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B. Kaliski
Verisign Labs
C. Bonnell
DigiCert, Inc.
D. Hook
Keyfactor
R. Housley
Vigil Security

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A Layman’s Guide to a Subset of ASN.1, BER, and DER
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Abstract

This note gives a layman’s introduction to a subset of the Abstract Syntax Notation One (ASN.1), Basic Encoding Rules (BER), and Distinguished Encoding Rules (DER). The purpose of this note is to provide background material sufficient for understanding and implementing standards that make use of ASN.1.

Status of This Memo

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Table of Contents

1. Introduction

It is a generally accepted design principle that abstraction is a key to managing software development. With abstraction, a designer can specify a part of a system without concern for how the part is actually implemented or represented. Such a practice leaves the implementation open; it simplifies the specification; and it makes it possible to state "axioms" about the part that can be proved when the part is implemented, and assumed when the part is employed in another, higher-level part. Abstraction is the hallmark of most modern software specifications.

The Open Systems Interconnection (OSI) [X200] series of standards involve a great deal of abstraction. OSI is an internationally standardized architecture for the interconnection of computers from the physical layer up to the user application layer. Objects at higher layers are defined abstractly and intended to be implemented with objects at lower layers. For instance, a service at one layer may require transfer of certain abstract objects between computers; a lower layer may provide transfer services for strings of ones and zeroes, using encoding rules to transform the abstract objects into such strings. OSI is called an open system because it supports many different implementations of the services at each layer.

OSI's method of specifying abstract objects is called ASN.1 (Abstract Syntax Notation One) [X680], and one set of rules for representing such objects as strings of ones and zeros is called the BER (Basic Encoding Rules) [X690]. ASN.1 is a flexible notation that allows one to define a variety data types, from simple types such as integers and bit strings to structured types such as sets and sequences, as well as complex types defined in terms of others. BER describes how to represent or encode values of each ASN.1 type as a string of eight-bit octets. There is generally more than one way to BER-encode a given value. Another set of rules, DER (Distinguished Encoding Rules [X690], which is a subset of BER, gives a unique encoding to each ASN.1 value.

The purpose of this note is to describe a subset of ASN.1, BER and DER sufficient to understand and implement OSI-based applications, Public-Key Cryptography Standards (PKCS), and Internet protocols that make use of ASN.1. The features described include an overview of ASN.1, BER, and DER and an abridged list of ASN.1 types and their BER and DER encodings.

Sections 2-4 give an overview of ASN.1, BER, and DER, in that order. Section 5 lists some ASN.1 types, giving their notation, specific encoding rules, examples, and comments about their application. Section 6 concludes with an example, X.500 [X500] distinguished names.

Advanced features of ASN.1, such as CLASS, are not described in this note. For information on the other features, and for more detail generally, the reader is referred to [X680] and [X690], which define ASN.1, BER, and DER.

1.1. Background

The first version of this document was published on June 3, 1991 as part of the initial public release of PKCS. It was published as NIST/OSI Implementors' Workshop document SEC-SIG-91-17.

The second version of this document was published on November 1, 1993 as a RSA Laboratories Technical Note.

The third version of this document is the Internet-Draft [draft-kaliski-asn1-layman-guide], which is a republication of the second version. It includes the following notice:

> This document represents a republication of A Layman's Guide to a Subset of ASN.1, BER, and DER, originally authored and published by RSA Security USA LLC. This document is submitted with permission from, and on behalf of RSA Security USA LLC. By

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This document is the fourth version, and the first under the transfer of change control. The changes from the third version include:

Discussion of CLASS was added as the replacement for ANY following the modern ASN.1 specification.

Discussion of UTF8String and GeneralizedTime were added.

References were updated. PKCS documents are now referenced by their RFC number.

1.2. Terminology and notation

In this note, an octet is an eight-bit unsigned integer. Bit 8 of the octet is the most significant and bit 1 is the least significant.

The following meta-syntax is used for describing ASN.1 notation:

n1	denotes a variable
[]	square brackets indicate that a term is optional
{}	braces group related terms
|	vertical bar delimits alternatives with a group
...	ellipsis indicates repeated occurrences
=	equals sign expresses terms as subterms

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

2. Abstract Syntax Notation One

Abstract Syntax Notation One, abbreviated ASN.1, is a notation for describing abstract types and values.

In ASN.1, a type is a set of values. For some types, there are a finite number of values, and for other types there are an infinite number. A value of a given ASN.1 type is an element of the type's set. ASN.1 has four kinds of type: simple types, which are "atomic" and have no components; structured types, which have components; tagged types, which are derived from other types; and other types, which include the CHOICE type and the ANY type. Types and values can be given names with the ASN.1 assignment operator (::=) , and those names can be used in defining other types and values.

Every ASN.1 type other than CHOICE and ANY has a tag, which consists of a class and a nonnegative tag number. ASN.1 types are abstractly the same if and only if their tag numbers are the same. In other words, the name of an ASN.1 type does not affect its abstract meaning, only the tag does. There are four classes of tag:

Universal:
: for types whose meaning is the same in all applications; these types are specified in [X680].

Application:
: for types whose meaning is specific to an application, such as X.500 directory services; types in two different applications may have the same application-specific tag and different meanings.

Private:
: for types whose meaning is specific to a given enterprise.

Context-specific:
: for types whose meaning is specific to a given structured type; context-specific tags are used to distinguish between component types with the same underlying tag within the context of a given structured type, and component types in two different structured types may have the same tag and different meanings.

