Binary Encodings for JavaScript Object Notation: JSON-B, JSON-C, JSON-D

draft-hallambaker-jsonbcd-13

Abstract

Three binary encodings for JavaScript Object Notation (JSON) are presented. JSON-B (Binary) is a strict superset of the JSON encoding that permits efficient binary encoding of intrinsic JavaScript data types. JSON-C (Compact) is a strict superset of JSON-B that supports compact representation of repeated data strings with short numeric codes. JSON-D (Data) supports additional binary data types for integer and floating-point representations for use in scientific applications where conversion between binary and decimal representations would cause a loss of precision.

This document is also available online at http://mathmesh.com/Documents/draft-hallambaker-jsonbcd.html [1].

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1.  Introduction

JavaScript Object Notation (JSON) is a simple text encoding for the JavaScript Data model that has found wide application beyond its original field of use. In particular JSON has rapidly become a preferred encoding for Web Services.

JSON encoding supports just four fundamental data types (integer, floating point, string and boolean), arrays and objects which consist of a list of tag-value pairs.

Although the JSON encoding is sufficient for many purposes it is not always efficient. In particular there is no efficient representation for blocks of binary data. Use of base64 encoding increases data volume by 33%. This overhead increases exponentially in applications
where nested binary encodings are required making use of JSON encoding unsatisfactory in cryptographic applications where nested binary structures are frequently required.

Another source of inefficiency in JSON encoding is the repeated occurrence of object tags. A JSON encoding containing an array of a hundred objects such as "first":1,"second":2 will contain a hundred occurrences of the string "first" (seven bytes) and a hundred occurrences of the string "second" (eight bytes). Using two byte code sequences in place of strings allows a saving of 11 bytes per object without loss of information, a saving of 50%.

A third objection to the use of JSON encoding is that floating point numbers can only be represented in decimal form and this necessarily involves a loss of precision when converting between binary and decimal representations. While such issues are rarely important in network applications they can be critical in scientific applications. It is not acceptable for saving and restoring a data set to change the result of a calculation.

1.1. Objectives

The following were identified as core objectives for a binary JSON encoding:

- Easy to convert existing encoders and decoders to add binary support
- Efficient encoding of binary data
- Ability to convert from JSON to binary encoding in a streaming mode (i.e. without reading the entire binary data block before beginning encoding.
- Lossless encoding of JavaScript data types
- The ability to support JSON tag compression and extended data types are considered desirable but not essential for typical network applications.

Three binary encodings are defined:

JSON-B (Binary) Encodes JSON data in binary. Only the JavaScript data model is supported (i.e. atomic types are integers, double or string). Integers may be 8, 16, 32 or 64 bits either signed or unsigned. Floating points are IEEE 754 binary64 format [IEEE754]. Supports chunked encoding for binary and UTF-8 string types.
JSON-C (Compact)  As JSON-B but with support for representing JSON tags in numeric code form (16 bit code space). This is done for both compact encoding and to allow simplification of encoders/decoders in constrained environments. Codes may be defined inline or by reference to a known dictionary of codes referenced via a digest value.

JSON-D (Data)  As JSON-C but with support for representing additional data types without loss of precision. In particular other IEEE 754 floating point formats, both binary and decimal and Intel’s 80 bit floating point, plus 128 bit integers and bignum integers.

Each encoding is a proper superset of JSON, JSON-C is a proper superset of JSON-B and JSON-D is a proper superset of JSON-C. Thus a single decoder MAY be used for all three new encodings and for JSON.  

Figure 1 shows these relationships graphically:

Encoding Relationships.

2. Definitions

This section presents the related specifications and standard, the terms that are used as terms of art within the documents and the terms used as requirements language.

2.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

2.2. Defined Terms

The terms of art used in this document are described in the Mesh Architecture Guide [draft-hallambaker-mesh-architecture].

2.3. Related Specifications

The JSON-B, JSON-C and JSON-D encodings are all based on the JSON grammar [RFC7159].  IEEE 754 Floating Point Standard is used for encoding floating point numbers [IEEE754].
2.4. Terminology

No new terms of art are defined

3. Extended JSON Grammar

The JSON-B, JSON-C and JSON-D encodings are all based on the JSON grammar [RFC7159] using the same syntactic structure but different lexical encodings.

