National Archives

Relational data is probably the oldest and most widespread type of information among the electronic digital holdings of national archives, typically dating back to the 70’s and 80’s of the past century. (In fact, even the oldest collections are of no age compared to usual archival time scales.) These collections comprise data from almost any field of activity of governmental institutions and are thus of high information and evidential value, and are increasingly important to researchers in diverse fields such as History, Sociology, Politics, Economics, Meteorology, or Geography.

Nevertheless, national archives nowadays are hardly ever able to provide broad access to their digital data sets on a level of usage comparable to paper-bound or analog electronic holdings. (A few archives have put a lot of effort into it, though, and provide public access to selected collections through the world-wide web.) Most national archives are still far from enabling the public to locate government information regardless of format.

In terms of archival appraisal, databases may serve various purposes which are not in the primary focus of national archives to preserve evidence in business records of the federal administration. (Business records are evidence of what an agency has done or decided.) In the opinion of many archivists, databases are mainly used by the administration to store and manage registers, master data records, and statistical (e.g. census) data, thus may be at best considered as finding aids. This may be true for databases of the past.

Nowadays, modern database systems are widely used for managing and recording business processes and transactions. Thus they have become integral parts of almost any record and document management system or E-government web site, and thus often contain high evidential value. It has become an essential necessity for archives to assess the evidential value of databases kept in RDBMS, and to develop appropriate criteria and guidelines for such assessments.

Criteria and guidelines are also required for appropriate archival description of relational databases since they are rarely integrated into any filing plan of the agency. In consequence, there is only a purely technical ordering of database records which will not correspond to the logical ordering of business records (e.g. belonging to a business case, dossier, or document). A business record may comprise several technical table records and may extend across several tables, and a single database table is often not a meaningful entity for archival description. It can be a challenge to identify and precisely describe something like a dossier, business record, or document in a relational database made up of dozens of tables.

E. Relevance to Natural Science Data and Research

It is broadly accepted that experimental scientific data has often a high long-term value, and the urgency of solutions for their long-term preservation has been pointed out many times during the past decade. By contrast with national archives, science data archives focus on the information value, while evidential value of scientific data is rarely considered. Moreover, there are completely different criteria and schemes for appraisal and description of scientific data.

Scientific data may have a high long-term value because, for example, it cannot be reproduced (e.g. cli-
mate and oceanographic data) or it was produced at
enormous costs (e.g., high-energy physics experiments
or space flight missions). As theories evolve and new
questions arise, archived data may be reconsidered
and re-evaluated in future research, and may turn out to be
of essential scientific value. For example, satellite data
from the 60’s and 70’s of the past century turned out
to be essential for current research on global warming.
Long-term preservation solutions of scientific and techni-
cal data is also needed, for example, in the automobile
and aeroplane industry since construction data has to be
retained for cases of insurance claims.

However, the driving force in development of solutions
for long-term preservation of scientific data is to provide
sustained global data access and exchange between glob-
ally distributed research collaborations (47, 48, 49).

III. OBJECTIVES

From the discussion of the previous sections we briefly
formulate objectives for research and development in the
field of long-term preservation of relational databases. A
solution for the archiving of relational databases

- has to enable, to a good level of authenticity, per-
  manent retention of the original internal data struc-
  ture, the referential data integrity, and all techni-
  cal and non-technical meta-information needed to
  keep the data technically accessible and intellectu-
  ally understandable over the long term;
- must ensure that the data remains utilizable and
  processable by future data processing systems;
- must be able to completely detach databases from
  its proprietary database management software,
  hardware, and operating system environments;
- must completely rely on widely accepted and inter-
  nationally standardized technologies;
- shall no longer require any specific software, main-
  tenance, or administration for at least ten years,
  and reasonably longer if the full documentation
  of applied standard technologies remains available,
  provided that the physical bit-streams of all files
  remain intact;
- shall easily enable the reload to current and future
  relational database management system products,
  and thereby allow queries in almost the same com-
  plexity (on the database level) as in the original
  system from which the database was archived from;
- shall support the acquisition and standardization of
  non-technical data (which is usually not available
  from the physical database) across different busi-
  ness units and persons, and seamless integration
  with data and technical metadata.

IV. SOLUTIONS: SIARD WORKFLOW AND FEATURES

The method and Java application SIARD (“Software-
Invariant Archiving of Relational Databases”) meets the
aims outlined in Section III. The development of SIARD
was a subproject of the strategic project ARELDA
(Arching of Electronic digital Data) of the Swiss Fed-
eral Archives and the Swiss Federal Administration.