The types with universal tags are defined in X.208, which also gives the types' universal tag numbers. Types with other tags are defined in many places, and are always obtained by implicit or explicit tagging (see Section 2.3). Table 1 lists some ASN.1 types and their universal-class tags.

Type	Decimal Tag Number	Hexadecimal Tag Number
INTEGER	2	02
BIT STRING	3	03
OCTET STRING	4	04
NULL	5	05
OBJECT IDENTIFIER	6	06
UTF8String	12	0c
SEQUENCE and SEQUENCE OF	16	10
SET and SET OF	17	11
PrintableString	19	13
T61String	20	14
IA5String	22	16
UTCTime	23	17
GeneralizedTime	24	18

Table 1: Some types and their universal-class tags.

ASN.1 types and values are expressed in a flexible, programming-language-like notation, with the following special rules:

* Layout is not significant; multiple spaces and line breaks can be considered as a single space.

* Comments are delimited by pairs of hyphens ('--'), or a pair of hyphens and a line break.

* Identifiers (names of values and fields) and type references (names of types) consist of upper- and lower-case letters, digits, hyphens, and spaces; identifiers begin with lower-case letters; type references begin with upper-case letters.

The following four subsections give an overview of simple types, structured types, implicitly and explicitly tagged types, and other types. Section 5 describes specific types in more detail.

2.1. Simple types

Simple types are those not consisting of components; they are the "atomic" types. ASN.1 defines several; the types that are relevant to the PKCS standards are the following:

BIT STRING, an arbitrary string of bits (ones and zeroes).

IA5String, an arbitrary string of IA5 (ASCII) characters.

INTEGER, an arbitrary integer.

NULL, a null value.

OBJECT IDENTIFIER, an object identifier, which is a sequence of integer components that identify an object such as an algorithm or attribute type.

OCTET STRING, an arbitrary string of octets (eight-bit values).

UTF8String, an arbitrary string of international characters using UTF-8 encoding.

PrintableString, an arbitrary string of printable characters.

T61String, an arbitrary string of T.61 (eight-bit) characters.

UTCTime, a "coordinated universal time" or Greenwich Mean Time (GMT) value.

GeneralizedTimeTime, a time value in the local time zone, GMT, or the difference between local and GMT.

Simple types fall into two categories: string types and non- string types. BIT STRING, IA5String, OCTET STRING, PrintableString, T61String, and UTCTime are string types.

String types can be viewed, for the purposes of encoding, as consisting of components, where the components are substrings. This view allows one to encode a value whose length is not known in advance (e.g., an octet string value input from a file stream) with a constructed, indefinite- length encoding (see Section 3).

The string types can be given size constraints limiting the length of values.

2.2. Structured types

Structured types are those consisting of components. ASN.1 defines four, all of which are relevant to the PKCS standards:

SEQUENCE: an ordered collection of one or more types.

SEQUENCE OF: an ordered collection of zero or more occurrences of a given type.

SET: an unordered collection of one or more types.

SET OF: an unordered collection of zero or more occurrences of a given type.

The structured types can have optional components, possibly with default values.

2.3. Implicitly and explicitly tagged types

Tagging is useful to distinguish types within an application; it is also commonly used to distinguish component types within a structured type. For instance, optional components of a SET or SEQUENCE type are typically given distinct context-specific tags to avoid ambiguity.

There are two ways to tag a type: implicitly and explicitly.

Implicitly tagged types are derived from other types by changing the tag of the underlying type. Implicit tagging is denoted by the ASN.1 keywords [class number] IMPLICIT (see Section 5.1).

Explicitly tagged types are derived from other types by adding an outer tag to the underlying type. In effect, explicitly tagged types are structured types consisting of one component, the underlying type. Explicit tagging is denoted by the ASN.1 keywords [class number] EXPLICIT (see Section 5.2).

The keyword [class number] alone is the same as explicit tagging, except when the "module" in which the ASN.1 type is defined has implicit tagging by default. ("Modules" are among the advanced features not described in this note.)

For purposes of encoding, an implicitly tagged type is considered the same as the underlying type, except that the tag is different. An explicitly tagged type is considered like a structured type with one component, the underlying type. Implicit tags result in shorter encodings, but explicit tags may be necessary to avoid ambiguity if the tag of the underlying type is indeterminate (e.g., the underlying type is CHOICE or ANY).

2.4. Other types

Other types in ASN.1 include the CHOICE and ANY types. The CHOICE type denotes a union of one or more alternatives; the ANY type denotes an arbitrary value of an arbitrary type, where the arbitrary type is possibly defined in the registration of an object identifier or integer value.

3. Basic Encoding Rules

The Basic Encoding Rules for ASN.1, abbreviated BER, give one or more ways to represent any ASN.1 value as an octet string. (There are certainly other ways to represent ASN.1 values, but BER is the standard for interchanging such values in OSI.)

There are three methods to encode an ASN.1 value under BER, the choice of which depends on the type of value and whether the length of the value is known. The three methods are primitive, definite-length encoding; constructed, definite-length encoding; and constructed, indefinite-length encoding. Simple non-string types (such as BOOLEAN, INTEGER, NULL, and OBJECT IDENTIFIER) employ the primitive, definite-length method; structured types employ either of the constructed methods; and simple string types employ any of the methods, depending on whether the length of the value is known. Types derived by implicit tagging employ the method of the underlying type and types derived by explicit tagging employ the constructed methods.

In each method, the BER encoding has three or four parts:

Identifier octets. These identify the class and tag number of the ASN.1 value, and indicate whether the method is primitive or constructed.

