DIGITAL LIBRARIES: ARCHAEOLOGY, AUTOMATION, ETDS, AND ENHANCEMENTS

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ABSTRACT

How can we build digital libraries (DLs) more quickly and better? Our next-generation approach is based on the 5S framework, of Streams, Structures, Spaces, Scenarios, and Societies. In particular, we have developed metamodels using 5S for several broad classes of DLs. One metamodel is for a 'minimal DL' (adopting a minimalist approach, which can be extended to common cases of institutional repositories, such as of electronic theses and dissertations, ETDs). Another is for archaological DLs, initially aimed to support integration of a number of (ETANA) sites in the Near East, but flexible enough to adapt to other regions as well. Using 5S and these metamodels, we can semi-automatically specify and generate tailored digital libraries, drawing on a pool of basic components, along with suitable enhancements, like multidimensional browsing.

INTRODUCTION

Digital libraries (DLs) (Arms 2000; Fox 1993a; Fox 1993b; Fox et al. 1995; Fox and Lunin 1993; Fox and Marchionini 1998, 2001; Fox and Sornil 1999, 2000; Fox and Urs 2002; Lesk 1997, 2005; Witten and Bainbridge 2002) have evolved since their emergence in the early 1990s as a new class of advanced and integrated information system. Already, there are many software solutions available (EPrints.org 2002; Informedia 2005; MIT 2003; Suleman 2002; Suleman and Fox 2001; Suleman et al. 2003; VTLS 2005; Witten and Bainbridge 2002; Witten et al. 2000). Building on more than a decade of research and development projects (Chen 2000a, 2000b; Fox 1999b; Griffin 1999; Lesk 1999; Rusch-Feja and Becker 1999), further advances and automation in the DL domain should have even broader benefit for all types of knowledge management: "Key to achieving productivity gains is reducing the human overhead required to obtain and use information." (Larsen and Wactlar 2004). As more and more DLs appear, it is essential that a science unfolds, as has been proposed for related fields like human-computer interaction and data mining (Carroll 2003; Ramakrishnan and Grama 1999).

Since 1999, we have been working to develop a science of, and theory for, digital libraries, referred to as "5S" (Table 1), since it relies upon five essential concepts, Streams, Structures, Spaces, Scenarios, and Societies (Fox 1999c). We have used 5S to define the key ideas in the DL field (Gonçalves et al. 2004a), construct an ontology (Gonçalves, Watson and Fox 2004b), and describe what it means to have a "high quality" DL (Gonçalves 2004). We have applied 5S to automate the implementation of tailored DLs, that suit the needs of particular users and are appropriate for content of interest (Figure 1), using tools like 5SGraph (Zhu 2002; Zhu et al. 2004), 5SLGen (Kelapure 2003), and related logging software (Gonçalves et al. 2002; Gonçalves et al. 2003).

Accordingly, in the next section we summarize key aspects of the 5S framework. The following section highlights our application of 5S to support education, in particular with regard to work on electronic theses and dissertations (ETDs). Then we show, in the domain of archaeology, how 5S can facilitate handling of complex challenges faced in the world of information technology, such as automation, quality, and rapid enhancement. Finally, we conclude this paper, and summarize our findings.

5S FRAMEWORK

Scientific theories rest upon formal definitions of primitive concepts and of essential concepts. As with other work in computer science, we employ basic primitives: event, function, grammar, graph, language, relation, sequence, state, and tuple. Next, since DLs are high-end information systems, a set of essential concepts is needed to provide adequate coverage and definitional power. After studying the terminology used in hundreds of papers in the DL field, we found that five concepts suffice. Accordingly, we employ and define the very different, but complementary, concepts of Streams, Structures, Spaces, Scenarios, and Societies (Gonçalves et al. 2004a) – and show how they can be applied, individually and in combination, to meet our objectives (Table 1).