SIARD consists of three stand-alone software applica-
tions, named A0, A1, and A2. Each application may be
used by different people at different places during differ-
en stages of the workflow: database administrators and
application responsibles of the RDBMS, records man-
gers of the data producers, IT professionals and general
personnel of the archives, or archives customers. The
output of each application is used as the input of the
next stage’s application. Unfinished work can be saved
any time and resumed later. All three applications are
independent of the computer platform (cf. subsection
IV.A) and location. Communication between SIARD
components and the RDBMS can take place either lo-
ally or through a TCP/IP network (which will be the
usual case). All applications have XML-based, external
configuration files that may also be edited manually.

Figure 1 summarizes the SIARD components and
workflow. The RDBMS which contains the database to
be archived is at the top of the figure. As examples, Fig-
ure 1 shows two commercial RDBMS products (Micro-
soft SQL-Server and Oracle) as well as an unspecific “other
RDBMS” which could be an Open Source product, for ex-
ample. (SIARD may also be used with Microsoft Access,
that works best when Access is used in the SQL-Server
compatibility mode.) Figure 1 sketches various set-ups
for starting work with SIARD:

- Direct connection to the operational RDBMS.
- Migration of the database from the operational
  RDBMS to another RDBMS (including another in-
  stance of the same RDBMS product) using migra-
nation tools that are supplied by the vendors. (We
denoted this intermediate RDBMS with “Oracle”,
but it could be any other product.)
- Connection to the operational RDBMS through a
  vendor-supplied transparent gateway.

The first method (direct connection) is the usual case.
However, direct connections of SIARD to the operational
RDBMS may not be allowed or desired, for example due
to security reasons or because the RDBMS is a high-
availability system. (However, we emphasize that SIARD
does not alter the RDBMS in any way! It solely performs
read-only access operations on the RDBMS.)

But there are other possible reasons to add this in-
termediate step: For example, using transparent gate-
ways or migration of the database from the original to
another RDBMS may help to get more out of SIARD
since it provides so-called “expert modes” for some spe-
cific products. These expert modes take into account
As shown in Figure 1, the first SIARD application A0 analyzes and extracts a database from the RDBMS (with guidance by the user), and creates the archive files. After these tasks have been completed, the XML reference file (which contains all meta information about the results of the extraction) is loaded into application A1. In A1, the user adds further, mandatory and optional non-technical metadata on all levels of the object hierarchy (database, tables, columns etc.) as well as context metadata defined by the archival institution. Being complemented this way, the XML reference file is written back to the SIARD archive which is now ready for long-term preservation. The third application A2 comes into play when the archived database is requested for access and usage by a customer or required for other dissemination purposes. The reload is initiated through A2 by either the customer itself or by archive staff. We will describe the features of the three SIARD applications in more detail below.

Several tests have proven the applicability of the solution. The complexity of the tests performed so far range from tens of tables and a few thousand rows up to 250 tables and 250'000 rows from several commercial and open source database management products. The main difficulties were, as expected, proprietary, non-standard extensions to SQL in all RDBMS products, implementation-specific character sets, and extraction of some specific metadata from the system dictionaries, respectively.

A. A0: Analysis and Extraction

This is undoubtedly the core of SIARD since it determines the quality and extent of the database archive as far as technical aspects are concerned. A0 usually will be operated by the RDBMS application responsible (who has knowledge of the databases content), maybe assisted by a database system administrator (DBA) who has a deeper understanding of the technical background of the specific RDBMS. (Of course, A0 can also be used within the archival institution to migrate older non-SIARD data collections, for example.)

There are two ways to connect to the RDBMS with A0. The straight forward method is to allow A0 to connect as a DBA. Although A0 solely performs read-only operations on the database, this method is is not recommended since it requires disclosure of the DBA password. The recommended method is that a DBA creates a new user in the RDBMS (named SIARD-A0, for example) and exploit product-specific features. Thus it may be advantageous to previously migrate the database from the original RDBMS to a RDBMS product for which SIARD provides an expert mode. Another reason could be that pre-processing of the database is required prior to archiving, for example data conversions or filtering. (SIARD can only exclude entire columns or tables from archiving.) Of course, such operations will never be performed on a production database.
and grants to it only those rights which are required by A0 to be operated properly. This also allows fine-tuning of privileges to an extent where A0 can only see exactly those parts of the database that are in fact subject to archiving 2.

At startup, A0 asks for the Java Database Connectivity (JDBC) parameters to be used. The user either must enter the parameters manually into a panel, or else open up an XML-based A0 configuration file. (Usually, a DBA will provide a configuration file.) Afterwards, A0 asks for the access mode to be used. There are so-called “expert modes” for specific RDBMS products as well as a generic mode, used if no specific expert mode is provided by SIARD or the type of RDBMS is unknown. At the moment, there are only two expert modes (Oracle 7/8/9 and Microsoft SQL-Server 7/2000). Expert modes provide a broader range of database objects and metadata that can be archived since they exploit product-specific features. The generic mode has a rather narrow focus and is solely for internal purposes of the RDBMS (which is continuously evolving from version to version, though.) New expert modes may be easily programmed and added to A0 without changes in existing code.