Length octets. For the definite-length methods, these give the number of contents octets. For the constructed, indefinite-length method, these indicate that the length is indefinite.

Contents octets. For the primitive, definite-length method, these give a concrete representation of the value. For the constructed methods, these give the concatenation of the BER encodings of the components of the value.

End-of-contents octets. For the constructed, indefinite-length method, these denote the end of the contents. For the other methods, these are absent.

The three methods of encoding are described in the following sections.

3.1. Primitive, definite-length method

This method applies to simple types and types derived from simple types by implicit tagging. It requires that the length of the value be known in advance. The parts of the BER encoding are as follows:

Identifier octets. There are two forms: low tag number (for tag numbers between 0 and 30) and high tag number (for tag numbers 31 and greater).

Low-tag-number form. One octet. Bits 8 and 7 specify the class (see Table 2), bit 6 has value "0", indicating that the encoding is primitive, and bits 5-1 give the tag number.

High-tag-number form. Two or more octets. First octet is as in low-tag-number form, except that bits 5-1 all have value "1". Second and following octets give the tag number, base 128, most significant digit first, with as few digits as possible, and with the bit 8 of each octet except the last set to "1".

Class	Bit 8	Bit 7
universal	0	0
application	0	1
context-specific	1	0
private	1	1

Table 2: Class encoding in identifier octets.

Length octets. There are two forms: short (for lengths between 0

and 127), and long definite (for lengths between 0 and 2^1008 -1).

Short form. One octet. Bit 8 has value "0" and bits 7-1 give the length. For example the length for an encoding that has 32 contents octets would encode simply as: 20

Long form. Two to 127 octets. Bit 8 of first octet has value "1" and bits 7-1 give the number of additional length octets. Second and following octets give the length, base 256, most significant digit first. For example the length for an encoding that has 3200 contents octets would encode simply as:

82 0c 80 the first octet indicating that the length is in the following 2 octets and the next two octets give the value of the length.

Contents octets. These give a concrete representation of the value (or the value of the underlying type, if the type is derived by implicit tagging). Details for particular types are given in Section 5.

3.1.1. Prefixes and Magic Numbers

It is worth noting that definite-length encodings, by their nature, are simple enough to parse without the need for a complete ASN.1 decoder and prefixes to the contents octets can often be treated like magic numbers in order to recognise the contents octets that are following.

For example, the private key field of an encoded ML-DSA-44 private key, which is defined as a CHOICE item with the following structure:

ML-DSA-44-PrivateKey ::= CHOICE { seed [0] OCTET STRING (SIZE (32)), expandedKey OCTET STRING (SIZE (2560)), both SEQUENCE { seed OCTET STRING (SIZE (32)), expandedKey OCTET STRING (SIZE (2560)) } } can be recomposed as a series of contents octets preceeded by one of the following prefixes and breakdowns:

Prefix	CHOICE Item	Breakdown
80 20	seed	tag 0x80, short form, length 1 octet, value 32
04 82 0a 00	expandedKey	tag 0x04, long form, length 3 octets, value 2560
30 82 0a 26	both	tag 0x30, long form, length 3 octets, value 2598

Table 3: Prefixes for an ML-DSA private key CHOICE item.

As can be seen from the table, the first octet of each prefix can be used to distinguish the CHOICE item that has been used to describe the ML-DSA-44 private key value.

The three-octet lengths for "expandedKey" and "both" start with 0x82 and indicate that the real length of the contents octets is two octets long. In the case "both" CHOICE item, the contents octets will contain the the prefixes given in the first two rows, as they appear at the start of the encodings of each of the elements in the SEQUENCE.

3.2. Constructed, definite-length method

This method applies to simple string types, structured types, types derived from simple string types and structured types by implicit tagging, and types derived from anything by explicit tagging. It requires that the length of the value be known in advance. The parts of the BER encoding are as follows:

Identifier octets. As described in Section 3.1, except that bit 6 has value "1", indicating that the encoding is constructed.

Length octets. As described in Section 3.1.

Contents octets. The concatenation of the BER encodings of the components of the value:

- For simple string types and types derived from them by implicit tagging, the concatenation of the BER encodings of consecutive substrings of the value (underlying value for implicit tagging). For example an OCTET string of length 8 encoded as a definite-length constructed encoding would encode as: 24 0c 04 04 00000000 04 04 00000000

- For structured types and types derived from them by implicit tagging, the concatenation of the BER encodings of components of the value (underlying value for implicit tagging).

- For types derived from anything by explicit tagging, the BER encoding of the underlying value.

Details for particular types are given in Section 5.

3.3. Constructed, indefinite-length method

This method applies to simple string types, structured types, types derived simple string types and structured types by implicit tagging, and types derived from anything by explicit tagging. It does not require that the length of the value be known in advance. The parts of the BER encoding are as follows:

Identifier octets. As described in Section 3.2.

Length octets. One octet, 80.

Contents octets. As described in Section 3.2.

End-of-contents octets. Two octets, 00 00.

Since the end-of-contents octets appear where an ordinary BER encoding might be expected (e.g., in the contents octets of a sequence value), the 00 and 00 appear as identifier and length octets, respectively. Thus the end-of-contents octets is really the primitive, definite-length encoding of a value with universal class, tag number 0, and length 0.

