XML INDEX COMPRESSION BY DTD SUBTRACTION

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Keywords: XML, Compression, Index, Data Streams.

Abstract: Whenever XML is used as format to exchange large amounts of data or even for data streams, the verbose behaviour of XML is one of the bottlenecks. While compression of XML data seems to be a way out, it is essential for a variety of applications that the compression result can be queried efficiently. Furthermore, for efficient path query evaluation, an index is desired, which usually generates an additional data structure. For this purpose, we have developed a compression technique that uses structure information found in the DTD to perform a structure-preserving compression of XML data and provides a compression of an index that allows for efficient search in the compressed data. Our evaluation shows that compression factors which are close to gzip are possible, whereas the structural part of XML files can be compressed even better.

1 INTRODUCTION

1.1 Motivation

XML is widely used as a data exchange standard and DTDs are one of the key concepts to ensure correctness of XML data. While the structural information contained in XML trees is considered being one of the strengths of XML, it has the following disadvantages: structure makes XML files rather verbose compared to the text values enclosed in the structures of an XML file.

Whenever the structure of an XML document is defined by a DTD, we can take advantage of the fact that the DTD defines some structure patterns that occur repeatedly in the XML document. The key idea of our structure preserving compression is to compress the verbose structural parts of XML documents that are redundant when regarding the structure of a given DTD. In order to be able to construct an index for path queries, our structure preserving data format separates a compressed structure index, called *kleene size tree (KST)* from the compressed data values of the XML document.

Our paper has the following contributions:

1. From the DTD, we derive a set of grammar rules that can be used for the following: to compress the structural part of the XML data to a structure preserving kleene size tree (KST) and a data format called *constant XML stream* (*CXML)* to store the text constants and attribute values of XML documents.

2. The same grammar rules can be used to decompress the generated data structures KST and CXML back to the XML data given before.

3. The kleene size tree (KST) can be used for transforming path-oriented search operations on an XML document to equivalent queries on the constant XML (CXML) stream.

4. We have evaluated our approach and show that significant compression of the XML structure is possible. Our experiments have shown that the size of the KST is on average only 3.6% of the size of the structure of the original XML file.

Our approach – which we call *DTD subtraction* - is especially useful, when the structure of the XML document is the bottleneck of the data exchange. Finally, our approach can be used for extremely large XML documents and it supports streaming of XML documents.

DTD subtraction can be summarized as follows. We represent each element declaration of a given DTD as both a syntax tree and a set of grammar rules (Section 2). The set of grammar rules is then augmented to an attribute grammar for either compression of an XML document to a KST and a CXML stream, for decompression of a KST and a

Böttcher S., Steinmetz R. and Klein N. (2007).
XML INDEX COMPRESSION BY DTD SUBTRACTION.
In *Proceedings of the Ninth International Conference on Enterprise Information Systems - DISI*, pages 86-94
DOI: 10.5220/0002365900860094

CXML stream or for transforming path queries on the XML data into queries on CXML data and an index generated from the KST (Section 3). Section 4 outlines how our approach can be extended to arbitrary DTDs and to XML streams. Section 5 summarizes our experimental results, whereas Section 6 discusses related works and Section 7 outlines the summary and conclusions.

2 TRANSFORMING A DTD INTO A SET OF GRAMMAR RULES

2.1 Element Declarations

For simplicity of the presentation, we consider DTDs containing only *element declarations*. For example, the element declaration

< !ELEMENT E1 (E2 , (E3|E4))* >

defines each element E1 to enclose an arbitrary number of sequences each of which consists of the element E2 followed by either an element E3 or an element E4. We call (E2, (E3|E4))* the *right hand side* of the element declaration. This right hand side applies the kleene operator (*) to the sequence operator (,) which itself is applied to the child element E2 of E1 and the choice operator (|) that itself is applied to the child elements E3 and E4 of E1.

In comparison, an element declaration

< !ELEMENT E2 (#PCDATA) >

defines the element E2 to contain only PCDATA. In this case, the right-hand side of the element declaration contains only the expression #PCDATA.

In general, each right hand of an element declaration can be regarded as a regular expression which combines zero or more child elements or the #PCDATA entry or the EMPTY entry by using the operators sequence (,), choice (|) or kleene(*). Note that the (+) operator found in element declarations can always be expressed by using the sequence and kleene operators, i.e., we replace (E) + with (E, (E*)). Similarly, the option operator (?) can be expressed by using choice and EMPTY, i.e., we replace (E?) with (E|EMPTY). Furthermore, an extension of our approach to attributes is straight forward, i.e., a list of attributes defined in an ATTLIST declaration for an element E can be treated similar to a sequence of child elements of E where optional attributes are treated like optional elements. In order to keep the following discussion simple, we only talk about elements and do not explicitly mention attributes.