1. Automatic Analysis and Mapping

After successful connection to the RDBMS, A0 lists all 3 schemata 4 in the database and asks the user to select all or only some of them to be archived by SIARD. Afterwards, the database schemata (data dictionaries) are analyzed by A0’s built-in SQL parser and validator. Additionally, A0 checks for data integrity and identifies, for example, isolated tables (which do not have any primary keys and no foreign or unique keys pointing to them).

During this process, A0 tries to automatically translate non-standard SQL constructs into forms that fully conform to the standard, provided that this conversion will not lead to any loss of information in the primary data. Otherwise the conversion is not performed. (The exact details of this criteria are described in the SIARD documentation.) Correspondingly, objects that do not conform to the SQL standard, nor can be automatically mapped to standard forms, are automatically set to the status “Cannot be archived”.

When finished, the results are presented to the user as shown in Figure 2. There is a hierarchical, collapsible tree of database objects in the left-hand pane, while the right-hand pane shows the technical metadata from the data dictionary as well as the results of the analysis for the database object that is currently selected in the object tree. The tree of database objects comprises schemata, tables, table columns, one- and multiple-column primary key constraints, check constraints, triggers, views, the views’ SQL code, view columns, stored procedure, functions, users, user roles, user role privileges, synonyms, and database links. There is either a small colored bullet or a document symbol attached to each object in the tree. Additionally, each root of a branch of the tree has assigned either a green check mark, a yellow triangle with an exclamation mark, or a red cross. The colors and symbols indicate the status of an object:

- A green bullet means “The object is or was made fully conforming with standard SQL and has proper data integrity – Ready for archiving”.

- An orange bullet means “The object is or was made fully conforming with standard SQL but has problems with data integrity – Ready for archiving”.

- A red bullet means “The object does not conform to and could not made conforming with standard SQL – Archiving is not possible without user intervention which may cause loss of information”. Red bullets usually occur for unknown, proprietary or non-standard user-defined data types.

- A gray document symbol means “The object does not conform to and could not made conforming to standard SQL – A0 decided to exclude it from archiving.” This usually occurs when the SQL code of a view, constraint, trigger, stored routine, or function does not conform to standard SQL.

- A green check mark indicates that everything is okay (green bullets) or consolidated (gray document symbols) on subsequent nodes of the respective branch. This branch is ready for archiving.

- An exclamation mark indicates that there is at least one warning (i.e. a orange bullet) on subsequent nodes. The branch can be archived, though.

- A red cross indicates that there is at least one un-resolvable problem (i.e. a red bullet) on subsequent nodes. A decision by the user is required (for example manual exclusion of the object from archiving).

If an object was automatically excluded or has a red bullet, the detected problems are explained in the “Details” tab of the right-hand pane.

2. Clearance

Archiving of the database is not possible as long as red crosses appear (i.e. any red bullets on lower levels of a branch), and the “Create Archive” button is disabled.

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2 Privilege tuning for A0 is described in the user manual and may depend on the specific RDBMS product used.
3 To be more precise: All schemata are listed only if A0 has logged in with DBA permissions. Otherwise, if A0 is logged in as an individual SIARD user, the list of schemata depends on the privileges that were granted by the DBA. Schemata and tables which are solely for internal purposes of the RDBMS are automatically ignored by the expert modes.
4 If the RDBMS supports catalogs, e.g. Microsoft SQL-Server, these are listed before the schemata.
Thus, the minimal action required by the user is to treat at least all objects with red bullets. To do so, the user has four possibilities. Three of them can be chosen either from the function button panel or the context menu of the right mouse button: First, the object may simply be manually excluded from archiving. In this case, the red bullet turns into a gray document symbol. However, the red bullet may come from an unknown data type which in fact is a valid standard SQL type but has a non-standard name (thus SIARD does not recognize the type). This usually should happen only in the generic access mode, but could also occur in expert modes when the version of A0’s expert mode is older than the version of the RDBMS. (In fact, many RDBMS use non-standard names for standard data types.) Pressing A0’s “Unknown and Proprietary Data Type” button, the user can define a catalog of synonyms for data type names to disclose to A0 the correct data type for this “unknown” data type name.

In the example shown in Figure 2 all red crosses are caused by a single problem which could not be resolved by A0’s initial automatic conversion algorithm: The data type “MY_TYPE” of the column “CODE” in table “PRINT_MEDIA” is an unknown data type and thus could not be automatically converted to a standard SQL data type without loss of information. In consequence, A0 assigned it a red bullet, and the analysis result (visible in the right-hand pane) says “SQL3 Check: Type conversion to SQL3 impossible”. A0 did not assign a gray document, however, since there may be still the chance to solve a possible naming conflict by a user-supplied synonym rule as described above. In this example, the data type “MY_TYPE” is a user-defined data type with a non-standard definition. However, inspection of the original database would reveal that (in this example) “MY_TYPE” can be mapped onto the standard SQL
data type “varchar(10)” without loss of information. The user can easily resolve the problem by defining a naming rule “MY_TYPE → VARCHAR(10)” using A0’s “Unknown and Proprietary Data Type” button.

