Revealing digital documents
Concealed structures in data

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Abstract. This short paper gives an introduction to a research project to analyze how digital documents are structured and described. Using a phenomenological approach, this research will reveal common patterns that are used in data, independent from the particular technology in which the data is available. The ability to identify these patterns, on different levels of description, is important for several applications in digital libraries. A better understanding of data structuring will not only help to better capture singular characteristics of data by metadata, but will also recover intended structures of digital objects, beyond long term preservation.

Keywords: data, data description, metadata, data modeling, patterns

1 Introduction

Given the growing importance of digital documents in libraries, the theoretical underpinning of data in library and information science is still insufficient. The majority of bibliographic descriptions only exist in digital form. Increasingly documents only exist as digital objects, which impacts on traditional concepts such as ‘document’, ‘page’, ‘edition’, and ‘copy’. Meanwhile most metadata consists of digital documents that describe other digital documents. With the advent of networked environments these documents basically exist as streams of bits, abstracted from any storage medium and location. Although in practice concrete forms, such as ‘files’, ‘records’, and ‘objects’, are dealt with, these forms are rather different views on the same thing, than inherent properties of a digital document. So what is this ‘same thing’ if you talk about a digital document? It has been shown that the nature of documents can better be defined in terms of function rather than format, and the key properties, which constitute and identify a document, depend on context. This highlights the importance of descriptive metadata to put data in context, but it does not eliminate the need to actually look at data at some level of description. In practice, we often have to deal with heterogeneous documents provided as data that must be indexed and

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1 An ongoing trend that is most visible in hypes, for instance, today, cloud computing and Semantic Web.
preserved, or with metadata, that is aggregated from diverse sources, without exact description of the data on a higher level.

This paper proposes that a deeper look at data is required, to reveal how digital documents are actually structured and described. The question should not be answered by simply pointing to concrete technologies and formats, which are subject to rapid change and obsolescence, but at a more fundamental level. The main hypothesis of this research is that all methods to structure and describe data share common patterns, independent from technology and level of description.

2 Background and related works

The concept of data is used in many disciplines with various meanings. Ballsun-Stanton explores how different individuals understand data in different “philosophies of data” [3]: the concept can range from the product of objective, reproducible measurements (“data as hard numbers”) to the product of any recorded observations (“data as observations”), or processable encodings of information and knowledge (“data as bits”). With this research I commit to the third philosophy, which is often found in computer science and in library and information science. However, both disciplines do not use data as a core concept but relate it to information as the main topic of interest. The growing amount of freely available “open data” and tools to analyze this data has brought up ideas of “data science” and “data journalism”. Both deal with aggregating, filtering, and visualizing large sets of data, based on statistical methods of data analysis. The growth of data-driven science combined with principles of Open Access also raises the awareness of the need to publish and share data sets. Library institutions begin to recognize this need and start to provide infrastructure for collecting and identifying research data [1]. Data discussed in this context is mainly seen as “data as observations” and the main concern of data science evangelists seems to be “big data”, that is “when the size of the data itself becomes part of the problem” [17]. The problem, that I want to tackle, does not depend on the size of the data or on problems of preservation [19], but on the inherent complexity of data, independent from its applications.

While disciplines that deal with physical documents, such as codicology and palaeography, have long been acknowledged as part of library and information science, there is no established curriculum of data studies as yet. The best examination of data by libraries so far can be found in long-term preservation of digital material and in metadata research and practice. The former is still in an early stage of development [8]. It provides two general strategies to cope with the rapid change and decay of technologies: either you need to emulate the environment

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2 This does not imply that results will not be applicable to other philosophies of data. Revealed data patterns may also reflect typical structures of data observation and measurements. However, this is beyond the scope of this work.

3 By definition you can only speak retrospectively of successful long-term preservation, but most digital objects are too young to judge.
of digital objects or you must regularly migrate them to other environments and formats. Both strategies require good descriptions of the data to be archived. When time passes, these descriptions themselves become subject of preservation and digital objects may get buried in nested layers of metadata. Metadata research deals with data on a more explicit level. Although metadata has become one of the core concepts of library and information science, there is no commonly agreed upon definition. The general “data about data” definition at least makes clear that metadata is data about something. Coyle’s definition of metadata as something constructed, constructive, and actionable [6] highlights the relevance of function and context as Buckland [5] and Yeo [26] do for documents. As a result there are numerous ways to describe the same object by data and the same data can describe different things. Metadata research provides at least some guidelines for interoperability by metadata registries, application profiles, and crosswalks. However, in practice a lot of manual work is needed to make use of metadata, because context and function are not fully known or creators of data just do not comply to assumed standards. Currently, the Resource Description Framework (RDF) and persistent identifiers promise to solve most problems. However, as also confirmed by the preliminary results below, there is no silver bullet in data description. Data is always a simplified, context-dependent image of the information, knowledge, or reality where an attempt has been to encode it in data. Some good criticism of the expressive power of particular data encoding languages has been given by Kent [14,15,16].

