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An efficient approach to generic multimedia adaptation

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Abstract

This paper addresses efficiency issues identified in the Bitstream Syntax Description Language used by the MPEG-21 generic multimedia adaptation framework. In particular, when used to adapt modern content formats such as H.264/AVC, the time required for processing increases exponentially relative to the duration of the bitstream. In response, the paper proposes several additional features for the Bitstream Syntax Description Language which reduce the complexity of adaptation using BSDL to a linear function of bitstream duration. These features are implemented and validated using bitstreams of real-world length.

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An Efficient Approach to Generic Multimedia Adaptation

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ABSTRACT
This paper addresses efficiency issues identified in the Bitstream Syntax Description Language used by the MPEG-21 generic multimedia adaptation framework. In particular, when used to adapt modern content formats such as H.264/AVC, AAC, and SLS, the time required for processing increases exponentially relative to the duration of the bitstream. In response, the paper proposes several additional features for the Language which reduce the complexity of adaptation using BSDL to a linear function of bitstream duration. These features are implemented and validated using bitstreams of real-world length.

Categories and Subject Descriptors
H.5.1 **[Multimedia Information Systems]** – *Audio input/output, Evaluation/methodology, Video (e.g., tape, disk, DVI)*
H.3.4 **[Systems and Software]** – *Performance evaluation (efficiency and effectiveness)*
H.3.5 **[Online Information Services]** – *Data sharing*

General Terms
Algorithms, Performance, Standardization, Languages.

Keywords
Multimedia Content Adaptation, Bitstream Syntax Description, H.264/AVC, MPEG-21.

1. INTRODUCTION
Dynamic adaptation of scalable multimedia content has received considerable attention in recent literature [3, 4, 12]. This enables streaming multimedia to be consumed by a wide range of devices with varying processing power and memory capacities, across networks with divergent bandwidth and error characteristics. In particular, Devillers [4] proposes a generic adaptation architecture which allows processing nodes to perform the adaptation without specific knowledge about the bitstream being performed. Such an architecture facilitates interoperability for new content formats by enabling adaptation without modifying existing infrastructure.

This generic adaptation process is illustrated in Figure 1. It is based on performing the adaptation on a high-level representation of the bitstream rather than on the bitstream itself. This high-level representation is known as a Bitstream Syntax Description (BSD),

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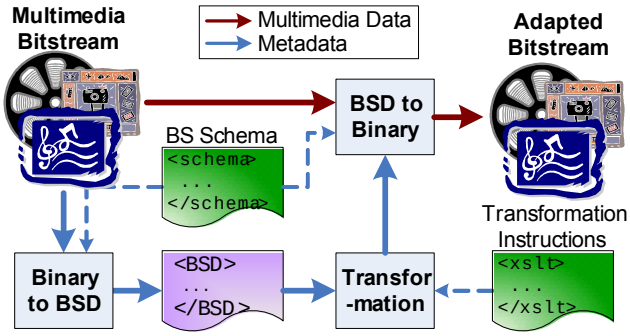


Figure 1 – Generic Adaptation (adapted from [11])

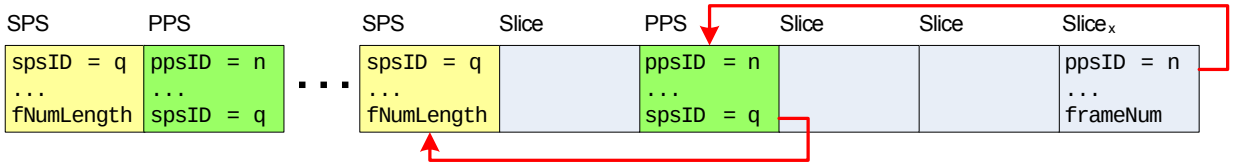
and is extracted from the bitstream via a generic processor, aided by a description of the content format – the Bitstream Syntax (BS) Schema file. This BSD is then transformed according to a set of instructions, which a BSD to Binary processor applies to the bitstream in order to execute the adaptation.