We exclude however the ANY operator from DTD element declarations because the ANY operator does not allow us to infer the type information that we need.

2.2 Representing Element Declarations as Syntax Trees

Grammar rules for compression and XML path query translation are generated from the element declarations of the DTD. For this purpose, each element declaration is parsed and transformed into a binary syntax tree consisting of 7 types of element declaration nodes. Some node types have a parameter. For example, the element declarations given in the previous section are represented by the syntax trees given in Figure 1:

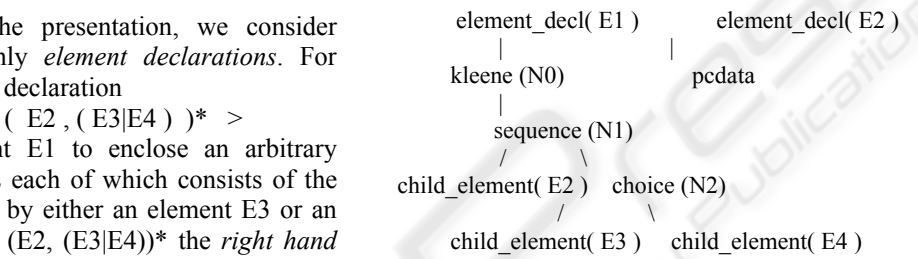


Figure 1: Syntax trees of the element declarations given in Section 2.1. Unique node IDs (N0, N1, N2) are generated for inner nodes.

In general, there are the following 7 element declaration node types which are used in syntax trees:

1. element_decl(Element name). A node of this type is generated for each element defined in an element declaration. The name of the defined element is passed as a parameter. Each element_decl node has exactly one successor node which is the root of the sub-tree representing the right hand side of the element declaration.

2. child_element(Element name). A node of this type is generated for each occurrence of an element in the right hand side of an element declaration. The name of this element is passed as a parameter. Each child element definition has no successor nodes in the syntax tree.

3. pcdata. The pcdata node is used whenever the right-hand side of an element declaration contains the string '#PCDATA'. The pcdata node does not have a parameter, and it does not have a successor node in the syntax tree.

4. sequence. A node of type sequence is generated for each sequence operator (,) occurring in the right hand side of an element declaration. A sequence node does not have a parameter. Each sequence node has two successor nodes representing the two arguments of this sequence operator (,) in the element declaration.

5. choice. A node of type choice is generated for each choice operator (|) occurring in the right hand side of an element declaration. A choice node does not have a parameter. Each choice node has two successor nodes representing the two arguments of this choice operator (|) in the element declaration.

6. kleene. A node of type kleene is generated for each kleene operator (*) occurring in the right hand side of an element declaration. A kleene node does not have a parameter. Each kleene node has one successor node representing the argument of this kleene operator (*) in the element declaration.

7. empty. A node of type empty is generated for each string 'EMPTY' occurring in an element declaration. Nodes of type empty do neither have a parameter nor a successor node in the syntax tree.

Each element declaration is parsed and translated into a syntax tree, each node of which has exactly one of the 7 node types described above.

2.3 Determining a Set of Starting Terminal Symbols

As a final step of parsing an element declaration, we collect the *set of starting terminal symbols* for each node except the root node of the element declaration syntax tree. These sets of starting terminal symbols allow the parser to decide during parsing, which grammar rule has to be applied. The set of starting terminal symbols (STS) can be computed by the following rules:

STS(child_element(name)) := { name }
STS(pcdata) := { pcdata }
STS(empty) := { empty }
STS(sequence(a,b)):=STS(a), if empty $\notin$ STS(a)
STS(sequence(a,b)):=STS(a)$\cup$STS(b),
if empty $\in$ STS(a)
STS(choice(a,b)) := STS(a) $\cup$ STS(b)
STS(kleene(a)) := { empty } $\cup$ STS(a)

For the following presentation in Section 2 and Section 3, we assume that the sets of starting terminal symbols of two sibling nodes that follow a choice node are always disjoint, such that the current context node found in the input XML document uniquely determines which choice has to be taken. This is a legitimate assumption, as the determinism of XML content models is a non-normative constraint of the XML specification ((XML, 2000), Appendix E).