Patterns as structured methods of describing good design practice, were first introduced by Alexander et al. in the field of architecture [2]. In their words “each pattern describes a problem which occurs over and over again in our environment, and then describes the core of the solution to that problem.” Patterns were later adopted in other fields of engineering, especially in (object-oriented) software design [4,9]. There are some works that describe pattern for specific data structuring or data modeling languages, among them Linked Data in RDF [8], Markup languages [7], data models in enterprises [11,20], and meta models [12,21]. A general limitation of existing approaches is the focus to one specific formalization method. This practical limitation blocks the view to more general data patterns, independent from a particular encoding, and it conceals blind spots and weaknesses of a chosen formalism.

3 Method

A preliminary analysis of different structuring methods shows that each data language highlights some structuring features that are then overused and even conceal intended structures of data. For instance, the nesting and order of elements in an XML document can be chosen with intent. However, they can also be chosen in an arbitrary manner because an XML document must always be an ordered tree. For this reason we cannot rely only on official descriptions and specifications to reveal patterns in data. Most existing approaches to analyze data structuring are either normative (theoretical descriptions how data
should be), or empirical but limited. Existing empirical approaches only view
data at one level of description, in order to have a base for statistical methods
(data mining) and other automatic methods (machine learning). In contrast, I
use a phenomenological research method that includes all aspects of data struc-
turing and description. Beside technical standards that specify data, software
that shapes data, typical examples of data, and at how data is actually used by
people, must also be considered.

The phenomenological method views data as social artifacts, that cannot be
described from an absolute, objective point of view. Instead data are studied as
“phenomena”: appearances of things, or things as they appear in our experi-
ence” [23]. The analysis begins with a detailed review of methods and systems
for structuring and describing data, from simple character encodings to data lan-
guages and even graphical notations. The focus is on conceptual properties, while
details of implementation, such as performance and security, are only mentioned
where they show how and why specific techniques have evolved.

4 Preliminary results

The first outcome of this work is a broad typology of existing methods to struc-
ture and describe data. These methods are normally described as data codes,
systems, languages, or models without consistent terminology jointly among
technologies. The following groups of methods can be identified, each with a
primary but not exclusive purpose:

- character and number encodings to express data
- identifiers and query languages to identify data
- file systems and databases to store data
- data structuring languages and markup languages to structure data
- schema languages to define and constrain data
- conceptual modeling languages to abstract and describe data

These methods are rarely discussed together as general structures with data
as their common domain. Instead a strong focus on trends and families of basic
technologies is found, that often concentrate on one specification or implement-
tation. Examples include; the dominance of the Structured Query Language
(SQL) and the hype around the extensible markup language (XML) in the late
1990s. With size and speed as a main driving force of development, there is little
progress at the conceptual level. An example of this being the large gap between
research and practice in conceptual modeling languages, which are mostly used
in form of an oversimplification of the Entity-Relationship Model (ERM) [22].

The main empirical part of the analysis consists of a detailed description
and placement of the most relevant instances and subgroups from the typology
above. It is shown how each structuring method has its strengths and limitations,
and how each method shapes digital objects independent from the object’s char-
acteristic properties. A deeper look at data also shows that the most influential
technologies of data structuring are not used in one exact and established form,
but they occur as groups of slightly differing variants. For example, the set of
data expressible in RDF/XML differs from the full RDF triple model. This triple
model with URIs, blank nodes and literals, also has different characteristics and
limitations depending on which technology (serialization, triple store, SPARQL,
reasoners etc.) and which entailment regime (simple, RDF, OWL etc.) is ap-
plied. Other examples include; SQL databases, which substantially differ from
the original relational database model, and the family of XML-related stan-
dards. In many cases confusion originates from differences between syntaxes and
implementations on one side and abstract models on the other.

To some degree, common patterns can be derived from specific systems by
modeling them in a higher level modeling language, such as ERM and Object
Role Modeling (ORM), or in schema and ontology languages such as Backus
Naur Form (BNF), XML Schema (XSD) and the Web Ontology language (OWL).
In software engineering it is common practice to use domain specific modeling
languages in nested layers of abstraction [13]. These languages exist in many
variants as tools to communicate between levels of description. As a result, each
language highlights a specific subset of patterns and makes other patterns less
visible or more difficult to apply. Typical instances of data further show that
in practice, patterns and levels of abstraction often overlap and that methods
of structuring are often used against their original purpose. Typical examples
include; the creation of dummy values for non-existing mandatory elements and
the use of separators to add lists to non-repeatable fields. It appears that in
practice it is often difficult to judge which properties of data are intended and
which arise as artifacts from the constraints of a given modeling language. The
example of XML was already mentioned above: XML structures data in form of
an ordered tree, but many instances of XML documents use this feature to ap-
ply other patterns but hierarchy and strict ordering. Figure [1] shows an example
from a yet to be finished catalog of data patterns.