JSON-B0 and JSON-C0 replace the JSON lexical encodings for strings and numbers with binary encodings. JSON-B1 and JSON-C1 allow either lexical encoding to be used. Thus any valid JSON encoding is a valid JSON-B1 or JSON-C1 encoding.

The grammar of JSON-B, JSON-C and JSON-D is a superset of the JSON grammar. The following productions are added to the grammar:

x-value  Binary encodings for data values. As the binary value encodings are all self delimiting

x-member  An object member where the value is specified as an X-value and thus does not require a value-separator.

b-value  Binary data encodings defined in JSON-B.

b-string  Defined length string encoding defined in JSON-B.

c-def  Tag code definition defined in JSON-C. These may only appear before the beginning of an Object or Array and before any preceding white space.

c-tag  Tag code value defined in JSON-C.

d-value  Additional binary data encodings defined in JSON-D for use in scientific data applications.

The JSON grammar is modified to permit the use of x-value productions in place of ( value value-separator ) :
JSON-text = (object / array)

object = *cdef begin-object [ *( member value-separator | x-member ) (member | x-member) ] end-object

member = tag value
x-member = tag x-value

tag = string name-separator | b-string | c-tag

array = *cdef begin-array [ *( value value-separator | x-value ) (value | x-value) ] end-array

x-value = b-value / d-value

value = false / null / true / object / array / number / string

name-separator = ws %x3A ws ; : colon
value-separator = ws %x2C ws ; , comma

Figure 1

The following lexical values are unchanged:
begin-array = ws %x5B ws ; [ left square bracket
begin-object = ws %x7B ws ; { left curly bracket
end-array = ws %x5D ws ; ] right square bracket
end-object = ws %x7D ws ; } right curly bracket

ws = *( %x20 %x09 %x0A %x0D )

false = %x66.61.6c.73.65 ; false
null = %x6e.75.6c.6c ; null
true = %x74.72.75.65 ; true

Figure 2

The productions number and string are defined as before:
number = [ minus ] int [ frac ] [ exp ]
decimal-point = %x2E ; .
digit1-9 = %x31-39 ; 1-9
e = %x65 / %x45 ; e E
exp = e [ minus / plus ] l*DIGIT
frac = decimal-point l*DIGIT
int = zero / ( digit1-9 *DIGIT )
minus = %x2D ; -
plus = %x2B ; +
zero = %x30 ; 0

string = quotation-mark *char quotation-mark
char = unescaped /
escape ( %x22 / %x5C / %x2F / %x62 / %x66 /
%x6E / %x72 / %x74 / %x75 4HEXDIG )
escape = %x5C ; \n
quotation-mark = %x22 ; "
unescaped = %x20-21 / %x23-5B / %x5D-10FFFF

Figure 3

4. JSON-B

The JSON-B encoding defines the b-value and b-string productions:

b-value = b-atom | b-string | b-data | b-integer | b-float
b-string = *( string-chunk ) string-term
b-data = *( data-chunk ) data-last
b-integer = p-int8 | p-int16 | p-int32 | p-int64 | p-bignum16 |
n-int8 | n-int16 | n-int32 | n-int64 | n-bignum16
b-float = binary64