Table 1 The 5Ss, with examples and objectives

Ss	**Examples**	**Objectives**
Streams	Text; video; audio; image	Describes properties of DL content such as encoding and language for texts or particular forms of multimedia data
Structures	Collection; catalog; hypertext; document; metadata	Specifies organizational aspects of the DL content
Spaces	Measure; measurable, topological, vector, probabilistic	Defines logical and presentational views of the several DL components
Scenarios	Searching, browsing, recommending	Details the behavior of DL services
Societies	Service managers, learners, teachers, archaeologists, etc.	Defines managers, responsible for running DL services; actors, that use the services; and relationships among them

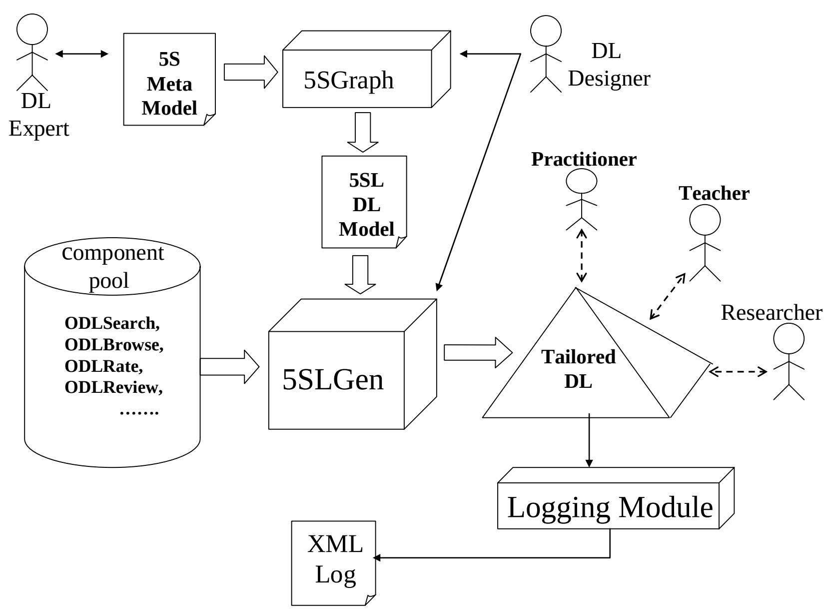

Fig.1 5S-related tools and applications, and their use in developing DLs

The first column of Table 1 identifies the Ss. The second column illustrates terms and aspects of DLs that directly fit into each of the Ss. The third column summarizes the basic intent of each S – but each S also can be employed in diverse other ways, in more advanced information systems, as well as in particular application domains. Thus, the Society of users is what most consider essential in basic systems, but authors also are in demand for pre-print services, and DL experts and designers are needed to develop DLs (Figure 1). Combinations of Ss are required too; an electronic thesis encoded in XML is a structured stream, while a searching service can be defined using four of the Ss: Stream, Structure, Space, and Scenario.

Building DLs has been more art than science. Using the 5S framework, as shown in Figure 1, a more scientific and automated approach is possible. The raw material for implementation is any pool of components, such as might be found in the Greenstone (Witten et al. 2002) or OpenDLib (Castelli and Pagano 2002) or Open Digital Library (Suleman 2002; Suleman and Fox 2002a; Suleman et al. 2003) projects. The challenge is to connect components (along with suitable "glue" to handle workflow) into a tailored DL, suitable for all types of users (Societies), along with support for monitoring quality, such as a logging module that follows appropriate standards (Gonçalves et al. 2002; Gonçalves et al. 2003). The key players are digital librarians, who function at various levels, especially as DL experts and DL designers (Figure 1). These players can be more efficient and effective in helping with the development of DLs if they can work with models instead of code (Shen et al. 2005). Accordingly we developed 5SL, a language for modeling DLs, that uses XML to describe a DL (Gonçalves and Fox 2002; Gonçalves et al. 2001). With the 5SGraph tool (Zhu 2002) a digital librarian can specify a particular DL by drawing upon a metamodel for that class of DLs. Thus, we see in Figures 2 and 3 metamodels for first a minimal DL (Gonçalves et al. 2004a), and then for an archaeological DL (Shen et al. 2005). The first metamodel suffices for any simple DL that is made up of digital objects, supported by basic services (Figure 2). The second metamodel is suitable for DLs that support archaeology (Figure 3), as is discussed later in this paper.