In [4] Devillers proposes a language for the BS Schema and BSD, which is discussed in section 2.1, and has been adopted as part of the MPEG-21 Multimedia Framework [11]. However, recent content formats including the H.264/AVC video standard [8], AAC [1], and the Scalable to Lossless (SLS) audio coder [9] pose significant scalability problems for generic adaptation via BSDL. Specifically, BSDL cannot efficiently describe numerous structures which are prevalent in these formats, and the description tools which are available lead to a processing time which increases relative to the bitstream duration according to $O(n^2)$. This leads to the situation where a two minute H.264/AVC bitstream requires more than an hour to process using BinToBSD on a Pentium 4 (see section 5).

After discussing the available alternatives to BSDL in section 2, we consider the problems with generic adaptation of recent coding formats in section 3. Section 4 presents our proposed solutions, and the consequent performance improvements are demonstrated in section 5.

2. GENERIC BITSTREAM DESCRIPTION

2.1 Bitstream Syntax Description Language
The BS Schema language [4] extends of XML Schema [10] with mechanisms to specify the bit-level equivalent for XML data types, as well as conditional structures to describe parsing of a bitstream. As a result, a BS Schema elegantly describes both the bitstream, its XML representation (the Bitstream Syntax Description, or BSD), and the translation between the two. It was designed specifically to support the generic adaptation architecture shown in Figure 1.



(a)

```
/avc:h264/avc:seqParameterSet[avc:spsID=/avc:h264/avc:picParameterSet[avc:ppsID=/avc:h264
/avc:slice[position()=last()]/avc:ppsID][position()=last()]/avc:spsID][position()=last()]
/avc:fNumLength_minus4
```

(b)

Figure 2 – Identifying the Picture and Sequence Parameter sets used by Slice$_x$ in a H.264/AVC bitstream

2.2 Flavor/XFlavor

Flavor [6], was developed to enable automatic generation of bitstream parsers, and a recent extension (XFlavor [6]) is able to produce metadata output from the process, which could potentially be utilized in generic adaptation. However, (X)Flavor parses every individual field of a bitstream, resulting in extremely verbose BSDs, making generic adaptation of complex formats such as H.264/AVC infeasible [3].

2.3 XFlavor+

In response to the verbosity of XFlavor, De Neve et al propose an extension to XFlavor [3] that attempts to harmonize XFlavor and BSDL. This extension – XFlavor+ – is targeted specifically at H.264/AVC, however it may be used only for a small subset of possible H.264 bitstreams – "those containing one Sequence Parameter Set and one Picture Parameter Set" [3]. As a result, it is unsuitable for the generic adaptation architecture of Figure 1.

3. PROBLEM DESCRIPTION

This section identifies the issues associated with the Bitstream Syntax Description Language using the recent H.264/AVC video coding format [8] as an example. Of primary concern are the extensive use of entropy-coded values in header fields, parameter sets, and dynamic length bit-fields.

3.1 Entropy-coded header fields

H.264/AVC makes extensive use of the Exponential-Golomb (expGolomb) encoding [8] throughout the header fields of most bitstream structures. For example, the ID fields shown in Figure 2(a) are represented by expGolomb codes. Parsing the Bitstream for adaptation requires that the Syntax Description tool be capable of interpreting such codes. However, BSDL [11] currently supports only simple numerical types and strings.

Consequently, the specification is currently being amended to normatively specify an expGolomb data type. This solution, while satisfactory for expGolomb, is very inflexible. It effectively necessitates amendments to the standard (a slow process, at best) for every encoded data type to be processed by BSDL.

3.2 Parameter Sets

Many of the fields found in packet headers of previous video formats tend to have identical values across numerous packets. H.264/AVC introduces the concept of a Parameter Set, which extracts much of this data into a separate structure. The Audio Data Interchange Format (ADIF) of AAC [1] is another example of the use of such parameter sets.