Figure 4

The lexical encodings of the productions are defined in the following tables where the column ‘tag’ specifies the byte code that begins the production, ‘Fixed’ specifies the number of data bytes that follow and ‘Length’ specifies the number of bytes used to define the length of a variable length field following the data bytes:
<table>
<thead>
<tr>
<th>Production</th>
<th>Tag</th>
<th>Fixed</th>
<th>Length</th>
<th>Data Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>string-term</td>
<td>x80</td>
<td>-</td>
<td>1</td>
<td>Terminal String 8 bit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>length</td>
</tr>
<tr>
<td>string-term</td>
<td>x81</td>
<td>-</td>
<td>2</td>
<td>Terminal String 16 bit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>length</td>
</tr>
<tr>
<td>string-term</td>
<td>x82</td>
<td>-</td>
<td>4</td>
<td>Terminal String 32 bit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>length</td>
</tr>
<tr>
<td>string-term</td>
<td>x83</td>
<td>-</td>
<td>8</td>
<td>Terminal String 64 bit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>length</td>
</tr>
<tr>
<td>string-chunk</td>
<td>x84</td>
<td>-</td>
<td>1</td>
<td>Terminal String 8 bit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>length</td>
</tr>
<tr>
<td>string-chunk</td>
<td>x85</td>
<td>-</td>
<td>2</td>
<td>Terminal String 16 bit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>length</td>
</tr>
<tr>
<td>string-chunk</td>
<td>x86</td>
<td>-</td>
<td>4</td>
<td>Terminal String 32 bit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>length</td>
</tr>
<tr>
<td>string-chunk</td>
<td>x87</td>
<td>-</td>
<td>8</td>
<td>Terminal String 64 bit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>length</td>
</tr>
<tr>
<td>data-term</td>
<td>x88</td>
<td>-</td>
<td>1</td>
<td>Terminal String 8 bit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>length</td>
</tr>
<tr>
<td>data-term</td>
<td>x89</td>
<td>-</td>
<td>2</td>
<td>Terminal String 16 bit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>length</td>
</tr>
<tr>
<td>data-term</td>
<td>x8A</td>
<td>-</td>
<td>4</td>
<td>Terminal String 32 bit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>length</td>
</tr>
<tr>
<td>data-term</td>
<td>x8B</td>
<td>-</td>
<td>8</td>
<td>Terminal String 64 bit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>length</td>
</tr>
<tr>
<td>data-chunk</td>
<td>X8C</td>
<td>-</td>
<td>1</td>
<td>Terminal String 8 bit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>length</td>
</tr>
<tr>
<td>data-chunk</td>
<td>x8D</td>
<td>-</td>
<td>2</td>
<td>Terminal String 16 bit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>length</td>
</tr>
<tr>
<td>data-chunk</td>
<td>x8E</td>
<td>-</td>
<td>4</td>
<td>Terminal String 32 bit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>length</td>
</tr>
<tr>
<td>data-chunk</td>
<td>x8F</td>
<td>-</td>
<td>8</td>
<td>Terminal String 64 bit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>length</td>
</tr>
</tbody>
</table>

Table 1

Table 1: Codes for String and Data items
Table 2: Codes for Integers, 64 Bit Floating Point, Boolean and Null items.

A data type commonly used in networking that is not defined in this scheme is a datetime representation. To define such a data type, a string containing a date-time value in Internet type format is typically used.

4.1. JSON-B Examples

The following examples show examples of using JSON-B encoding:
5. JSON-C

JSON-C (Compressed) permits numeric code values to be substituted for strings and binary data. Tag codes MAY be 8, 16 or 32 bits long encoded in network byte order.

Tag codes MUST be defined before they are referenced. A Tag code MAY be defined before the corresponding data or string value is used or at the same time that it is used.

A dictionary is a list of tag code definitions. An encoding MAY incorporate definitions from a dictionary using the dict-hash production. The dict hash production specifies a (positive) offset value to be added to the entries in the dictionary followed by the UDF fingerprint [draft-hallambaker-udf] of the dictionary to be used.
<table>
<thead>
<tr>
<th>Production</th>
<th>Tag</th>
<th>Fixed</th>
<th>Length</th>
<th>Data Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>c-tag</td>
<td>xC0</td>
<td>1</td>
<td>-</td>
<td>8 bit tag code</td>
</tr>
<tr>
<td>c-tag</td>
<td>xC1</td>
<td>2</td>
<td>-</td>
<td>16 bit tag code</td>
</tr>
<tr>
<td>c-tag</td>
<td>xC2</td>
<td>4</td>
<td>-</td>
<td>32 bit tag code</td>
</tr>
<tr>
<td>c-def</td>
<td>xC4</td>
<td>1</td>
<td>-</td>
<td>8 bit tag definition</td>
</tr>
<tr>
<td>c-def</td>
<td>xC5</td>
<td>2</td>
<td>-</td>
<td>16 bit tag definition</td>
</tr>
<tr>
<td>c-def</td>
<td>xC6</td>
<td>4</td>
<td>-</td>
<td>32 bit tag definition</td>
</tr>
<tr>
<td>c-tag</td>
<td>xC8</td>
<td>1</td>
<td>-</td>
<td>8 bit tag code and definition</td>
</tr>
<tr>
<td>c-tag</td>
<td>xC9</td>
<td>2</td>
<td>-</td>
<td>16 bit tag code and definition</td>
</tr>
<tr>
<td>c-tag</td>
<td>xCA</td>
<td>4</td>
<td>-</td>
<td>32 bit tag code and definition</td>
</tr>
<tr>
<td>c-def</td>
<td>xCC</td>
<td>1</td>
<td>-</td>
<td>8 bit tag dictionary</td>
</tr>
<tr>
<td>c-def</td>
<td>xCD</td>
<td>2</td>
<td>-</td>
<td>16 bit tag dictionary</td>
</tr>
<tr>
<td>c-def</td>
<td>xCE</td>
<td>4</td>
<td>-</td>
<td>32 bit tag dictionary</td>
</tr>
<tr>
<td>dict-hash</td>
<td>xD0</td>
<td>4</td>
<td>1</td>
<td>UDF fingerprint of dictionary</td>
</tr>
</tbody>
</table>

Table 3: Codes Used for Compression

All integer values are encoded in Network Byte Order (most significant byte first).