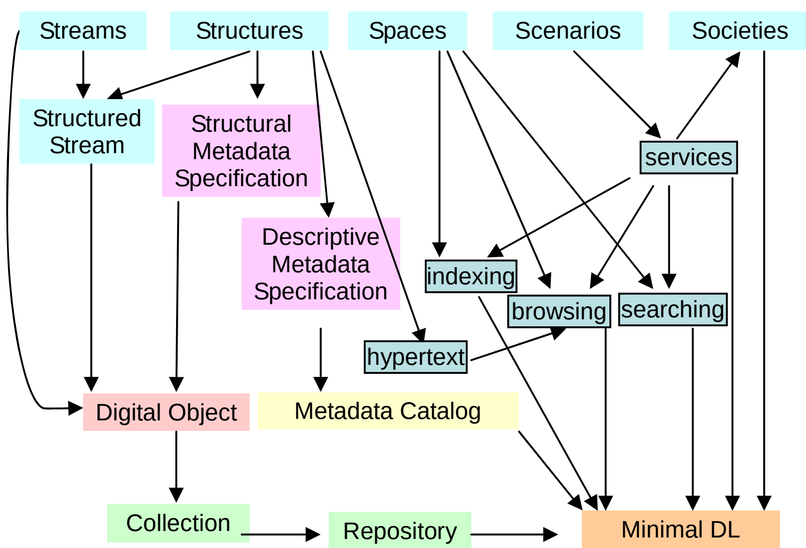

Fig.2 Metamodel for a minimal DL in the 5S framework

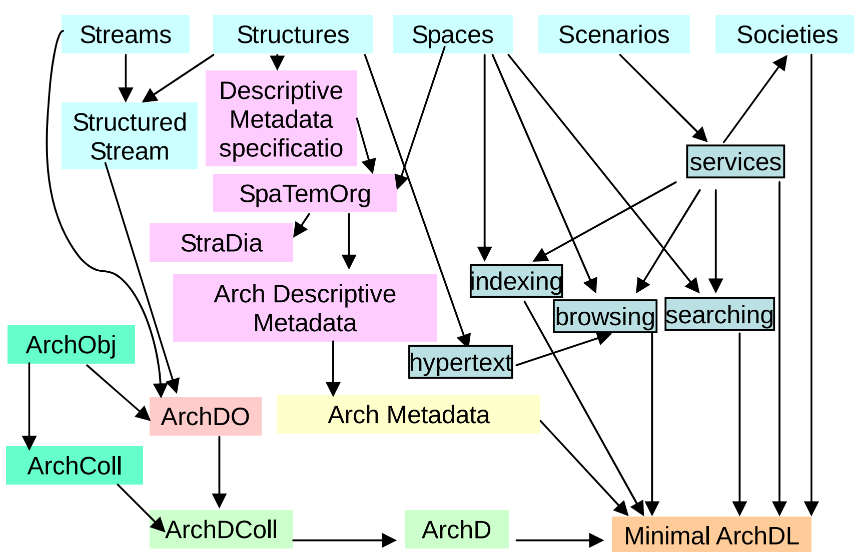

Fig.3 Metamodel for a minimal archaeological DL in the 5S framework

APPLICATIONS TO EDUCATION

One of the first (Fox 1993b), and one of the most important, applications of DLs is to support education (Fox, Gonçalves and Kipp 2001a). This is a worldwide concern (Kalinichenko 2003), as well as a national priority in diverse nations. In USA, one of the larger initiatives is the National Science Digital Library (NRC 1997; NSDL 2001, 2005; NSF 2005; Zia 2001). There have been well over 150 NSDL-supported projects (NSDL 2005), including a number in which Virginia Tech has engaged (Fox 2003), the largest being the Computing and Information Technology Interactive Digital Educational Library (CITIDEL 2002), around which a number of research investigations have unfolded (CITIDEL 2004; Kampanya et al. 2004; Perugini et al. 2004; Zhang, Gonçalves and Fox 2003). Core support for NSDL, as well as a number of separate funded projects, have advanced the overall technological base (Gupta, Ludäscher and Moore 2002; Lagoze et al. 2002). Other DL initiatives can build upon that base, which we hope also will be a strong support for innovation in education.

DLs can support teachers and learners, K-12 (Tucker et al. 2003) through undergraduate through lifelong learning, and all disciplines, e.g., Biology (BQCC 2000; NBDL 2001), Mathematics (Krowne 2005; MathForum 2000), Physics (Hilf 2000; Maly et al. 2002). Standards (ADL 2005; LTSC 2000; RHA 2001) have facilitated the development of learning object repositories (WCET 2005). Universities and other types of organizations have begun organized efforts to build local institutional repositories (Johnson 2002; Lynch 2003) to include and preserve these and related digital objects, using software like DSpace (MIT 2003). We believe 5S can help.