2.4 Rewriting Element Declaration Syntax Trees into Grammar Rules

For each inner node i occurring in an element declaration syntax tree, we generate a unique node ID, Ni, and for each node type, we generate its own grammar rule set. As there are 7 types of nodes occurring in an element declaration syntax tree, we get 7 different types of grammar rule sets, i.e., one set of grammar rules for each element declaration node type. In order to distinguish the rules generated for different nodes of the same type, we parameterize the rules with node IDs, Ni, associated with each node in the element declaration syntax tree. A further parameter occurring in the rules generated for nodes of the types sequence, choice, or kleene is the set of starting terminal symbols computed for that node. Finally, the rules for element_decl nodes contain the element to be defined as a parameter, and whenever child_element nodes occur in the syntax tree as a node referenced by a parent node P, the grammar rule defined for P contains a 'child_element' call with the child element found in the element declaration syntax tree as a parameter.

For example, the grammar rule sets generated for the syntax trees of Figure 1 are:

element_decl(E1) → kleene(N0, {E2}) .
kleene(N0, {E2}) → sequence(N1, {E2}).
sequence(N1, {E2}) → child_element(E2) ,
choice(N2, {E3,E4}) .
choice(N2, {E3,E4}) → child_element(E3) .
choice(N2, {E3,E4}) → child_element(E4) .

element_decl(E2) → pcdata.
pcdata → .

3 USING THE GRAMMAR RULE SET FOR COMPRESSION AND INDEX CREATION

3.1 Using the Grammar Rule Set for Compression

The goal of our compression algorithm is to generate the kleene size tree (KST), i.e., a tree that contains only that part of the XML document which is not pre-defined by the DTD. The KST can be regarded as a compression of the structure of the XML document. However, it can also be used to generate an index for efficient access to the XML document. Each node in the KST stores a value representing a concrete XML fragment where the DTD allows for several options, i.e., which choice is taken at a certain node of the XML document for which a choice operator (|) in the DTD allows different options, and how many times a child node or a group of child nodes is repeated in a certain fragment of

the XML document where the DTD uses the kleene operator (*) to allow an arbitrary number.

The grammar rule set can be used for compression by augmenting it to an attribute grammar, i.e., by adding attributes that perform compression as follows. We use the Definite Clause Grammar (DCG) rule notation of Prolog (Closkin, 1997) to describe the implementation of the attribute grammar rules, and we use the notation "[Input]/[OutputKst]" in order to describe that Input has to be read or consumed from the XML input file or XML input data stream, and OutputKst has to be written to the KST. Furthermore, parenthesis, {.}, are used in DCG rules to describe side-effects or conditions that have to be true if a DCG rule is applied. How each grammar rule is augmented depends on the rule head, i.e., on the node type represented by the rule.

Before we describe the general augmentation of grammar rules, we start with an example. The rule

element_decl(E1) → sequence(N1, {E2}).

is augmented to

element_decl(E1)→ [E1]/[], sequence(N1,{E2}).

The empty pair of brackets, [ ], indicates that nothing is written to the KST. Therefore, the augmented grammar rule can be read as follows: consume an opening E1 element tag from the input, output nothing to the KST file and continue with applying the sequence grammar rule that matches the node ID N1.

The augmentation technique is the same in the general case, i.e., each grammar rule

element_decl(E) → right hand side .

is augmented to

element_decl(E) → [E] / [ ] , right hand side.

Grammar rules for sequence node types are not augmented, i.e., they remain as they are, e.g.

sequence(N1, {E2}) → child_element(E2) ,
choice(N2, {E3,E4}).

or in general they remain:

sequence(Ni, S) → right hand side.

Grammar rules for choice node types occur whenever the DTD allows two different options. Therefore, grammar rules for choice node types are augmented with checking which input element is the next on the input stream, and they write the choice taken, i.e., whether it is the first or the second choice that is allowed by the DTD, to the KST. Within the example, the grammar rules

choice(N2, {E3, E4}) → child_element(E3) .
choice(N2, {E3, E4}) → child_element(E4) .

are augmented to the following grammar rules

choice(N2, {E3, E4 }) → {next tag ∈ {E3}} ,
[ ] / [1] , child_element(E3) .
choice(N2, {E4, E4}) → {next tag ∉ {E3}} ,
[ ] / [2] , child_element(E4) .

Within these augmented rules, the output [1] (or [2]) written on the KST expresses that the first (or second) choice described by the DTD has been taken. We write this information to the KST in order to be able to reconstruct the original XML data from the KST and the CXML file.