5.1. JSON-C Examples

The following examples show examples of using JSON-C encoding:

C8 20 80 05 48 65 6c 6c 6f       "Hello"  20 = "Hello"
C4 21 80 05 48 65 6c 6c 6f                  21 = "Hello"
C0 20 "Hello"
C1 00  20 "Hello"

D0 00 00 01 00 20 Insert dictionary at code 256
e3 b0 c4 42 98 fc 1c 14
9a fb f4 c8 99 6f b9 24
27 ae 41 e4 64 9b 93 4c
a4 95 99 1b 78 52 b8 55 UDF (C4 21 80 05 48 65 6c 6c 6f)

Figure 6
6. JSON-D (Data)

JSON-B and JSON-C only support the two numeric types defined in the JavaScript data model: Integers and 64 bit floating point values. JSON-D (Data) defines binary encodings for additional data types that are commonly used in scientific applications. These comprise positive and negative 128 bit integers, six additional floating point representations defined by IEEE 754 [IEEE754] and the Intel extended precision 80 bit floating point representation [INTEL].

Should the need arise, even bigger bignums could be defined with the length specified as a 32 bit value permitting bignums of up to $2^{35}$ bits to be represented.

d-value = d-integer | d-float

d-float = binary16 | binary32 | binary128 | binary80 |
decimal32 | decimal64 | decimal 128

Figure 7

The codes for these values are as follows:

<table>
<thead>
<tr>
<th>Production</th>
<th>Tag</th>
<th>Fixed</th>
<th>Length</th>
<th>Data Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>p-int128</td>
<td>xA4</td>
<td>16</td>
<td>-</td>
<td>Positive 128 bit Integer</td>
</tr>
<tr>
<td>n-int128</td>
<td>xAC</td>
<td>16</td>
<td>-</td>
<td>Negative 128 bit Integer</td>
</tr>
<tr>
<td>binary16</td>
<td>x90</td>
<td>2</td>
<td>-</td>
<td>IEEE 754 Floating Point</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Binary 16 bit</td>
</tr>
<tr>
<td>binary32</td>
<td>x91</td>
<td>4</td>
<td>-</td>
<td>IEEE 754 Floating Point</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Binary 32 bit</td>
</tr>
<tr>
<td>binary128</td>
<td>x94</td>
<td>16</td>
<td>-</td>
<td>IEEE 754 Floating Point</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Binary 64 bit</td>
</tr>
<tr>
<td>Intel80</td>
<td>x95</td>
<td>10</td>
<td>-</td>
<td>Intel extended Floating Point</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>80 bit</td>
</tr>
<tr>
<td>decimal32</td>
<td>x96</td>
<td>4</td>
<td>-</td>
<td>IEEE 754 Floating Point</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Decimal 32</td>
</tr>
<tr>
<td>Decimal64</td>
<td>x97</td>
<td>8</td>
<td>-</td>
<td>IEEE 754 Floating Point</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Decimal 64</td>
</tr>
<tr>
<td>Decimal128</td>
<td>x98</td>
<td>16</td>
<td>-</td>
<td>IEEE 754 Floating Point</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Decimal 128</td>
</tr>
</tbody>
</table>

Table 4

Table 4: Additional Codes for Scientific Data
7. JBCD Frames and Records

Tag codes in the range xF0–XFF are reserved for specifying markers for frames and records. These tags are not used to encode JSON data, they are only used to encapsulate opaque binary data blobs as a unit.

A JBCD record consists of a tag, a length, and the data item. The length indication provided by the record format allows efficient traversal of a sequence of records in the forward direction only.

A JBCD Frames consists of a tag, a length, and the data item followed by the tag-length sequence repeated with the bytes written in the reverse order. The first length indication allows efficient traversal of a sequence of records in the forward direction and the second allows efficient traversal in the reverse direction.