DLs for education can be modeled by making use of the metamodel given in Figure 2. This suffices when all resources are digital, when a single site maintains a repository that is based on a collection of digital objects, when a metadata catalog corresponds to the collection, and when there are at least a set of basic browsing and searching services (as well as a supporting hypertext structure and an indexing service).

A simple DL for education, supporting graduate education and research, is the Networked Digital Library of Theses and Dissertations, NDLTD (Fox 1997; Fox et al. 1996; Fox et al. 1997; Suleman et al. 2001a, 2001b). In discussions dating back to 1999, NDLTD has been described in varying levels of detail using the 5S framework (Fox 1999a, 1999c; Gonçalves 2004). The main Societies involved are graduate students, faculty, university administrators, and researchers (Fox et al. 2001b; Moxley 2001). Scenarios supported include: uploading electronic theses and dissertations (ETDs); having them checked and cataloged; harvesting (Suleman and Fox 2003) into a union catalog (CALIS 2004; OCLC 2004; Suleman and Fox 2002b; VTLS 2004); and subsequent search (Luo and Fox 2004) and downloading. (5S) Spaces cover the locations of authors' institutions and readers, as well as internal system representations to support searching, and external presentations involved in human-computer interaction. Structures include those that support browsing, as well as those associated with metadata records that conform to suitable standards (Atkins et al. 2001; Dublin-Core-Community 1999; Weibel 1999). Streams cover all of the content connected with ETDs, in all media types (Fox, McMillan and Eaton 1999), as well as all the communications among computers, and with users.

However, the 5S metamodel of Figure 2 is inadequate in cases when theses or dissertations only exist as paper or microforms, whereupon there may not be a digital object, though there typically is a metadata object. Such a situation is part of the expansion needed as we develop richer metamodels, like that shown in Figure 3, to support archaeological DLs.

ARCHAEOLOGY AND DLS: ADVANCES AND ENHANCEMENTS

In archaeology, as is shown in Figure 3, there are "real world" objects (ArchObj) that are in collections (ArchColl). This is in addition to corresponding surrogates (e.g., digital images), which are digital objects (ArchDO), and which in turn are part of collections (ArchDColl). The other key addition in Figure 3 is for spatial-temporal organizations (SpaTemOrg) and stratigraphic diagrams (StraDia), since in archaeology there is an intimate connection between time and space, which must be characterized and represented in order to understand the link between an archaeological site and the history of that location.

This connection can be understood in part through work with ETANA-DL (Ravindranathan et al. 2004a; Ravindranathan et al. 2004b; Ravindranathan et al. 2004c; Shen et al. 2005), a DL developed based on the 5S approach, to support the field of archaeology, especially building upon work on sites in the Near East. Figure 4 shows one of the screens that comprise the ETANA-DL user interface, demonstrating our approach to multi-dimensional browsing. We support identification of a subset of the collection based on selection of particular periods and sites, thus focusing on key aspects of time and space, but also can deal with other dimensions, such as that of artifact type. After repeated refinement of the selection, all records can be shown that fit the chosen constraints, first through a result list that includes thumbnails and metadata, and then in detail.

ETANA-DL has been a testbed to allow us to further develop the 5S approach, to enhance automation, and to add significant enhancements. Our first prototype was constructed in about 6 months (Ravindranathan 2004), making use of components from the Open Digital Library initiative (Suleman 2002; Suleman and Fox 2002a). But since integration of data from a large number of archaeological sites is our aim, we sought additional assistance from 5S as we worked to automate further the integration of more sites (Raghavan et al. 2005). Figure 5 summarizes the challenge and our approach, which also relates to CITIDEL (Kampanya et al. 2004).

In order to build an integrated "Union DL", we must consider all of the key aspects of the DLs that are to be integrated, e.g., DL1 and DL2 as shown in Figure 5. The resulting Union Society is the union of the societies of each of the separate DLs. Likewise, we can develop union versions of the key parts of a DL, such as the repository and the catalog. However, the Union Service must include more than the sum of the parts; additional services are needed to effect the integration (e.g., harvesting and mapping), and to provide help for users to manage and work with a much larger and more heterogeneous content collection (Raghavan et al. 2005; Ravindranathan et al. 2004b; Ravindranathan et al. 2004c; Shen et al. 2005).