Considering our previous example of an 8 byte OCTET STRING in constructed form with 4 byte elements, the indefinite length encoding would produce: 24 80 04 04 00000000 04 04 00000000 0000

4. Distinguished Encoding Rules

The Distinguished Encoding Rules for ASN.1, abbreviated DER, are a subset of BER, and give exactly one way to represent any ASN.1 value as an octet string. DER is intended for applications in which a unique octet string encoding is needed, as is the case when a digital signature is computed on an ASN.1 value. BER and DER are defined in [X690].

DER adds the following restrictions to the rules given in Section 3:

1. When the length is between 0 and 127, the short form of length must be used

2. When the length is 128 or greater, the long form of length must be used, and the length must be encoded in the minimum number of octets.

3. For simple string types and implicitly tagged types derived from simple string types, the primitive, definite-length method must be employed.

4. For structured types, implicitly tagged types derived from structured types, and explicitly tagged types derived from anything, the constructed, definite-length method must be employed.

Other restrictions are defined for particular types (such as BOOLEAN, BIT STRING, SEQUENCE, SET, and SET OF), and can be found in Section 5.

5. Notation and encodings for some types

This section gives the notation for some ASN.1 types and describes how to encode values of those types under both BER and DER.

The types described are those presented in Section 2. They are listed alphabetically here.

Each description includes ASN.1 notation, BER encoding, and DER encoding. The focus of the encodings is primarily on the contents octets; the tag and length octets follow Sections 3 and 4. The descriptions also explain where each type is used in PKCS and related standards. ASN.1 notation is generally only for types, although for the type OBJECT IDENTIFIER, value notation is given as well.

5.1. Implicitly tagged types

An implicitly tagged type is a type derived from another type by changing the tag of the underlying type.

Implicit tagging is used for optional SEQUENCE components with underlying type other than ANY in many protocols, including [RFC5280] and [RFC5652].

ASN.1 notation:

[[class] number] IMPLICIT Type

class = UNIVERSAL | APPLICATION | PRIVATE

where Type is a type, class is an optional class name, and number is the tag number within the class, a nonnegative integer.

In ASN.1 modules whose default tagging method is implicit tagging, the notation [[class] number] Type is also acceptable, and the keyword IMPLICIT is implied. (See Section 2.3.) For definitions stated outside a module, the explicit inclusion of the keyword IMPLICIT is preferable to prevent ambiguity.

If the class name is absent, then the tag is context-specific. Context-specific tags can only appear in a component of a structured or CHOICE type.

Example: PKCS #8 PrivateKeyInfo type [RFC5958] has an optional attributes component with an implicit, context-specific tag:

```
PrivateKeyInfo ::= SEQUENCE {
  version Version,
  privateKeyAlgorithm PrivateKeyAlgorithmIdentifier,
  privateKey PrivateKey,
  attributes [0] IMPLICIT Attributes OPTIONAL }
```

Here the underlying type is Attributes, the class is absent (i.e., context-specific), and the tag number within the class is 0.

BER encoding. Primitive or constructed, depending on the underlying type. Contents octets are as for the BER encoding of the underlying value.

Example: The BER encoding of the attributes component of a PrivateKeyInfo value is as follows:

- the identifier octets are 80 if the underlying Attributes value has a primitive BER encoding and a0 if the underlying Attributes value has a constructed BER encoding

- the length and contents octets are the same as the length and contents octets of the BER encoding of the underlying Attributes value

DER encoding. Primitive or constructed, depending on the underlying type. Contents octets are as for the DER encoding of the underlying value.

5.2. Explicitly tagged types

Explicit tagging denotes a type derived from another type by adding an outer tag to the underlying type.

Explicit tagging is used for optional SEQUENCE components with underlying type ANY throughout in many protocols, including the version component of the Certificate type [RFC5280].

Implicit tagging is used for optional SEQUENCE components with underlying type other than ANY ASN.1 notation:

[[class] number] EXPLICIT Type

class = UNIVERSAL | APPLICATION | PRIVATE

where Type is a type, class is an optional class name, and number is the tag number within the class, a nonnegative integer.

If the class name is absent, then the tag is context- specific. Context-specific tags can only appear in a component of a SEQUENCE, SET or CHOICE type.

In ASN.1 "modules" whose default tagging method is explicit tagging, the notation [[class] number] Type is also acceptable, and the keyword EXPLICIT is implied. (See Section 2.3.) For definitions stated outside a module, the explicit inclusion of the keyword EXPLICIT is preferable to prevent ambiguity.

Example 1: The CMS ContentInfo type [RFC5652] has an optional content component with an explicit, context-specific tag:

```
ContentInfo ::= SEQUENCE {
  contentType ContentType,
  content [0] EXPLICIT ANY DEFINED BY contentType OPTIONAL }
```

Here the underlying type is ANY DEFINED BY contentType, the class is absent (i.e., context-specific), and the tag number within the class is 0.

Example 2: the Certificate type [RFC5280] has a version component with an explicit, context-specific tag, where the EXPLICIT keyword is omitted:

```
Certificate ::= ...
  version [0] Version DEFAULT v1988,
   ...
```

The tag is explicit because the default tagging method for the ASN.1 module in [RFC5280] that defines the Certificate type is explicit tagging.

BER encoding. Constructed. Contents octets are the BER encoding of the underlying value.

Example: the BER encoding of the content component of a ContentInfo value is as follows:

- identifier octets are a0
- length octets represent the length of the BER encoding of the underlying ANY DEFINED BY contentType value
- contents octets are the BER encoding of the underlying ANY DEFINED BY contentType value

DER encoding. Constructed. Contents octets are the DER encoding of the underlying value.