In general, the choice operator may not only combine elements, but may combine two expressions. Then, each pair of grammar rules for a choice operator taking a node ID Ni and two sets STS1 and STS2 of starting terminal symbols as parameters

choice(Ni, (STS1∪STS2)) → right hand side 1.
choice(Ni, (STS1∪STS2)) → right hand side 2.

is replaced with the following pair of grammar rules:

choice(Ni, (STS1∪STS2))→{next tag ∈ STS1 }
[ ] / [1], right hand side 1.
choice(Ni, (STS1∪STS2))→{next tag ∉ STS1 }
[ ] / [2], right hand side 2.

child_element calls in a grammar rule simply call the element grammar rule for the element given as the parameter.

child_element(E) → element_decl(E).

Finally, grammar rules for kleene node types are replaced with a set of augmented grammar rules that count the arguments taken by a kleene operator within the CXML stream. Within the example, the grammar rule

kleene(N0, {E2}) → sequence(N1, {E2}).

is replaced with the following grammar rules

kleene(N0, {E2}) → [ ] / [Count] ,
repeat(N0, {E2} , Count) .
repeat(N0, {E2}, Count) → {next tag∈{E2}},
sequence(N1,{E2}), repeat(N0,{E2},
Count1) , { Count is Count1+1 }.
repeat(N0, {E2}, 0) → { next tag∉{E2} } .

Here, the repeat rules count how often the argument of the kleene operator (*) occurs and the kleene rule writes the Count value into the KST

In general, each given grammar rule for a kleene operator taking a node ID Ni and a set S of starting terminals as parameters

kleene(Ni, S) → right hand side .

is replaced with the following new grammar rules

kleene(Ni, S) →[]/[Count], repeat(Ni, S, Count).
repeat(Ni, S, Count) → {next tag ∈ S},
right hand side , repeat(Ni, S, Count1) ,
{ Count is Count1+1 } .
repeat(Ni, S, 0) → { next tag ∉ S } .

The variable Count in the new grammar rules counts how often the first repeat grammar rule is executed, i.e., how often the sub-tree described by the right hand side of the given kleene grammar rule is repeated. This number of repetitions will be used in

indexing, i.e., translating XML path queries to index positions for certain data.

3.2 The Constants' Data Stream

Furthermore, we hash text values in a compressed data storage model, which allows us to transfer each constant only once.

pcdata calls simply store the position of each constant in the CXML stream. A function positionOf(…) is used to store new constants in the data storage model, i.e., each constant is stored only once, and to attach the current position to the constant. Altogether, the data storage model stores constants together with a set of positions.

Given the function positionOf(…), the pcdata grammar rule is implemented as follows:

pcdata()→[Constant]/[], {positionOf(Constant)}.

An empty operator can be seen as a text constant of length 0, and it is treated in a similar way as a special kind of pcdata, i.e., the function call positionOf( ) is used for collecting positions of empty nodes. The only difference is that the empty operator does not consume or read any input.

empty() → { positionOf( ) } .

3.3 The Kleene Size Tree (KST)

Besides compressing the constants in an XML stream, our goal is to compress a structure-oriented index, i.e., an index supporting efficient access to structural information without decompressing all of the compressed data. The key idea of our index compressing technique is to use the structure information provided by element declarations of the DTD in order to compute the position of certain elements or text values, such that the compressed index is much smaller than the structure of the XML document.

For the DTD rule operators sequence, pcdata, empty, and child element, a relative position of the searched data in the data stream can be uniquely determined by the DTD alone. However, for each kleene operator (*), the number of repetitions may vary, and therefore the size of the data elements "in the scope of" a kleene operator may vary. Furthermore, for each choice operator (|), the size of the sub-tree may depend on the choice taken. We have to store this information somewhere in order to support loss-less decompression. We write this information into an index called the *kleene size tree (KST)*.

The kleene size tree (KST) is organized as follows: It contains a choice node for each choice operator (|), and a counter for each kleene operator (*) that is applied in a DTD rule when parsing the XML document with the DTD grammar rules. The hierarchy of the KST nodes corresponds to the calling hierarchy of DTD element declaration syntax rules. That is, whenever a rule for a kleene operator or a choice operator O1 directly or indirectly calls a rule for a kleene operator or a choice operator O2, then the KST node K1 representing O1 is an ancestor of the KST node K2 representing O2.

Note that the KST does not contain any node for other operators than kleene (*) and choice(|) as all other operators have a fixed size, i.e., their size can be computed from the DTD. As the KST contains only numbers, the KST is a very small data structure.