The second possibility is that the red bullet in fact comes from a proprietary non-standard data type. The user may either exclude the object from archiving (third possibility) or use the “Proprietary Data Type” button to define a deep conversion to a standard data type. This may cause loss of information, though, and is only possible in expert modes (since the input and output of a conversion must be well defined). The fourth possibility is to perform a conversion of unknown or proprietary data types within the original database (i.e. outside of SIARD’s A0 application), for example by using vendor-supplied specific SQL CAST functions.

All conversions initiated in A0 are never performed in the original database but only after the extraction of the database from the RDBMS. We also emphasize that exclusion of an object from archiving does not mean that the object will be invisible in the final archive. In contrast, all meta information about the object (available from the original database) will be documented in the archive (including its non-standard SQL code). But it means that the object (for example a table, table column, check constraint, stored routine, or trigger) cannot be actively restored anymore in a RDBMS later.

Of course, the user may also exclude any valid object (with a green bullet) from archiving, for example if archiving is not desired due to appraisal decisions. The excluded object will still be fully documented in the SIARD archive (though its data content will be excluded). We emphasize that automatic and manual exclusion of objects (for example entire tables or single table columns) is only possible because A0 restores a proper data integrity after any exclusion. For example, when a table is excluded from archiving, the user is warned if there are any primary keys in this table, or if any foreign or unique keys of other tables are pointing to that table. If the user confirms exclusion, A0 removes the key constraints from the referencing tables (without a cascading deletion of the table rows) and automatically also excludes from archiving all views, triggers, check constraints etc. which contain references to the excluded table. A similar procedure applies if single table columns are excluded. Finally, we note that any exclusion operation can be reversed again by using A0’s ‘Undo’ function.

Orange bullets primarily indicate isolated tables (with no key constraints in it and no foreign keys pointing to it) and do not require user intervention. However, using the context menu of the right-mouse button or the function panel, the user may define its own primary as well as foreign and unique key constraints manually on any table, assisted by an interactive panel. A similar function and panel is provided to define user-added check constraints (using standard SQL code only). Both possibilities may be optionally used if linkage information or check constraints for the table do implicitly exist but are hidden in external application software which operates on the original database. Adding the corresponding information from the external application’s system documentation will complement and improve the database archive while external software usually will not be archived. (Note that user-added key and check constraints are only defined within the SIARD archive, while the original database is not altered.)

During work, the user can save intermediate states at any time, and resume his work later. Furthermore, the application A0 has a special added-on object at the end of the object tree, named ‘changelog’. In fact, A0 traces and remembers all changes to the original state of the database. This includes activities performed automatically by A0 during its initial analysis of the original database, as well as all changes caused by manual operations of the user later on. Each entry in the ‘changelog’ contains a time stamp, a short description of the activity, and the nature of the change. The log file will be part of the SIARD archive (and be extended further in the subsequent module A1 of SIARD). This enables re-tracing of the archiving process at any time in the future and thus supports authenticity of the database archive.

3. Creation of the Archive

The “Create Archive” button is enabled when the database is ready for archiving. This happens as soon as all root nodes of branches in the object tree have assigned either green checkmarks or yellow exclamation marks. The latter indicate warnings (orange bullets) on subsequent nodes (for example isolated tables) which may be acceptable. For the example shown in Figure 2 this state can be reached by either defining the before-mentioned synonym rule for the data type “MY_TPE”, or by exclusion of the table column “CODE” from archiving (while its metadata will still be included in the SIARD archive). When pushing the “Create Archive” button, A0 asks for the location where the archive shall be saved. Afterwards, A0 starts to load the primary table data from the original database, performs all necessary conversion operations on them, and creates all SIARD archive files.

5 This conversion functionality is not yet implemented in the current release of SIARD.
6 A similar procedure may be applied to non-standard SQL code in views, triggers etc. However, we think that it is not desirable to change a database too deeply for the purpose of archiving. Furthermore, many RDBMS use a proprietary procedural programming language for stored procedures which cannot be easily mapped onto the SQL/PSM language (cf. subsection 1.4.1).

7 In contrast to objects which belong to the original database, user-added key and check constraints cannot be excluded from archiving but only deleted completely (using the ‘Delete’ function or button). The delete function is disabled for all other objects.

8 Depending on the amount of data and the network transfer ca-
• **SQL-DDL files**: These files contain standard SQL:1999 Data Definition Language (DDL) statements only. Together they represent the definition of a self-contained relational database, comprising all objects and attributes of the original database, except for those that were excluded.