5 Evaluation and application
The preliminary results show a large variety of methods to structure and describe
data. The research hypotheses can be confirmed, as common patterns like iden-
tifiers, repeatability, grouping, sequences and ordering are used on all levels in
different variants and explicitly. The ability to identify and apply these patterns
is crucial for several applications in digital libraries. Some patterns are already
recognized, but the results show that it lacks a more systematic view, indepen-
dent from the constraints of particular technologies. A better understanding of
methods to structure and describe data can help both, the creation of data and
its consumption. These applications are shortly illustrated in the following.

Creation of data in libraries is most notably present as creation of metadata.
This process is guided by complex cataloging rules and specialized formats. Both
are deeply intertwined and often criticized as barriers to innovation. However,
simpler forms of metadata do not provide a solution [25]. Remarkably, alterna-
tives are most visible as technologies, for instance XML [24] or RDF [6]. Despite
| name       | sequence pattern |
|------------|------------------|
| idea       | strictly order multiple objects, one after another |
| context    | a collection of multiple objects |
| implementations |                  |
| • If objects have a known size, they can be directly concatenated. If objects have same size, this results in the array pattern. |
| • The separator pattern can be used to separate each object from its successor object. To distinguish objects and separators, this implies the forbidden objects pattern. If separators may occur directly after each other, this may also imply the empty object pattern. |
| • You can link one object to its successor with an identifier. To avoid link structures that result in other patterns (tree, graph, ...) additional constraints must apply. |
| • If objects have consecutive positions, a sequence is implied by their order. |
| examples |                |
| • string of ASCII characters (array) |
| • string of Unicode characters in UTF-8 (each character has known size) |
| • 'Kernighan and Ritchie' (sequence with ' and ' as separator) |
| • extract → transform, transform → load, (sequence of linked steps) |
| counter examples | files in a file system, records in a database table, any unordered collection |
| motivation | sequences are a natural method to model one-dimensional phenomena, for instance sequences of events in time. As digital storage is structured as sequence of bits, sequences seem to be the natural form of data and counterexamples, such as formal diagrams and visual programming languages, are often not considered as data. |
| problems | empty sequences and sequences of only one element are difficult to spot, like in other collection patterns. |
| similar patterns | without context, sequences are difficult to distinguish from other collection patterns. Many implementations of other patterns use sequences on a lower level. |
| implied patterns | position pattern |
| specialized patterns | array, ordered set, ring |

Fig. 1. Example of a pattern description. Pattern names are underlined.
the strengths of each technology, it is unlikely that one method will provide the ultimate tool to express all metadata. Instead, a look at metadata patterns can aid in the construction of more precise and interoperable metadata that better captures an object’s unique characteristics. The nature of patterns in general shows that data creation is no automatic process, but a creative act of design. Recognizing the artificial nature of data will to some degree free data designers from apologies and unquestioned habits that are justified as enforced by natural needs or technical requirements.

Consumption of data can benefit even more from an understanding of data patterns. Since the invention of digital computers, technologies and formats rapidly change. The fluctuation will unlikely slow down because it is also driven by trends, as progress in data description (in contrast to quantitative data processing) is difficult to measure. The results show that many description methods result in other structures than originally intended, when the the patterns that are actually applied are examined. Relevant structures are less visible, if you concentrate on single technologies. Knowledge of general data patterns can therefore help to reveal concealed structures in digital documents. This application could be named “data archeology” 4 Data archeology, in contrast to long-term preservation, which tries to prevent the need of the former, deals with the retrospective analysis of incompletely defined or unknown data. Similar to traditional archeology, data archeology belongs to the humanities, as it involves study of the cultural context of data creation and usage. Existing techniques from computer science, like data mining and knowledge discovery, provide useful tools to discovery detailed views on data. However, they cannot reveal its meaning as part of social practice. Data patterns can provide a contribution to intellectual data analysis, which is needed to underpin and interpret algorithmic data analysis.

Beside the creation of a catalog of the most common data patterns as basic primitives and derived patterns, there are some open tasks that may be answered by the analysis described in this paper. It is assumed that no closed system or meta-system can fully describe all aspects of practical data. This thesis could be proved at least for formal systems of description based on results of G"odel [10]. Further research, which will probably not be covered fully in this work, includes how to best find known patterns in given data using semi-automatic methods and which methods are best suited to express a given set of patterns.

In any case, libraries can benefit from a general understanding of data and data patterns, at least as deep as the current understanding of physical publication types and material.

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