5.3. ANY

In the original ASN.1 specification, the ANY type denotes an arbitrary value of an arbitrary type, where the arbitrary type is possibly defined in the registration of an object identifier or associated with an integer index.

In [RFC5652], the ANY type is used for content of a particular content type within the ContentInfo type. In [RFC5280] and [RFC5652], the ANY type is used for parameters of a particular algorithm within the AlgorithmIdentifier type. In [RFC5280], the ANY type is used for attribute values within the Attribute type.

ASN.1 notation:

ANY [DEFINED BY identifier]

where identifier is an optional identifier.

In the ANY form, the actual type is indeterminate.

The ANY DEFINED BY identifier form can only appear in a component of a SEQUENCE or SET type for which identifier identifies some other component, and that other component has type INTEGER or OBJECT IDENTIFIER (or a type derived from either of those by tagging). In that form, the actual type is determined by the value of the other component, either in the registration of the object identifier value, or in a table of integer values.

Example: The AlgorithmIdentifier type [RFC5280] has a component of type ANY:

```
AlgorithmIdentifier ::= SEQUENCE {
  algorithm OBJECT IDENTIFIER,
  parameters ANY DEFINED BY algorithm OPTIONAL }
```

Here the actual type of the parameter component depends on the value of the algorithm component. The actual type would be defined in the registration of object identifier values for the algorithm component.

BER encoding. Same as the BER encoding of the actual value.

Example: The BER encoding of the value of the parameter component is the BER encoding of the value of the actual type as defined in the registration of object identifier values for the algorithm component.

DER encoding. Same as the DER encoding of the actual value.

In the modern ASN.1 specification, the CLASS construction replaces the ANY type.

Example: The AlgorithmIdentifier type can be implemented as shown below, which is a simplification of the definition in [RFC5912]:

```
ALGORITHM ::= CLASS {
  &id OBJECT IDENTIFIER UNIQUE,
  &Params OPTIONAL,
} WITH SYNTAX {
  IDENTIFIER &id
  [PARAMS [TYPE &Params]]
}

AlgorithmIdentifier{ALGORITHM:AlgorithmSet} ::= SEQUENCE {
  algorithm ALGORITHM.&id({AlgorithmSet}),
  parameters ALGORITHM.&Params({AlgorithmSet}{@algorithm}) OPTIONAL }
```

Of course, the BER and DER encoding are unchanged.

The AlgorithmSet makes it easier for implementers to determine all of the algorithm identifiers and the associated type for parameters, if any are defined.

5.4. BIT STRING

The BIT STRING type denotes an arbitrary string of bits (ones and zeroes). A BIT STRING value can have any length, including zero. This type is a string type.

The BIT STRING type is used for digital signatures on for digital signatures on certificates and for public keys in certificates in SubjectPublicKeyInfo type [RFC5280].

ASN.1 notation:

```
BIT STRING
```

Example: SubjectPublicKeyInfo type [RFC5280] has a component of type BIT STRING:

```
SubjectPublicKeyInfo ::= SEQUENCE {
  algorithm AlgorithmIdentifier,
  publicKey BIT STRING }
```

BER encoding. Primitive or constructed. In a primitive encoding, the first contents octet gives the number of bits by which the length of the bit string is less than the next multiple of eight (this is called the "number of unused bits"). The first contents octet is always encoded; if the length of the bit string is 0 bits, then the first contents octet will have the value 0 and there not be any subsequent contents octets. The second and following contents octets give the value of the bit string, converted to an octet string. The conversion process is as follows:

1. The bit string is padded after the last bit with zero to seven bits of any value to make the length of the bit string a multiple of eight. If the length of the bit string is a multiple of eight already, no padding is done.

2. The padded bit string is divided into octets. The first eight bits of the padded bit string become the first octet, bit 8 to bit 1, and so on through the last eight bits of the padded bit string.

In a constructed encoding, the contents octets give the concatenation of the BER encodings of consecutive substrings of the bit string, where each substring except the last has a length that is a multiple of eight bits.

Example: The BER encoding of the BIT STRING value "011011100101110111" can be any of the following, among others, depending on the choice of padding bits, the form of length octets, and whether the encoding is primitive or constructed:

```
03 04 06 6e 5d c0                                 DER encoding

03 04 06 6e 5d e0                           padded with "100000"

03 81 04 06 6e 5d c0                  long form of length octets

23 09        constructed encoding: "0110111001011101" + "11"
   03 03 00 6e 5d
   03 02 06 c0
```

DER encoding. Primitive. The contents octets are as for a primitive BER encoding, except that the bit string is padded with zero-valued bits. Additionally, BIT STRINGs that represent named bit lists, such as the value of the Key Usage certificate extension [RFC5280], have all trailing 0 bits removed before it is encoded.

Example: The DER encoding of the BIT STRING value "011011100101110111" is:

```
03 04 06 6e 5d c0
```

Example: The DER encoding of a Key Usage certificate extension value, asserting only the digitalSignature bit:

```
03 02 07 80
```

5.5. BOOLEAN

BER encoding. Primitive. A single octet in length, for FALSE the octet is set to zero, for TRUE, the octet is non-zero.

DER encoding. Primitive. A single octet in length, for FALSE the octet is set to zero, for TRUE, the octet is set to 0xFF.

Example: The DER encoding of the BOOLEAN value TRUE is:

```
01 01 FF
```

5.6. CHOICE

The CHOICE type denotes a union of one or more alternatives.

The CHOICE type is used to represent the union of an extended certificate and an X.509 certificate in the ExtendedCertificateOrCertificate type specified in [RFC5652].