• **Table data files**: These are files which contain the primary data (except for large objects, see below) of the database defined in the DDL files above. There is one file per table. The data of one table row is contained in one line of the file, and data items have variable lengths. Rather than putting absolute delimiters between two adjacent data items, we use a simple algorithmic token for delimitation.

• **Large Object Files**: Each file contains a single data item of a so-called large object string type (provided that there really exist such data types in the original database, of course). This is either a character large object (CLOB) or a binary large object (BLOB) which was embedded in a table row of the original database. The former type is an arbitrary sequence of characters (for example a narrative document encoded in XML), the latter is an arbitrary sequence of bytes (for example an image file). Both may be up to several gigabytes in size. BLOB files just contain a hexadecimal dump of the original BLOB, thus may contain anything.

The SIARD archive has a fixed structure of file directories. This directory structure as well as some other

- **XML Reference File** This XML document contains all information from A0’s workbench. More precisely, it contains three kinds of metadata: Firstly, the complete database logic that is also contained in the SQL-DDL files (but encoded in XML). Secondly, all metadata from those database objects that were excluded from archiving (and thus do not appear in the DLL files), including the code of stored routines, triggers, views etc. Thirdly, the data from the “changelog” which reveals when and what actions were performed during the archiving process, either automatically be A0 itself or manually by the user.

Note that a SIARD archive is made up of all files listed above, not only of the DLL files (which only contains those parts of the original database which may be reloaded into another RDBMS again). In particular, the XML Reference file accomplishes the smooth integration of archived database objects, excluded objects, and all kinds of metadata. All files are plain text files (but may contain hexadecimal strings for binary data), and Unicode/UTF-16 encoding is used to overcome implementation-defined character encodings of the original RDBMS, and to preserve multilingual character sets (including non-latin alphabets).

The XML reference file may also be exploited for various other tasks. For example, it may be used by XML schema mapping tools to generate metadata subsets for import into finding aid or catalog systems. Or it may be used in the future for easy migration of the SIARD archive to other formats, for example to a future release of SQL (though SQL is developed upward compatible).

Furthermore, for more convenient handling by humans only, every table data file has a short XML header that contains the main table and column metadata such as names, data types, sizes, key constraints (primary, foreign, and unique), or default values. These table data files will not be altered anymore during the next steps of the SIARD workflow and therefore may be right away utilized for other purposes. For example, they can be viewed with any trivial text editor program. In addition, every SIARD archive contains a XML stylesheet language (XSL) file named “dmpFile.xsl” in its data file directory. Therefore, if a table data file is opened with a web browser from within this directory, the user automatically gets a pretty-print version of the data file (rather than clumsy to read raw data rows), including named columns as well as vertical and horizontal table lines. For example, the user may print this version (or catch the HTML output) for the purpose of non-technical distribution of the data.

The SIARD archive has a fixed structure of file directories. This directory structure as well as some other

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11 Actually, before writing the CLOB files, SIARD A0 converts the CLOBs of the original database into National Character Large Objects (NCLOB) via translation of all characters (which are stored in the implementation-defined character encoding of the RDBMS) to the fixed-length Unicode character encoding UTF-16. Otherwise, the characters in CLOB files would be rather useless without exact knowledge of the original, implementation-dependent character encoding.

12 This requires a browser which supports XSL, for example current releases of Mozilla or Microsoft Internet Explorer.
information is contained in an XML file named “archive-Info.xml” that is located in the root directory of each archive (and may be used by other software programs).

B. A1: Description

After creation of the SIARD database archive, the next step shown in Figure 4 is to add complementary metadata which is not available from the original database or the RDBMS. As discussed in Section IV.B, this kind of metadata is indispensable to enable long-term intelligibility and comprehensibility of the archived database.

Such metadata is added to the database archive using application SIARD A1. The users of A1 will not have to be the same as those of A0. Instead, it may be more nontechnical staff as, for example, records managers, data asset managers, experimental scientists, or application responsible. A1 only reads and modifies the XML reference file created by the application A0 (cf. Section IV.B), and the state of work may be saved at any time and resumed later. Thus the complementary metadata for A1 may be gathered across different business units by simply forwarding this XML file from one person to the other.

Figure 3 shows the graphical user interface of A1. Again, there is a database object tree on the left-hand pane. It is basically the same as in A0, except for the colors which now have a different meaning: red crosses indicate that there are mandatory but not yet filled in metadata fields on subsequent nodes, while green checkmarks indicate that all mandatory metadata has been provided on subsequent nodes.