[[This figure is not viewable in this format. The figure is available at http://mathmesh.com/Documents/draft-hallambaker-jsonbcd.html [3].]]

JBCD Records and Frames

The JBCD-Frame tags currently defined are:

<table>
<thead>
<tr>
<th>Production</th>
<th>Tag</th>
<th>Fixed</th>
<th>Length</th>
<th>Data Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>uframe</td>
<td>xF0</td>
<td>-</td>
<td>1</td>
<td>Record, 8 bit length</td>
</tr>
<tr>
<td>uframe</td>
<td>xF1</td>
<td>-</td>
<td>2</td>
<td>Record, 16 bit length</td>
</tr>
<tr>
<td>uframe</td>
<td>xF2</td>
<td>-</td>
<td>4</td>
<td>Record, 32 bit length</td>
</tr>
<tr>
<td>uframe</td>
<td>xF3</td>
<td>-</td>
<td>8</td>
<td>Record, 64 bit length</td>
</tr>
<tr>
<td>bframe</td>
<td>xF4</td>
<td>-</td>
<td>1</td>
<td>Frame, 8 bit length</td>
</tr>
<tr>
<td>bframe</td>
<td>xF5</td>
<td>-</td>
<td>2</td>
<td>Frame, 16 bit length</td>
</tr>
<tr>
<td>bframe</td>
<td>xF6</td>
<td>-</td>
<td>4</td>
<td>Frame, 32 bit length</td>
</tr>
<tr>
<td>bframe</td>
<td>xF7</td>
<td>-</td>
<td>8</td>
<td>Frame, 64 bit length</td>
</tr>
<tr>
<td></td>
<td>xF8-xFF</td>
<td>-</td>
<td>-</td>
<td>Reserved</td>
</tr>
</tbody>
</table>

Table 5

The author does not expect additional framing tags to be added but codes F8-FF are reserved in case this is desired.

It may prove convenient to represent message digest values as large integers rather than binary strings. While very few platforms or programming languages support mathematical operations on fixed size
integers larger than 64, this is not a major concern since message
digests are rarely used for any purpose other than comparison for
equality.

+------------+-----+-------+--------+--------------------------+
<table>
<thead>
<tr>
<th>Production</th>
<th>Tag</th>
<th>Fixed</th>
<th>Length</th>
<th>Data Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>p-int128</td>
<td>Xa4</td>
<td>16</td>
<td>-</td>
<td>Positive 128 bit Integer</td>
</tr>
<tr>
<td>p-int256</td>
<td>Xa5</td>
<td>32</td>
<td>-</td>
<td>Positive 256 bit Integer</td>
</tr>
<tr>
<td>p-int512</td>
<td>Xa6</td>
<td>64</td>
<td>-</td>
<td>Positive 512 bit Integer</td>
</tr>
</tbody>
</table>
+------------+-----+-------+--------+--------------------------+

Table 6

8. Acknowledgements

This work was assisted by conversations with Nico Williams and other
participants on the applications area mailing list.

9. Security Considerations

A correctly implemented data encoding mechanism should not introduce
new security vulnerabilities. However, experience demonstrates that
some data encoding approaches are more prone to introduce
vulnerabilities when incorrectly implemented than others.

In particular, whenever variable length data formats are used, the
possibility of a buffer overrun vulnerability is introduced. While
best practice suggests that a coding language with native mechanisms
for bounds checking is the best protection against such errors, such
approaches are not always followed. While such vulnerabilities are
most commonly seen in the design of decoders, it is possible for the
same vulnerabilities to be exploited in encoders.

A common source of such errors is the case where nested length
encodings are used. For example, a decoder relies on an outermost
length encoding that specifies a length on 50 bytes to allocate
memory for the entire result and then attempts to copy a string with
a declared length of 1000 bytes within the sequence.

The extensions to the JSON encoding described in this document are
designed to avoid such errors. Length encodings are only used to
define the length of x-value constructions which are always terminal
and cannot have nested data entries.
10. IANA Considerations

[TBS list out all the code points that require an IANA registration]

11. References

11.1. Normative References

[draft-hallambaker-udf]
Hallam-Baker, P., "Uniform Data Fingerprint (UDF)", draft-hallambaker-udf-10 (work in progress), April 2018.


[INTEL] Intel Corp., "Unknown".


11.2. Informative References

[draft-hallambaker-mesh-architecture]

11.3. URIs


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