ASN.1 notation:

```
CHOICE {
  [identifier1] Type1,
  ...,
  [identifierN] TypeN }
```

where identifier1 , ..., identifierN are optional, distinct identifiers for the alternatives, and Type1, ..., TypeN are the types of the alternatives. The identifiers are primarily for documentation; they do not affect values of the type or their encodings in any way.

The types must have distinct tags. This requirement is typically satisfied with explicit or implicit tagging on some of the alternatives.

Example: In [RFC5652], the ExtendedCertificateOrCertificate type is a CHOICE type:

```
ExtendedCertificateOrCertificate ::= CHOICE {
  certificate Certificate, -- X.509
  extendedCertificate [0] IMPLICIT ExtendedCertificate }
```

Here the identifiers for the alternatives are certificate and extendedCertificate, and the types of the alternatives are Certificate and [0] IMPLICIT ExtendedCertificate.

BER encoding. Same as the BER encoding of the chosen alternative. The fact that the alternatives have distinct tags makes it possible to distinguish between their BER encodings.

Example: The identifier octets for the BER encoding are 30 if the chosen alternative is certificate, and a0 if the chosen alternative is extendedCertificate.

DER encoding. Same as the DER encoding of the chosen alternative.

5.7. IA5String

The IA5String type denotes an arbitrary string of IA5 characters. IA5 stands for International Alphabet 5, which is the same as ASCII. The character set includes non-printing control characters. An IA5String value can have any length, including zero. This type is a string type.

The IA5String type is used in the PKCS #9 [RFC2985] electronic-mail address, unstructured-name, and unstructured-address attributes.

ASN.1 notation:

IA5String

BER encoding. Primitive or constructed. In a primitive encoding, the contents octets give the characters in the IA5 string, encoded in ASCII. In a constructed encoding, the contents octets give the concatenation of the BER encodings of consecutive substrings of the IA5 string.

Example: The BER encoding of the IA5String value "test1@example.com" can be any of the following, among others, depending on the form of length octets and whether the encoding is primitive or constructed:

```
16 11 74 65 73 74 31 40 65 78 61 6d 70 6c 65 2e 63 6f 6d DER encoding

16 81 11                       long form of length octets
   74 65 73 74 31 40 65 78 61 6d 70 6c 65 2e 63 6f 6d

36 17     constructed encoding: "test1" + "@" + "example.com"
   16 05 74 65 73 74 31
   16 01 40
   16 0B 65 78 61 6d 70 6c 65 2e 63 6f 6d
```

DER encoding. Primitive. Contents octets are as for a primitive BER encoding.

Example: The DER encoding of the IA5String value "test1@example.com" is

16 11 74 65 73 74 31 40 65 78 61 6d 70 6c 65 2e 63 6f 6d

5.8. INTEGER

The INTEGER type denotes an arbitrary integer. INTEGER values can be positive, negative, or zero, and can have any magnitude.

The INTEGER type is used for version numbers in many protocols, including [RFC5280] and [RFC5652]. The INTEGER type is used for cryptographic values such as modulus, exponent, and primes in the PKCS #1 RSAPublicKey and RSAPrivateKey types [RFC8017]. The INTEGER type is used for a message-digest iteration count in PKCS #5 PBEParameter type [RFC8018].

ASN.1 notation:

```
INTEGER [{ identifier1(value1) ... identifierN(valueN) }]
```

where identifier1, ..., identifierN are optional distinct identifiers and value1, ..., valueN are optional integer values. The identifiers, when present, are associated with values of the type. INTEGER is always signed.

Example: Version type [RFC5280] is an INTEGER type with identified values:

```
Version ::= INTEGER  { v1(0), v2(1), v3(2) }
```

The identifier v1 is associated with the value 0. The Certificate type [RFC5280] uses the identifier v1 to give a default value of 0 for the version component:

```
Certificate ::= ...
  version Version DEFAULT v1,
  ...
```

BER encoding. Primitive. Contents octets give the value of the integer, base 256, in two's complement form, most significant digit first, with the minimum number of octets. The value 0 is encoded as a single 00 octet.

Some example BER encodings (which also happen to be DER encodings) are given in Table 3.

Integer value	BER encoding
0	02 01 00
127	02 01 7F
128	02 02 00 80
256	02 02 01 00
-128	02 01 80
-129	02 02 FF 7F

Table 4: Example BER encodings of INTEGER values.

DER encoding. Primitive. Contents octets are as for a primitive BER encoding.

5.9. NULL

The NULL type denotes a null value.

The NULL type is used for algorithm parameters in several places in as required algorithm parameters, including [RFC4055].

ASN.1 notation:

NULL

BER encoding. Primitive. Contents octets are empty.

Example: The BER encoding of a NULL value can be either of the following, as well as others, depending on the form of the length octets:

05 00

05 81 00

DER encoding. Primitive. Contents octets are empty; the DER encoding of a NULL value is always 05 00.

5.10. OBJECT IDENTIFIER

The OBJECT IDENTIFIER type denotes an object identifier, a sequence of integer components that identifies an object such as an algorithm, an attribute type, or perhaps a registration authority that defines other object identifiers. An OBJECT IDENTIFIER value can have any number of components, and components can generally have any nonnegative value. This type is a non-string type.

OBJECT IDENTIFIER values are given meanings by registration authorities. Each registration authority is responsible for all sequences of components beginning with a given sequence. A registration authority typically delegates responsibility for subsets of the sequences in its domain to other registration authorities, or for particular types of object. There are always at least two components.