For a database object that is selected in the object tree, the right-hand pane shows the metadata that was contributed by A0 (and thus comes from the original database), plus metadata that was added using A1. On the object level, the user can enter metadata at three locations in the right-hand pane: An arbitrary full text object name which may be more meaningful than its technical name (which is often an abbreviation), an arbitrary narrative description of the object which may improve the intelligibility of the object, and finally a user-added code list. The latter may be essential since code lists are frequently documented only outside a database. In our example in Figure 3, the column GRADE of the table STUDENT.SCHEDULE contains grades that were assigned to students after visiting certain college courses. The grades are coded with one or two characters (e.g. A+ or F-). However, the original database does not contain any information about what these codes mean. Therefore, the user has added a code list (using the “Add/Edit Value List” button) which explains that, for example, A- means “85 - 90% of the exam questions were answered correctly by the student”. Often codes are even less self-explanatory (imagine a code “92” which in fact means “application rejected”).

The context metadata on the database level is added and edited in a separate, multi-tab “Context Metadata Editor” panel (see Figure 3). It contains various tabs, each of them covering a certain subject in the context of the database’s usage, creation, original IT environment, history of the system, data authority, or provenance. Each tab contains a number of metadata fields with colored buttons that indicate whether filling in is mandatory or optional. A field is either a free text field or a pull-down list to select from predefined values. If the user points into a field, a description of the field is shown at the top of the panel. In addition, the descriptions can be displayed in different languages (which can be selected at the upper-right corner of the panel).

The extend and structure of the context metadata usually depends on specific requirements of the archival institution. Therefore, the “Context Metadata Editor” (CME) panel is fully customizable by using SIARD’s “Context Metadata Schema Editor” (CMSE) which is part of A1. Actually, the CME is built from an XML file which contains the CME layout, and the CMSE is basically a graphical user interface to manipulate this XML file. The user may define its own CME panel, including individual tabs as well as individual metadata fields and descriptions (using arbitrary languages). Thus it is possible to define several standardized context metadata schemata (CME panels) for different classes of databases or archival scopes. Depending on the class or purpose, the appropriate CME to be loaded in A1 to add customized context metadata to the SIARD archive.

In addition, there is a special CME tab “System Documentation” which allows the user to enclose arbitrary files to the context metadata part of a SIARD archive13. These may be, for example, PDF documents or TIFF images that are taken from the original RDBMS and database documentation, for example system and user manuals, log files, security reports, original data dictionaries etc. (One could even think of MPEG video documents showing people at work with the original production database system.)

While the user is working with A1, the application records all user modifications in the subnode “A1” of the “changelog” which was already mentioned in Section IV.A. Furthermore, for all context metadata entered through the CME panel, A1 does not only store the filled in data values of a metadata field but also the entire, language-specific version of the field description which was visible in the panel at that moment when the user entered or modified the data value. Making the field descriptions and the mandatory/optional characteristic integral parts of the SIARD archive is necessary since metadata catalogs (i.e. CME panel configurations) may change or evolve over time, and the meaning of single metadata items may change.

At any time, the user may convert the current version of the XML reference file into an HTML document for

13 Note that A1 does not inspect these files at all. It’s up to the user’s responsibility to use document and data formats that are suited for long-term preservation.
FIG. 3 A1’s workbench to add complementary narrative and context metadata to the database archive. For a single database object (selected in the object tree on the left-hand side) metadata is entered in the right-hand pane, while context metadata on the database level is entered in a multi-tab “Context Metadata Editor” window (shown in front of the right-hand pane).

convenient review or distribution. When all mandatory metadata has been filled in, the “Finalize” button is enabled. When this button is pushed, A1 will warn the user that no further changes to the reference file will be possible later, and will then write the final version of the XML reference file. This version now contains all metadata that was generated or collected by A0 and A1. The SIARD database archive has been completed and is now suitable long-term preservation. It does not depend on any specific hardware and software (not on SIARD as well), it consists of plain text files only (except for optional, user-added PDF or TIFF files), and it is solely based on technologies which are widely used and internationally standardized.

C. A2: Reload and Access

Apart from their primary purpose, SIARD database archives may also be utilized and processed by other software applications, for example in data dissemination and exchange or data warehouses. Because of its open technologies and its high level of standardization, SIARD archives may also be easily converted into forms that can be accessed directly in the World Wide Web. However, this may require some additional, expensive hardware and complex software (e.g. an application web server).

We have therefore added a third application to SIARD, named A2, which does not require additional infrastructure at all. The same infrastructure that was used for archiving the database (i.e. creating a SIARD archive) will be perfect. Basically, A2 is a simple RDBMS client but enables users to reload SIARD archives into a RDBMS “on demand”, and then provides multi-user remote network access for querying and browsing the data together with its technical and descriptive metadata in one graphical user interface.