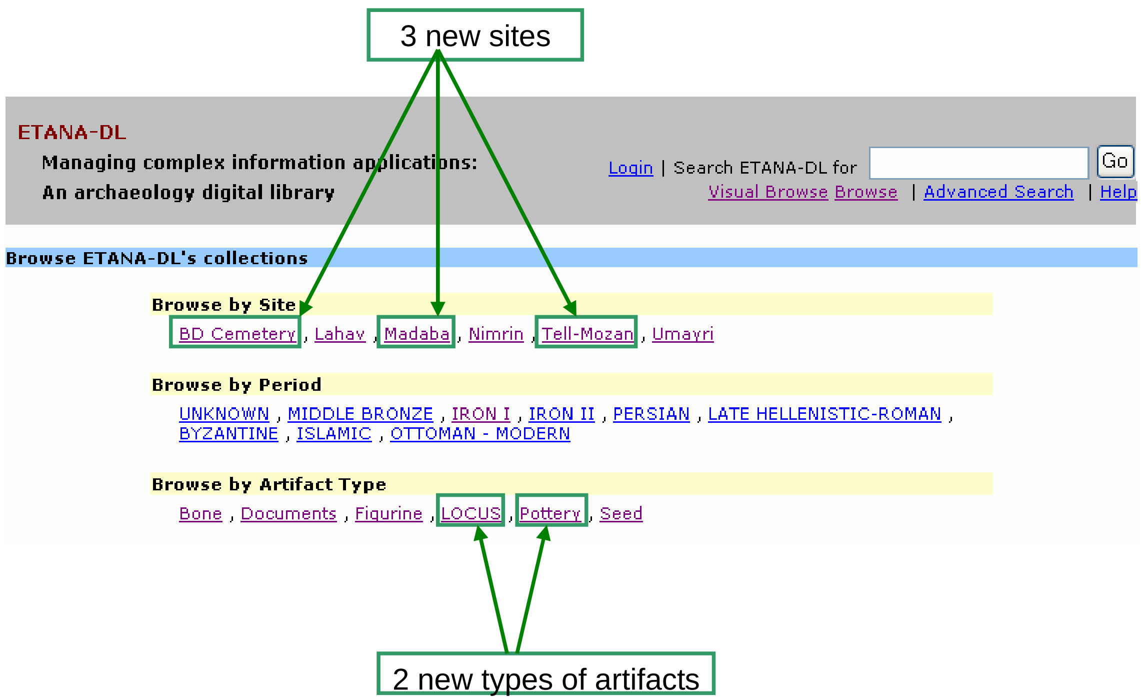

Fig.4 ETANA-DL Multi-dimensional browsing

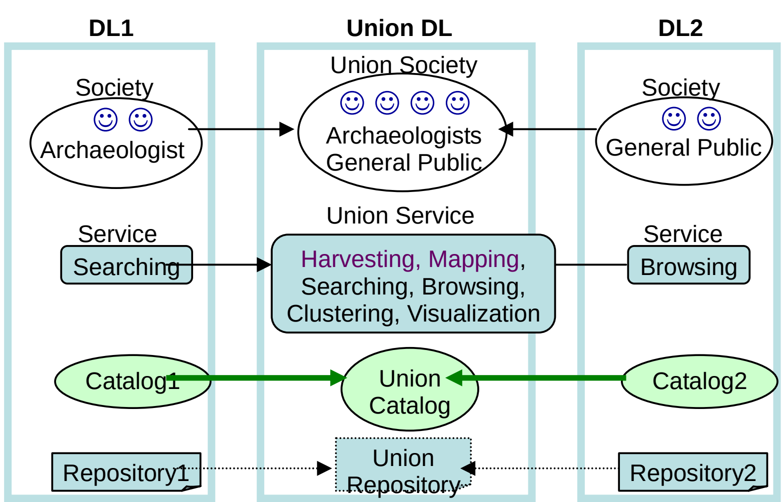

Fig.5 Architecture of a union DL

Figures 6 and 7 give details of our approach. We developed Schema Mapper, a tool to map the schema of diverse DLs into a global schema for a union DL, so that would have a global metadata format and union catalog (Raghavan et al. 2005). Schema Mapper generates a wrapper for each separate DL, so that its contents can be mapped into the union catalog. Figure 7 gives additional detail on our tools and processes for integration.