The OBJECT IDENTIFIER type is used to identify content in ContentInfo type [RFC5652], to identify algorithms in AlgorithmIdentifier type [RFC5280] and [RFC5652].

ASN.1 notation:

OBJECT IDENTIFIER

The ASN.1 notation for values of the OBJECT IDENTIFIER type is

{ [identifier] component1 ... componentN }

componentI = identifierI | identifierI (valueI) | valueI

where identifier, identifier1, ..., identifierN are identifiers, and value1, ..., valueI are optional integer values.

The form without identifier is the "complete" value with all its components; the form with identifier abbreviates the beginning components with another object identifier value. The identifiers identifier1, ..., identifierN are intended primarily for documentation, but they must correspond to the integer value when both are present. These identifiers can appear without integer values only if they are among a small set of identifiers defined in [X680].

Example: The following values both refer to the object identifier assigned to RSA Data Security, Inc.:

{ iso(1) member-body(2) 840 113549 }
{ 1 2 840 113549 }

(In this example, which gives ASN.1 value notation, the object identifier values are decimal, not hexadecimal.) Table 4 gives some other object identifier values and their meanings.

Object identifier value	Meaning
{ 1 2 }	ISO member bodies
{ 1 2 840 }	US (ANSI)
{ 1 2 840 113549 }	RSA Data Security, Inc.
{ 1 2 840 113549 1}	RSA Data Security, Inc. PKCS
{ 2 5 }	directory services (X.500)
{ 2 5 8 }	directory services-algorithms

Table 5: Some object identifier values and their meanings.

BER encoding. Primitive. Contents octets are as follows, where value1, ..., valuen denote the integer values of the components in the complete object identifier:

1. The first octet has value 40 * value1 + value2. (This is unambiguous, since value1 is limited to values 0, 1, and 2; value2 is limited to the range 0 to 39 when value1 is 0 or 1; and, according to [X680], n is always at least 2.)

2. The following octets, if any, encode value3, ..., valuen. Each value is encoded base 128, most significant digit first, with as few digits as possible, and the most significant bit of each octet except the last in the value’s encoding set to "1."

Example: The first octet of the BER encoding of RSA Data Security, Inc.’s object identifier is 40 * 1 + 2 = 42 = 2a (hexadecimal). The encoding of 840 = 6 * 128 + 48 (hexadecimal) is 86 48 and the encoding of 113549 = 6 * 1282 + 77 (hexadecimal) * 128 + d (hexadecimal) is 86 f7 0d. This leads to the following BER encoding:

```
06 06 2a 86 48 86 f7 0d
```

DER encoding. Primitive. Contents octets are as for a primitive BER encoding.

5.11. OCTET STRING

The OCTET STRING type denotes an arbitrary string of octets (eight-bit values). An OCTET STRING value can have any length, including zero. This type is a string type.

The OCTET STRING type is used for salt values in the PBEParameter type [RFC8018]. The OCTET STRING type is used for message digests, encrypted message digests, and encrypted content in [RFC5652]. The OCTET STRING type is used for private keys and encrypted private keys in PKCS #8 [RFC5958].

ASN.1 notation:

```
OCTET STRING [SIZE ({size | size1..size2})]
```

where size, size1, and size2 are optional size constraints. In the OCTET STRING SIZE (size) form, the octet string must have size octets. In the OCTET STRING SIZE (size1..size2) form, the octet string must have between size1 and size2 octets. In the OCTET STRING form, the octet string can have any size.

Example: The PBEParameter type in [RFC8018] has a component of type OCTET STRING:

```
PBEParameter ::= SEQUENCE {
  salt OCTET STRING SIZE(8),
  iterationCount INTEGER }
```

Here the size of the salt component is always eight octets.

BER encoding. Primitive or constructed. In a primitive encoding, the contents octets give the value of the octet string, first octet to last octet. In a constructed encoding, the contents octets give the concatenation of the BER encodings of substrings of the OCTET STRING value.

Example: The BER encoding of the OCTET STRING value 01 23 45 67 89 ab cd ef can be any of the following, among others, depending on the form of length octets and whether the encoding is primitive or constructed:

```
04 08 01 23 45 67 89 ab cd ef                    DER encoding

04 81 08 01 23 45 67 89 ab cd ef  long form of length octets

24 0c            constructed encoding: 01 ... 67 + 89 ... ef
   04 04 01 23 45 67
   04 04 89 ab cd ef
```

DER encoding. Primitive. Contents octets are as for a primitive BER encoding.

Example: The BER encoding of the OCTET STRING value 01 23 45 67 89 ab cd ef is

```
04 08 01 23 45 67 89 ab cd ef
```

5.12. PrintableString

The PrintableString type denotes an arbitrary string of printable characters from the following character set:

```
        A, B, ..., Z
        a, b, ..., z
        0, 1, ..., 9
    (space) ' ( ) + , - . / : = ?
```

This type is a string type.

The PrintableString type is used in PKCS #9 [RFC2985] challenge-password and unstructured-address attributes, and in several distinguished names attributes [RFC5280].

ASN.1 notation:

```
PrintableString
```

BER encoding. Primitive or constructed. In a primitive encoding, the contents octets give the characters in the printable string, encoded in ASCII. In a constructed encoding, the contents octets give the concatenation of the BER encodings of consecutive substrings of the string.