We emphasize that A2, in its current version, is only a prototype (thus still has some bugs, limited functionality, and some security deficits), and currently only works with an Oracle RDBMS as the reload target system. However, it will be rather simple to adapt A2 to work with other
FIG. 4 A2’s Data Browser after reload of two SIARD database archives into an Oracle database. The pane at the bottom shows the data of the table which is selected in the database object tree (left-hand pane), while the pane at the top shows its metadata. The other database (“BILLY”) is accessed by selecting the second tab of the left-hand pane.

RDBMS products as well.

Working with A2 requires a running standard Oracle database instance (reachable either through a TCP/IP network or the local host) and some very simple preparations prior to operate A2. This preparation, however, has to be done by a system administrator: A new tablespace to hold the restored SIARD schemata and data should be created (and provide enough space for the estimated SIARD restore operations). In addition, a user with specific rights (which are described in the user manual) has to be added to the RDBMS. This user will act as a “SIARD archive manager” to control and serve connections from A2 clients. Its database schema will be the repository for information about all reloaded archives, registered users that are allowed to reload SIARD archives to this RDBMS, and it records reload operations and connection times of individual users. This schema will be initialized automatically as soon as any SIARD A2 client is connecting to this RDBMS for the first time.

A2 is controlled by an XML configuration file which contains the profiles of one or more RDBMS that are available as targets for SIARD restores. A profile identifies the Oracle database instance, the tablespace used for restore operations, and the before-mentioned “SIARD archive manager” user. Moreover, it provides additional information required by A2 to connect to the RDBMS. This configuration file will be pre-configured and provided to end-users of A2 by the RDBMS system administrator.

After starting A2, the user is asked to choose (from a file selector panel) the “archiveInfo.xml” file from the SIARD database archive to be reloaded, to select one of the pre-configured connection profiles, and to decide whether or not large object string files (BLOB and NCLOB, cf. Section IV.A.3) shall be reloaded too. Finally, the user either pushes the “Create New User” button to create a personal database account for working with A2, or else chooses an existing account from a pull-down list. After entering the user password, A2 establishes the connection. After that, the user is prompted to enter the password of the “archive manager” account.

14 Warning: This user password only authenticates the human user of A2, not the connection between A2 and the RDBMS itself, whereas A2 connects to the RDBMS as the “archive manager” user which has granted DBA rights, and its password is con-
reloads all schemata contained in the SIARD database archive\textsuperscript{15}. The user may sequentially reload as many SIARD database archives as needed and use them all together in a single A2 session. If a SIARD database archive was already reloaded by another user, it will not be reloaded a second time. (Users of A2 only have read access to the reloaded database.)

Figure 4 shows the main component of A2, the “Data Browser” panel. Again, there is the database object tree navigator already known from A0 and A1. In addition, there are tabs at the top of the tree panel to switch between different reloaded databases. The pane at the bottom shows the data of the table which is selected in the database object tree, while the pane at the top shows its metadata. Further metadata is found on subsequent nodes and in the “Context Metadata” branches below the “archives” root node. For example, the code list for student grades (which was user-defined during work with A1 in Section IV.B) can be accessed on the corresponding leave node “code list” in the FLUGLE schema (table STUDENT, SCHEDULE, column GRADE).

As can be seen in Figure 4, there are some (but not all) views reloaded. These views (marked with a green bullet) are actually proper views, and selecting them will show the view’s data in the data pane. The other views (those with a grey document symbol) do not show any data because they were excluded from archiving by SIARD’s application A0 due to non-standard SQL code in the original database. However, the view’s definition as well as the reason why it was excluded will be visible in the upper metadata pane.

The user may browse the database, select parts of table data in the data pane, and export it as comma separated (CSV) files. Furthermore, users who are familiar with the SQL query language may use the “SQL” tab (at the top of the upper pane) to switch to a separate panel where arbitrary SQL:1999 query statements can be composed and send to the Oracle RDBMS. The results of the query will be shown in a second pane where they can be selected all or in parts for export to a CSV text file.

If a user A decides to quit A2, he or she will be asked if the restored database shall be deleted. However, if there is still another user B currently registered for using the same database, it will not be deleted (but the registration of user A for this database will be removed).

In conclusion, SIARD A2 seamlessly integrates all metadata and data (whereas the reloaded database only contains the metadata from the DDL files described in Section IV.A.3), and it enables the user to perform simple as well as complex SQL queries on restored databases. Query results can be exported to the local machine. Several A2 clients may connect simultaneously to the same restored database, and A2 provides controlled multi-user remote access\textsuperscript{16} to SIARD database archives.

D. Development Environment

Software development of SIARD was carried out by the Swiss Federal Archives together with Trivadis (Switzerland) AG [54]. The SQL parser and validator as well as the context metadata schema editor was developed by one of the authors (SH).

The SIARD software is platform independent, relying on the programming language Java and the Java virtual machine as an interface to the operating system. It was tested under Solaris 7 and 8, Red Hat Linux 7, and Windows NT / 2000 / XP. The JDBC driver may need a specific environment to run properly (e.g. an MS Windows for a Windows specific authentication on an MS SQL-Server), but these restrictions are solemly defined by the driver.