Parameter sets can be sent less frequently and potentially with a more reliable mechanism – since the perceptual quality of the video output is generally highly dependent upon such information [13]. Two levels of parameter set are used – the Picture Parameter Set (PPS), which provides parameters common to groups of pictures, and the Sequence Parameter Set (SPS), which specifies parameters common to groups of picture sequences.

Both the PPS and SPS contain data required to parse each picture element (slice). For example, the SPS contains a field specifying how many bits are used for the `frameNum` field in a slice header. To retrieve this information, the slice header has a pointer to a PPS (`ppsID` - Figure 2(a), which in turn points to the SPS. Both SPS' and PPS' may evolve over time, where several parameter sets may have identical IDs; for any slice x the correct SPS/PPS are the most recently received SPS and PPS with matching IDs.

When parsing a H.264 bitstream for adaptation, a BSDL parser must perform this dereferencing operation many times per slice. Unfortunately, the mechanism used for this – XPath [2] – requires an extremely complex expression to achieve the dereferencing (Figure 2(b). Such an expression is particularly error-prone, and evaluation exhibits a complexity of $O(n^2)$ where n is the duration of the bitstream (or more precisely, the number of slices in the bitstream). This complexity arises from evaluation of the filter `avc:slice[position()=last()]`, which requires the XPath processor to iterate through the partial set of slices every time it is evaluated – an arithmetic progression with a total of n(n+1)/2 comparisons.

3.3 Dynamic length bit-fields

Another common feature in H.264/AVC is header fields which use a variable number of bits. Some – such as those with expGolomb encoding – may be parsed without external information. For others, the length of the field is indicated elsewhere within the bitstream. The `frameNum` field in Figure 2(a) is one such example. Another is the maximum bit-plane side-information in the SLS scalable audio coder [9].

BSDL provides a mechanism for resolving XML Schema union datatypes, which allows fields with variable length to be described (Figure 3). However, an XPath expression is required for each possibility within the union. When the location of the length data is specified in a SPS or PPS (as is in fact usually the case), the computation complexity of the BS Schema increases to $O(pn^2)$ (the XPath expressions hidden by `"...and so on..."` in Figure 3 are that of Figure 2(b), and p is the number of ifUnion elements evaluated before a true result is returned).

Additionally, each possible bit-length must be individually enumerated. While not a significant problem for the given example, a field with possible lengths from 1 to 64 or even 32 bits will quickly become untenable.

```
  <xsd:simpleType name="frameNumType">
    <xsd:union memberTypes="bit:b4 bit:b5
bit:b6 bit:b7 bit:b8 bit:b9 bit:b10 bit:b11
bit:b12 bit:b13 bit:b14 bit:b15 bit:b16">
      <xsd:annotation><xsd:appinfo>
        <bs2:ifUnion value=".../avc:
                    fNumLength_minus4 = 0"/>
        <bs2:ifUnion value=".../avc:
                    fNumLength_minus4 = 1"/>
        <bs2:ifUnion value=".../avc:
                    fNumLength_minus4 = 2"/>
        <!-- ...and so on... -->
      </xsd:appinfo></xsd:annotation>
    </xsd:union>
  </xsd:simpleType>
```

Figure 3 – H.264/AVC frameNum simple type

4. PROPOSED SOLUTIONS

Adaptation of H.264 bitstreams using BSDL in its present state, while theoretically possible, is implausible for any bitstreams of real-world length, due to the scalability issues discussed in section 3, as demonstrated (section 5). However, it is possible to address these issues with a number of simple modifications.

4.1 User-defined simple data types

Rather than specify encoded data types as part of the BSDL standard, we propose a simple addition to BSDL to allow custom parsing operations to be specified within the BS Schema using ECMAScript [5]. This is shown in Figure 4, where user-defined data types are a restriction of a new type – `bs1:userType`.

The content of the restriction is a bs1:script node, which is required to specify two functions – `BintoBSD()` for the binary to BSD process, and `BSDtoBin(value)` for the reverse. BSDL provides `read(nBits)` and `write(value, nBits)` functions to allow the user functions to access the bitstream.