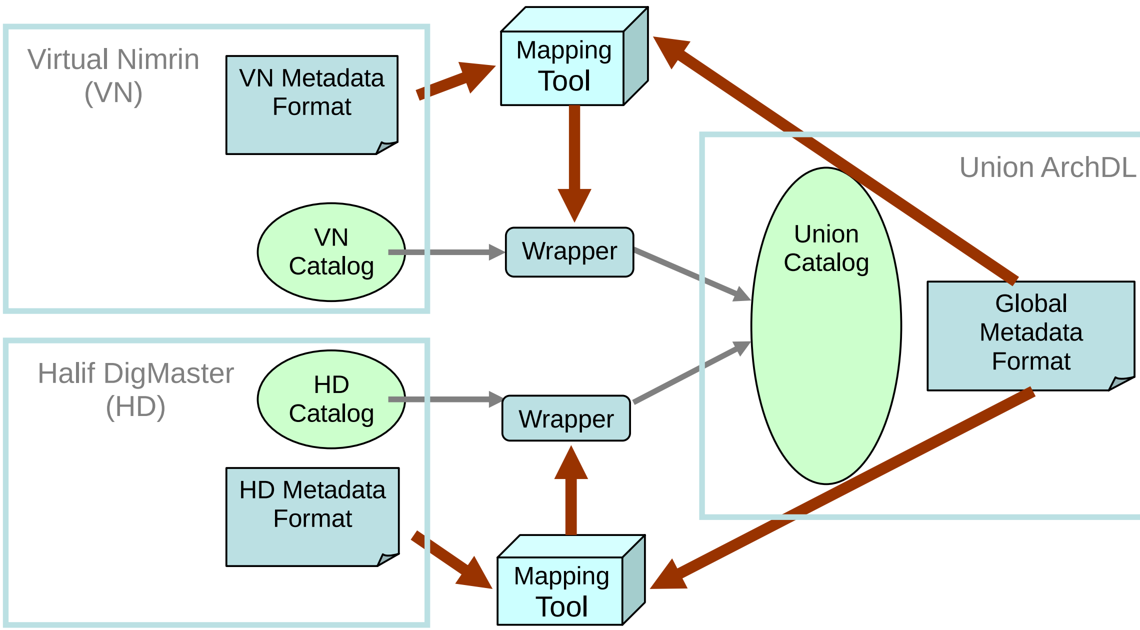

Fig.6 Union catalog integration

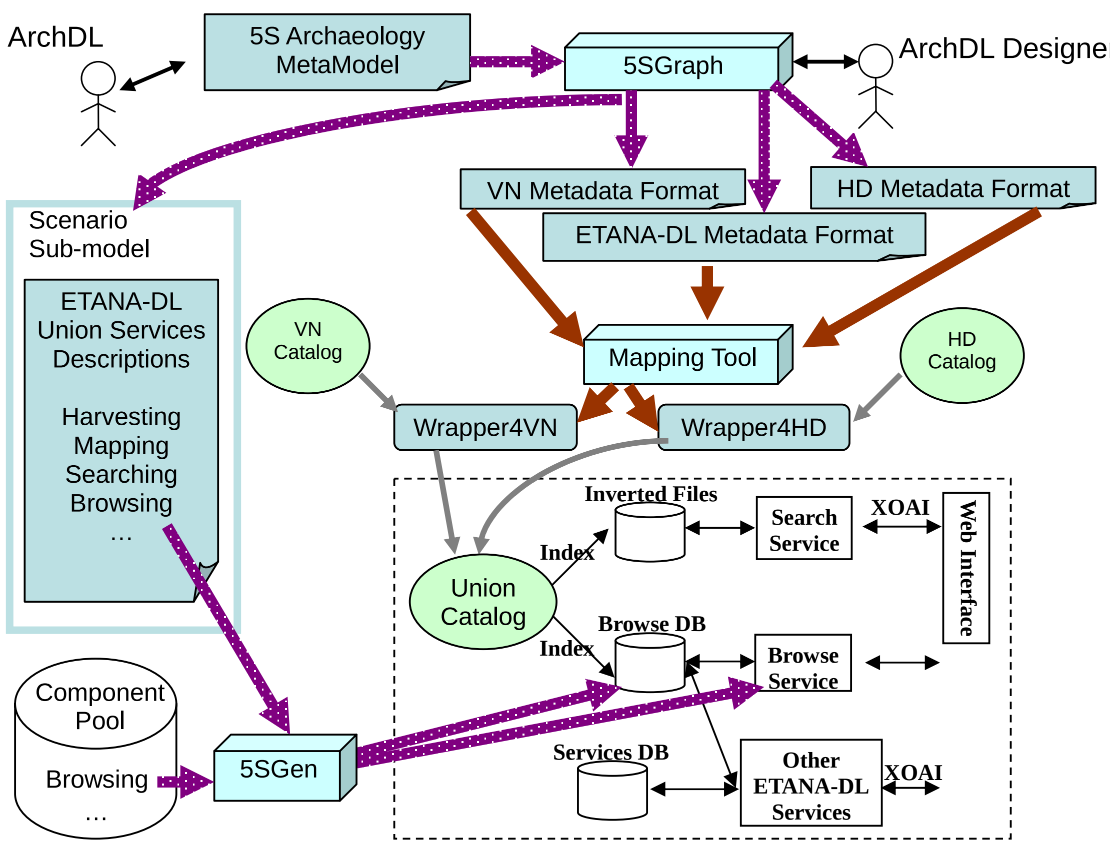

Fig.7 Extended 5S-related tools and applications, and their use in developing archaeological DLs

Figure 7 illustrates our semi-automatic approach, including extended versions under development for 5SGraph and 5SGen, which will integrate with other parts of the work undertaken for ETANA-DL. Figure 8 demonstrates the user interface for the browse service mentioned in Figure 7, which builds upon prior work on CitiViz (Kampanya et al. 2004). Thus, after the Nimrin site has been selected, and a list of periods of interest identified (see the lower right portion of the hyperbolic visualization that is given in the upper right of the figure, and the eight rows shown as yellow in the upper left table), for each of four selected types of animal bones (see last rows in that table), percentages of each bone type (colored parts of each histogram element) for each period (i.e., each of the eight columns) are shown in the lower right (Shen et al. 2005). Our aim is to semi-automatically generate the software for such DL services, like those shown in Figures 4 and 8.