Currently, Eclipse [55] is used as Integrated Development Environment, mainly because of its file-based approach. The technologies used in SIARD are

- Java 2 Software Development Kit (J2SDK) 1.4 by Sun Microsystems [56].
- Java Foundation Classes / Swing [57] were used for the graphical user interface.
- Java Database connectivity (JDBC) 3.0 [58] for data retrieval from and reload to the database management systems.
- Java API for XML Processing (JAXP) 1.2 [59] which handles operations on XML data (not needed anymore for J2SDK 1.4.2 and higher).
- The Extensible Markup Language (XML) 1.0 [22] for semantic markup of data in external text files created and read by SIARD components.
- The Extensible Stylesheet Language Family (XSL): XSL Transformations (XSLT) Version 1.0 [58] is a XML-based declaration language for displaying and transforming XML files.
- XML Schema (XSchema) 1.0 [24] provides automatic consistency and integrity checks on the SIARD XML files.
- The Structured Query Language (SQL) ISO/IEC 9075:1999 [59] for definition of database layouts.

\textsuperscript{15} Depending on the size of the archive and the network transfer capacity, this may require a few seconds up to many hours.

\textsuperscript{16} Any Firewalls between the A2 client and the RDBMS will have to be properly configured, though.
The Unicode Transformation Format UTF-16 (UCS-2) for platform independent and multilingual character encoding in all SIARD text files.

Oracle 8/9i and Microsoft SQL-Server 7/2000 relational database management systems and Microsoft Access 97/2000 were used for testing SIARD.

The JDBC driver implementations of the different database manufacturers provide a varying degree of compliance with the JDBC specifications. Especially, the functions for querying the database for metadata leave much to be desired. This metadata could be extracted from the database by database specific SQL-like queries, which is why the database access in SIARD is encapsulated in so-called “modes”, allowing for database-dependent enhancements.

“Expert modes” allow manufacturer-specific access to the database engines. Today, expert modes have been implemented and tested for JDBC Drivers for the Oracle and Microsoft products mentioned above. For the use with other RDBMS products, a generic mode is provided. The open architecture of SIARD allows the simple development of further expert modes for archiving from other database products since they can be added dynamically (i.e. without changes in existing code).

As explained in Section IV.A.3, SIARD ultimately produces plain text files only. Testing conformance of the SIARD XML files with the XML standard is simple: all have dedicated XML schemata and thus can be validated, and there exist a multitude of XML parsers which provide just this functionality. The compliance of the SQL structures files with standard SQL:1999 is governed by SIARD’s own, plugged-in SQL parser and validator that checks the syntax of the SQL expressions as well as the dependencies between these expressions. (For example, for a table to be created in a specific database schema, the schema must have been created first.) Independent cross-checking of SIARD’s SQL files is possible too, though we are aware of only one other tool which provides broad SQL validation functionality.

V. CONCLUSIONS

We have discussed problems and relevance of long-term preservation of relational databases for usual archival institutions like national archives and scientific data archives that have to ingest data from a broad diversity of vendor products. We have argued that the common current ingestion and preservation practices may suffice for ingestion of small and simply structured data sets but suffer from insufficient integration of data and metadata, lack of automation in the ingestion of large amounts of data, error-proneness, and in general require extensive manual effort and intervention to make the data accessible and usable. Without having more efficient solutions at hand, the rapidly growing size and complexity of relational databases in modern relational database management systems will rapidly outpace the ability of archives to ingest, manage, and preserve them.

Furthermore, we have surveyed the relation between present-day database management system products and the standardized data definition, query and manipulation language SQL, and have critically appreciated its applicability to long-term preservation of databases. From this discussion we concluded that widespread non-standard, vendor-supplied enhancements and additions do not allow for one-to-one ingestion from such systems, and that no “SQL for Archiving” exists. Nevertheless, standard SQL may be reasonably exploited for long-term preservation purposes when data and data logic are actively extracted from database management systems by specialized ingest tools which map different ”SQL flavors” to generic SQL, and transparently trace and document those parts which cannot be mapped.

Finally, we have presented the method and platform independent application “Software-Invariant Archiving of Relational Databases” (SIARD), developed at the Swiss Federal Archives. It is a an efficient, traceable and controllable ingest tool to detach relational data from any specific hardware and software environment, and thereby enables, up to a reasonable level, retention of its original authenticity, integrity, accessibility, and usability. SIARD integrates data with data logic and descriptive metadata and supports the intelligibility of databases for long-term archival preservation and access.

Readers who are interested in testing and reviewing SIARD or writing new expert modes may contact the authors. SIARD is property of the Swiss Federal Administration.

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