Note that the KST is significantly smaller than the index, i.e., transferring the KST from a sender to a receiver may be advantageous compared to transferring an index when bandwidth is a bottleneck. Furthermore, the KST and CXML file are not only much smaller than the XML file, but also allow for a direct access to XML nodes, i.e., using the KST for index computations and direct access to the CXML stream may be advantageous in scenarios where we can profit from skipping some XML data.

In order to reconstruct the index, i.e., the structure of the XML document, from the DTD syntax trees and the KST, we have to traverse the DTD syntax trees starting from the root node. Whenever a kleene node or a choice node is reached, we consume the next number from the KST and generate the number of nodes (for kleene nodes) or the node with the chosen element name of the alternative (for choice nodes). Note however, that the index does not have to be reconstructed physically in case of XML path query evaluation or partial decompression, but it only needs to be reconstructed 'virtually', i.e., only the positions of the required elements are computed from DTD and KST, but the index is not reconstructed physically in order to count the position. Only in case of a complete decompression, the index is reconstructed completely, as it is the major part of the decompressed document.

3.4 Using the Grammar Rules for Path Queries on Compressed Data

When searching data that matches a certain path of an XPath expression, we use the KST stream to identify the position of the information we look for.

Let us extend the previous example and assume that a given XML input document D has been compressed to a KST document KD and a CXML document CD. Furthermore, let us consider that an

XPath query /E1[2]# asks for the sub-tree enclosed in the second E1 element contained in the input stream. Finally, we assume that the first E1 element has 10 sequences, whereas 3 of them contain an E3 element and 7 of them contain an E4 element and the second E1 element has 5 sequences, whereas 4 of them contain E3 and one contains E4. This information is read from KD. Therefore, we can compute the size of the subtrees for the first E1 element to be E11size =10*size(E2) + 3*size(E3) + 7*size(E4) and for the second E1 Element to be E12size=5*size(E2) + 4*size(E3) + 1*size(E4). As E2 only contains pcdata, we know that size(E2)=1. We assume furthermore that E3 is a sequence of three elements with pcdata and E4 contains pcdata directly, i.e., size(E3)=3 and size(E4)=1. Given these sizes, the sizes of the compressed representations of the first two E1 elements are E11size= 10*1+3*3+7*1=26 and E12size =5*1+4*3+1*1=18. Altogether, when we query for /E1[2], we can skip the first E11size bytes from CD and then read and decompress the next E12size bytes from CD. Because we know that the fragment searched for matches the DTD for E1, we know which decompression grammar rule has to be used, in this case, the decompression grammar rule for E1. We explain decompression in the next section.

The general computation of sub-tree sizes extends the KST with constant size information that can be derived from the element declaration rules. However, this computation is only done for paths to accessed CXML elements.

3.5 Using the Grammar Rule Set for Decompression

Similarly as for compression, the grammar rule set can be used for decompression. In our Prolog implementation this is simply done by switching the roles of the input stream and the output stream. More precisely, within a Prolog call element_decl(Input, OutputKST), the first parameter, Input, which is the input stream for compression, will be the output stream for decompression. Similarly, the second parameter OutputKST which is the KST output stream for compression will be an input parameter for decompression. Within a first prototype, we have implemented the augmented DCG rule system in Prolog in such a way that it can be used for both directions compression and decompression, by either providing an XML document Inputstream or providing a CXML document Outputstream and the KST document Outputstream. For the performance evaluation, we have re-implemented the grammar rule system in a different language, i.e., Java using a SAX parser and the attribute grammar of JavaCC, and there we had one augmented rule set for compression, and an additional reverse implementation for decompression.

4 EXTENDING THE APPROACH TO XML STREAMS

4.1 Processing XML Streams and Recursive DTDs

We are not limited to compressing only XML documents of a fixed size. Instead, we are also able to compress XML streaming data because we do not have to read the whole document, before we can start data compression, i.e., the augmented grammar rules can be used to compress on the fly.[1]

Furthermore, we did not limit our approach to non-recursive DTDs, i.e., all the same ideas can be applied, when the element declaration defining E1 is changed to a recursive element declaration

< !ELEMENT E1 (E2, (E1|E4))* >

Therefore, our approach (including index computation and path evaluation) is also applicable to recursive DTDs.

4.2 Evaluation of XPath Queries on Compressed XML Streams

We assume that the XPath expression that is evaluated does not contain any backward-axes, but may contain any forward axes, predicate filters and node name tests (either an element name or the wildcard '*'). If an XPath expression contains backward-axes, the algorithm presented in (Olteanu, 2002) can be used to rewrite the XPath expression into an equivalent XPath expression containing no backward-axes.