The body of the `BintoBSD()` function (Figure 4) implements the expGolomb parsing process specified by [13].

4.2 User-defined XPath variables

The complexity of the dereferencing operation presented in Figure 2(a) may be greatly simplified by recognizing that the set of valid PPS (and equally SPS) at any point in time may be represented as an object array, indexed by the respective ID. Any time a new parameter set is encountered in the bitstream, it is inserted into the array in the appropriate location, potentially replacing a parameter set that was previously there. XPath does not directly support an array data type, however it does provide node-sets, which may be used for this purpose. In order to store a node-set of all the PPS (or SPS), the node set must be registered as an XPath variable. In so doing, the expression in Figure 2(b) simplifies to

```
$sps[$pps[../avc:ppsID+1]/avc:spsID+1]
                          /avc:fNumLengthminus4.
```

Since this expression doesn't involve any iteration over the set of slices, its evaluation time is constant, and the $O(n^2)$ complexity observed in the base specification reduces to O(n).

In order to enable the use of arbitrarily defined XPath variables in BSDL, a mechanism must be provided to assign their value, and also their position within the node-set. We propose the addition of a `bs2:variable` element for this purpose, as shown in Figure 6.

4.3 Bit-Length Facet

The use of `xsd:union` to specify variable length fields such as `frameNum`, while possible, is not intuitive. A far simpler solution

```
<xsd:simpleType name="expGolomb">
  <xsd:restriction base="bs1:userType">
    <xsd:annotation><xsd:appinfo>
      <bs1:script>
        <![CDATA[
          function BintoBSD() {
            while ((val=read(1))==0)
                nBits++;
            val = read(nBits);
            return (1<<nBits)-1+val);
          }
          function BSDtoBin(value) {
            //...
          }
        ]]>
      </bs1:script>
    </xsd:appinfo></xsd:annotation>
  </xsd:restriction>
</xsd:simpleType>
```

Figure 4 – BS Schema definition of expGolomb data type

is to provide a facet which directly calculates the length (in bits) of the type being defined. Indeed, such a facet exists within BSDL to specify a dynamic length in bytes – `bs2:length`; it is easily extended with a `unit` attribute (Figure 5). This has the effect of replacing numerous XPath expressions (12 in the example – Figure 3) with a single expression.

5. EXPERIMENTAL RESULTS

Each of the proposed solutions were tested via modifications to the BSDL reference software[1] [7], on H.264/AVC bitstreams of varying length. Tests were carried out on a P4 1.7Ghz machine running Linux and the Sun JVM 1.5.0. Each trial was repeated

```
<xsd:element name="sequenceParameterSet">
  <xsd:annotation><xsd:appinfo>
    <bs2:variable name="sps"
                  position="avc:spsID+1"/>
  </xsd:appinfo></xsd:annotation>
</xsd:element>
```

Figure 6 – sps variable

```
<element name="length">
  <complexType>
    <complexContent>
      <extension base="annotated">
        <attribute name="value"
                type="bs2:integerXPathExpr"/>
        <attribute name="unit"
              use="optional" default="byte">
          <simpleType>
            <restriction base="string">
              <enumeration value="bit"/>
              <enumeration value="byte"/>
            </restriction>
          </simpleType>
        </attribute>
      </extension>
    </complexContent>
  </complexType>
</element>
```

Figure 5 – Schema for Schema definition of `bs2:length`

[1] All tests were performed on the BSDL software with a more efficient XPath processor (Saxon 8.6.4) so as to minimize implementation deficiencies.