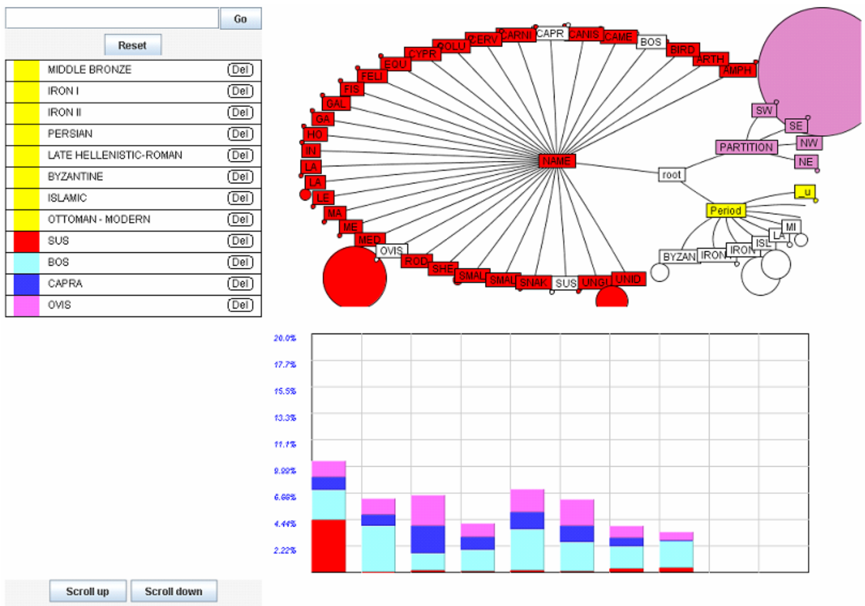

Fig.8 Multidimensional browsing: percentages of animal bones across Nimrin cultural phases

CONCLUSIONS

5S has been shown beneficial with regard to the advancement of the DL field toward becoming a science. It has been applied to describe simple DLs, to support work with ETDs, and to be helpful in the field of archaeology. 5S has helped with automation, as is needed to speed up and facilitate the development of digital libraries. 5S has made it easier to work on enhancements to digital libraries, such as multidimensional browsing,

Future work in the DL field can build upon the 5S framework. The theoretical framework for DLs can be extended and its scope expanded to other types of information systems. Difficult problems like interoperability and quality improvement can be solved, starting at the conceptual level. Practical solutions can be developed, such as those continuing to unfold at the prototype level with regard to our ETANA-DL efforts. We hope that the 5S framework will be considered by others, and will help them in their DL-related activities.

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