For the evaluation of XPath queries, we propose an adaptation of an approach presented in (Su, 2005). This approach optimizes XPath query evaluation on XML documents and especially on data streams, where the whole data has to be read at most once. The buffer size needed to store elements temporarily depends on the evaluation of XPath filters. Furthermore, schema information in the DTD reduces the computational time needed for deciding satisfiability of filters and determines parts of the

[1] Due to space limitations, we skip some technical details here, e.g., providing space for very large counters in an index and the treatment of very large kleene size trees and of very large text constants.

data that can be skipped, as they do not contain any information needed to determine the answer to the query. This 'skipping' of parts of the data corresponds to directly addressing the known position of the next element as proposed in our approach. The difference however is that we have to process compressed XML data, i.e., in order to use the approach presented in (Su, 2005), we have to translate location steps into position offsets in the CXML stream.

Which part of the data can be skipped, i.e., the concrete position-offset from a current position within the data, can be computed by combining the size information stored in the KST with offset information that is computed from the element declaration syntax trees.

4.3 Multiplexing Stream Data

When considering an XML stream, we have two kinds of output stream, the CXML data stream and the KST stream. In a practical implementation compressing XML streams, we multiplex these two data streams at the sender's side, and de-multiplex the multiplexed stream back into the two streams at the receiver's side.

5 EXPERIMENTAL RESULTS

We have implemented our approach using Java 1.5 and a SAXParser for parsing XML data. As compressed storage model for constant data, we have chosen a trie (Fredkin, 1960) the inner nodes of which are compressed using Deflate (LZ77(Ziv, 1977) + Huffmann encoding (Huffmann, 1952)). Note that the compressed storage model for constant data can be replaced by any other model that allows to store and evaluate pairs of positions and values.

We have evaluated our compression approach on the following datasets:

1. XMark(XM) – an XML document that models auctions (Schmidt, 2002)
2. hamlet(H) – an XML version of the famous Shakespeare play
3. catalog-01(C1), catalog-02(C2), dictionary-01(D1), dictionary-02(D2) – XML documents generated by the XBench benchmark (Yao, 2002)
4. dblp(DB) – a collection of publications

As it can be seen in Table 1, the sizes of the documents reach from a few hundred kilobytes to more than 300 Megabytes.

Table 1: Sizes of documents of our datasets.

document	XM	H	C1	C2	DB	D1	D2
Uncompressed size in MB	5.3	0.3	10.6	105.3	308.2	10.8	106.4

We have compared our approach with 3 other approaches:

- XGrind (Tolani, 2002) – a queryable XML compressor
- XMill (Liefke, 2000) – an XML compressor
- gzip[2] – a widely used text compressor

The results can be seen in Figure 2.

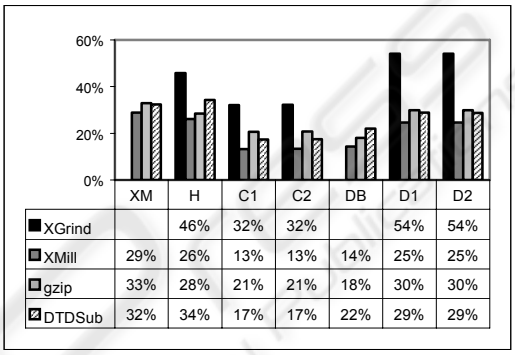


Figure 2: Compression ratio (size of the compressed data divided by size of the original data).

Using these datasets, XMill performs better achieving compression ratios that are 3-8% lower than the compressions ratios reached by our approach. However, in contrast to XMill, our approach allows to evaluate queries on the compressed data and to partially decompress data.

Compared to gzip, our approach achieves similar compression ratios, although gzip – as well as XMill – does not allow for evaluating queries on the compressed data. The difference of the compression ratios (gzip minus DTD subtraction) ranges from 6% (the gzip compression ratio is 6% smaller) to -3% (the gzip compression ratio is 3% bigger).

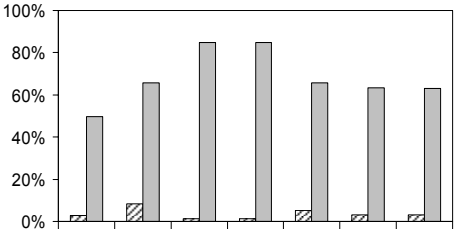
XGrind is the only compression approach in our tests that is capable to evaluate queries on the compressed data like our approach. Our results have shown that our approach significantly outperforms XGrind. In our dataset, our approach performs better achieving compression ratios that are 12-25% lower than the compression ratios achieved by XGrind[3].