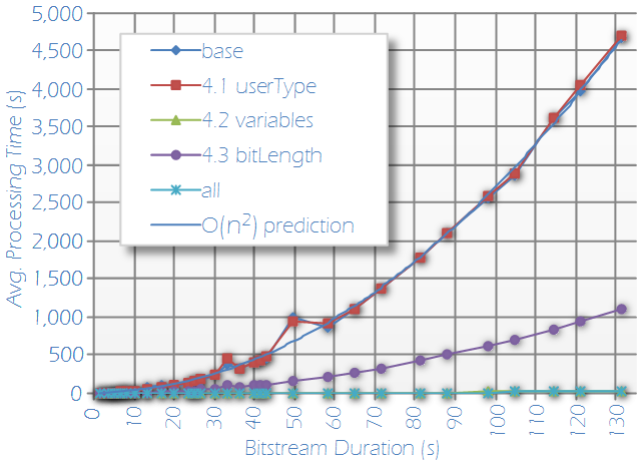


Figure 7a–Avg. BinToBSD Processing Time–by modification

three to ten times, and the results averaged (in each case the result of the first run was excluded because it includes additional time for JVM initialization and class loading).

As can be seen, the time required to process the bitstream using the unmodified BinToBSD software (the base series in Figure 7a) increases according to $O(n^2)$ – For a two minute bitstream, BinToBSD processing time exceeds an hour.

Subsequent series' in Figure 7a show the performance of the various proposed solutions. The introduction of user-defined types (4.1) is not intended to improve the scalability of the system. Rather, it enhances extensibility, by simplifying adoption of new encoded data types, and results demonstrate that the overhead of this enhancement is negligible.

The Bit-Length Pseudofacet (4.3) reduces parse time by approximately 75%, because of the removal of the p term discussed in section 3.3. However, complexity is still $O(n^2)$; the system still cannot scale to movies of real-world duration. In contrast, the introduction of user-defined variables (4.2) reduces the complexity to O(n). This results in a Bitstream Syntax Description Language that may be used to perform generic adaptation on real-world H.264/AVC streams – the series' labeled all in Figure 7a and b show the performance of BinToBSD with all modifications applied. The latter verifies the O(n) performance of the algorithm for bitstreams in excess of an hour. The resulting BSDL processing is around 10 times faster than playback.

A further benefit of the proposed modifications to BSDL is shown by the lowMemory series. All XPath expressions are now evaluated against the set of user variables – meaning that the BSD itself is no longer required to be stored in memory. This has the effect of removing the correlation between bitstream duration and memory consumption, which is approximately 5 MB.

6. CONCLUSIONS

This paper has demonstrated that the Bitstream Syntax Description Language (BSDL) displays $O(n^2)$ complexity when processing bitstreams of H.264/AVC and other recent coding formats including AAC and SLS, and is consequently unable to process such bitstreams of real-world duration. We have proposed a number of additions to BSDL which have the effect of reducing the complexity of BinToBSD processing to O(n). These results have been verified with bitstreams up to an hour in length. The

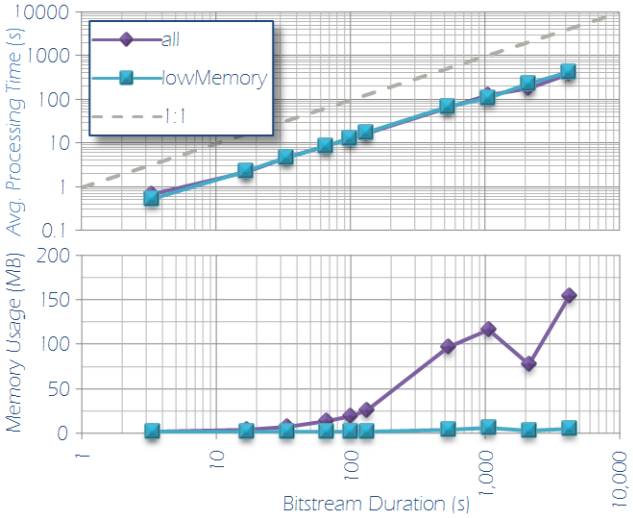


Figure 7b–Avg. BinToBSD Processing Time–all modifications

modifications additionally improve the extensibility and simplicity of the language.

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