In a second series of measurements, we have compared the size of the structural part of the original XML document with the size of the KST. This means that we have compared the structure to

[2] http://www.gzip.org/

[3] Note that on our test computer, we got access violations when running XGrind on XM and DB and therefore the compression ratios for these two documents are missing.

be parsed in order to evaluate XML path queries. Our measurements have shown, that the size of the KST ranges in average around 3.6% of the size of the structural parts of the XML document. The concrete results of our experiments can be seen in Figure 3. |str|/|doc| means the size of the structural part of the document divided by the document size and |KST|/|str| means the size of the KST divided by the size of the structural part of the document.



	XM	H	C1	C2	DB	D1	D2
▨ |KST| / |str|	2,8%	8,3%	1,3%	1,3%	5,3%	3,1%	3,1%
▩ |str| / |doc|	50%	66%	85%	85%	66%	63%	63%

Figure 3: Relative size of the KST in comparison to the uncompressed structure and relative size of uncompressed structure in comparison to uncompressed document.

6 RELATION TO OTHER WORKS

There exist several algorithms for XML compression, which can be divided into categories by their features: some compressed XML documents can only be used to answer queries, if they are decompressed, other algorithms allow querying the compressed data. Another feature is whether XML compression algorithms can be applied to data streams or whether they can only be applied to static XML documents.

The first approach to XML compression was the XMill algorithm presented in (Liefke, 2000). It compresses the structural information separately from the data. The data is – according to the enclosing tag – collected into several containers, and the whole container is compressed afterwards. The structure is compressed, by assigning each tag name a unique and short ID. After the compression, the compressed structure consists of the tag IDs which represent a start tag, the container IDs which represent a text value, and '/'-symbols which represent an end tag. An appropriate compressing algorithm is chosen for each container, depending on the data type it contains. This approach does not allow querying the compressed data and is not applicable to data streams.

The approaches XGrind (Tolani, 2002), XPRESS (Min, 2003) and XQueC (Arion, 2003) form extensions of the XMill-approach. Each of these approaches compresses the tag information using dictionaries and Huffman-encoding (Huffmann, 1952) and replaces the end tags by either a '/'-symbol or by parentheses. All three approaches allow querying the compressed data, and, although not explicitly mentioned, they all seem to be applicable to data streams. A disadvantage of XGrind is, that it does not support range queries (e.g., //a[@b<50]), but only match queries (e.g., //a[@b=50]) or prefix queries. Instead, it allows a validity test on compressed data using a DTD. In contrast, XQuec supports range queries as well, as XQuec uses an order-preserving compression approach for the compression of the data.

XQzip (Cheng, 2004) and the approach presented in (Buneman, 2003) compress the data structure of an XML document bottom-up by combining identical sub-trees. Afterwards, the data nodes are attached to the leaf nodes, i.e., one leaf node may point to several data nodes. The data is compressed by an arbitrary compression approach. These approaches allow querying compressed data, but they are not applicable to data streams. In addition, an approach to evaluate XQuery on the results of (Buneman, 2003) is presented in (Buneman, 2005).

An extension of (Buneman, 2003) and (Cheng, 2004) is the BPLEX algorithm presented in (Busatto, 2005). This approach does not only combine identical sub-trees, but recognizes patterns within the XML tree that may span several levels, and therefore allows a higher degree of compression. As its predecessors, it allows querying the compressed data, but it is not applicable to data streams.

In contrast to all these approaches, our algorithm allows querying (including match, prefix and range queries) and is applicable to data streams. It achieves an even higher level of compression, as it only contains compressed data plus some sparse information added for each choice operator and each kleene operator contained in the DTD. As our compressed XML data contains nearly no structural information, only valid documents can be decompressed, i.e., our approach does not allow for checking validity.

The approach presented in (Sundaresan, 2001) follows the same basic ideas as our approach: omit all information that is redundant because of the DTD. But the idea to realise this idea is completely different from our approach. In (Sundaresan, 2001) a DOM-tree is built and traversed simultaneously for the DTD and the XML document. Whenever the document contains information not found in the DTD, this information is written to the compressed document. So the resulting compressed document is

nearly the same as in our case (e.g., text values are encoded differently), but whereas our approach is capable to sequentially compress infinite data streams (and to perform path queries on the compressed data) the approach presented in (Sundaresan, 2001) is limited by the size of main memory (According to (Sundaresan, 2001) they had problems with a file of 281 kB (the smallest test file in our data set), as it exceeded their time threshold, whereas we were able to compress a document of more than 300 MB in decent time).

Another approach (Ng, 2006) also follows the idea to omit information that is redundant because of the DTD. It is also using a SAX-parser, i.e., this approach is capable to compress infinite data streams. However, this approach uses the paths allowed by a non-recursive DTD to define a set of buffers and stores constants found in the XML document in the buffer defined for their path before compressing the whole buffer. As the number of buffers must be finite, this approach does not support recursive DTDs. Furthermore, (Ng, 2006) leaves it open how to treat constants other than numbers. In comparison, our approach can store text constants and can handle recursive DTDs.

7 SUMMARY AND CONCLUSIONS

Structure preserving compression of XML data based on DTD subtraction reduces the verbose structural parts of XML documents that are redundant when regarding the structure of a given DTD, but preserves enough information to search for certain paths in the compressed XML data. Our approach uses given DTD element declarations to generate a set of grammar rules, which is then augmented to an attribute grammar for either compression of an XML document to a KST and a CXML document, for decompression of a KST and a CXML document or for translating XPath queries into index positions on CXML data. Our approach can be extended to arbitrary DTDs as well as to other schema languages that allow to derive a set of grammar rules (e.g., XML Schema and RelaxNG) and to XML streams.

Of course, our structure preserving compression technique can be combined with an ordinary compression and decompression, i.e., a normal compression and decompression technique could be applied to the data generated by our structure preserving compression, in order to send an even less amount of data from a sender to a recipient. Note however that our overall goal is not only to get a low compression size, but the main focus of our contribution is to enable path query processing on compressed data.

As XPath forms the major part of other query languages like XQuery and XSLT, we are optimistic that our approach could also be applied to XQuery and XSLT.

REFERENCES

Arion, A., Bonifati, A., Costa, G., D'Aguanno S., Manolescu, I., Pugliese, A., 2003. XQueC: Pushing queries to compressed XML data. In *Proc. VLDB.*

Buneman, P., Choi, B., Fan, W., Hutchison, R., Mann, R., Viglas. S., 2005. Vectorizing and Querying Large XML Repositories. In *ICDE 2005.*

Buneman P., Grohe, M., Koch, C., 2003. Path Queries on Compressed XML. In *VLDB 2003.*

Busatto, G., Lohrey, M., Maneth, S., 2005. Efficient Memory Representation of XML Documents. In *DBPL 2005.*

Cheng, J., Ng, W., 2004. XQzip: Querying Compressed XML Using Structural Indexing. In *EDBT 2004.*

Cloksin W.F., Mellish, C.S., 1997. *Programming in Prolog*, Springer. Berlin, 4th Edition.

Fredkin, E., 1960. Trie Memory. In *Communications of the ACM*.

Huffman, D., 1952. A Method for Construction of Minimum-Redundancy Codes. In *Proc. of IRE*.

Liefke, H., Suciu, D., 2000. XMill: An Efficient Compressor for XML Data. In *Proc. of ACM SIGMOD*.

Min, J.K., Park, M.J., Chung, C.W., 2003. XPRESS: A Queriable Compression for XML Data. In *Proceedings of SIGMOD*.

Ng, W., Lam, W.-Y., Wood, P.T., Levene, M., 2006 XCQ: A Queriable XML Compression System. In *Knowledge and Information Systems*, Springer-Verlag.

Olteanu, D., Meuss, H., Furche, T., Bry, F., 2002. XPath: Looking Forward. In *EDBT Workshops 2002.*

Schmidt, A., Waas, F., Kersten, M., Carey, M., Manolescu I., Busse, R., 2002. XMark: A benchmark for XML data management. In *VLDB 2002*.

Su, H., Rundensteiner, E.A., Mani, M., 2005. Semantic Query Optimization for XQuery over XML Streams. In *VLDB 2005*.

Sundaresan N., Moussa, R., 2001. Algorithms and programming models for efficient representation of XML for Internet applications. In *WWW 2001.*

Tolani, P.M., Hartisa, J.R., 2002. XGRIND: A query-friendly XML compressor. In *Proc. ICDE 2002*.

Yao, B.B., Ozsu, M.T., Kennleyside, J., 2002. XBench - A family of benchmarks for XML DBMSs. In *Proceedings of EEXTT.*

Extensible Markup Language (XML) 1.0, 2000. http://www.w3.org/TR/2000/REC-xml-20001006

Ziv, J., Lempel, A., 1977. A Universal Algorithm for Sequential Data Compression. In *IEEE Transactions on Information Theory*.