Example: The BER encoding of the PrintableString value "Test User 1" can be any of the following, among others, depending on the form of length octets and whether the encoding is primitive or constructed:

```
13 0b 54 65 73 74 20 55 73 65 72 20 31          DER encoding

13 81 0b                            long form of length octets
   54 65 73 74 20 55 73 65 72 20 31

33 0f               constructed encoding: "Test " + "User 1"
   13 05 54 65 73 74 20
   13 06 55 73 65 72 20 31
```

DER encoding. Primitive. Contents octets are as for a primitive BER encoding.

Example: The DER encoding of the PrintableString value "Test User 1" is

```
13 0b 54 65 73 74 20 55 73 65 72 20 31
```

5.13. SEQUENCE

The SEQUENCE type denotes an ordered collection of one or more types.

The SEQUENCE type is used throughout by just about every standard that makes use of ASN.1.

ASN.1 notation:

```
SEQUENCE {
  [identifier1] Type1 [{OPTIONAL | DEFAULT value1}],
  ...,
  [identifierN] TypeN [{OPTIONAL | DEFAULT valueN}] }
```

where identifier1 , ..., identifierN are optional, distinct identifiers for the components, Type1, ..., TypeN are the types of the components, and value1, ..., valuen are optional default values for the components. The identifiers are primarily for documentation; they do not affect values of the type or their encodings in any way.

The OPTIONAL qualifier indicates that the value of a component is optional and need not be present in the sequence. The DEFAULT qualifier also indicates that the value of a component is optional, and assigns a default value to the component when the component is absent.

The types of any consecutive series of components with the OPTIONAL or DEFAULT qualifier, as well as of any component immediately following that series, must have distinct tags. This requirement is typically satisfied with explicit or implicit tagging on some of the components.

Example: Validity type [RFC5280] is a SEQUENCE type with two components:

```
Validity ::= SEQUENCE {
  start Time,
  end Time }
```

Here the identifiers for the components are start and end, and the types of the components are both Time.

BER encoding. Constructed. Contents octets are the concatenation of the BER encodings of the values of the components of the sequence, in order of definition, with the following rules for components with the OPTIONAL and DEFAULT qualifiers:

* if the value of a component with the OPTIONAL or DEFAULT qualifier is absent from the sequence, then the encoding of that component is not included in the contents octets

* if the value of a component with the DEFAULT qualifier is the default value, then the encoding of that component may or may not be included in the contents octets

DER encoding. Constructed. Contents octets are the same as the BER encoding, except that if the value of a component with the DEFAULT qualifier is the default value, the encoding of that component is not included in the contents octets.

5.14. SEQUENCE OF

The SEQUENCE OF type denotes an ordered collection of zero or more occurrences of a given type.

The SEQUENCE OF type is used in distinguished names [RFC5280].

ASN.1 notation:

```
SEQUENCE [SIZE ({size | size1..size2})] OF Type
```

where Type is a type, and where size, size1, and size2 are optional size constraints. In the SEQUENCE SIZE (size1..size2) OF form, the SEQUENCE must have between size1 and size2 items present. In the SEQUENCE OF form, the SEQUENCE can have any number of items, including zero.

Example: The RDNSequence type [RFC5280] consists of zero or more occurrences of the RelativeDistinguishedName type, most significant occurrence first:

```
RDNSequence ::= SEQUENCE OF RelativeDistinguishedName
```

BER encoding. Constructed. Contents octets are the concatenation of the BER encodings of the values of the occurrences in the collection, in order of occurrence.

DER encoding. Constructed. Contents octets are the concatenation of the DER encodings of the values of the occurrences in the collection, in order of occurrence.

Example: The Extensions type in [RFC5280] requires that at least one item be present in the SEQUENCE OF:

```
Extensions  ::=  SEQUENCE SIZE (1..MAX) OF Extension
```

There are some widely used ASN.1 specifications that define an OPTIONAL SEQUENCE OF component without a size constraint. In this case, the sender can encode either an empty SEQUENCE, or it can elect to not encode the SEQUENCE. Absent some requirement established in the prose of the specification, it is preferable to not encode the empty SEQUENCE OF, as it minimizes the size of the message.

5.15. SET

The SET type denotes an unordered collection of one or more types. The SET type is not used in the ESSSecurityLabel [RFC5035].

ASN.1 notation:

```
SET {
  [identifier1] Type1 [{OPTIONAL | DEFAULT value1}],
  ...,
  [identifierN] TypeN [{OPTIONAL | DEFAULT valueN}] }
```

where identifier1, ..., identifierN are optional, distinct identifiers for the components, Type1, ..., TypeN are the types of the components, and value1, ..., valueN are optional default values for the components. The identifiers are primarily for documentation; they do not affect values of the type or their encodings in any way.

The OPTIONAL qualifier indicates that the value of a component is optional and need not be present in the set. The DEFAULT qualifier also indicates that the value of a component is optional, and assigns a default value to the component when the component is absent.

The types must have distinct tags. This requirement is typically satisfied with explicit or implicit tagging on some of the components.

Example. The SET type is used in the ESSSecurityLabel type [RFC5035].

```
ESSSecurityLabel ::= SET {
  security-policy-identifier SecurityPolicyIdentifier,
  security-classification SecurityClassification OPTIONAL,
  privacy-mark ESSPrivacyMark OPTIONAL,
  security-categories SecurityCategories OPTIONAL }
```

BER encoding. Constructed. Contents octets are the concatenation of the BER encodings of the values of the components of the set, in any order, with the following rules for components with the OPTIONAL and DEFAULT qualifiers:

- if the value of a component with the OPTIONAL or DEFAULT qualifier is absent from the set, then the encoding of that component is not included in the contents octets

- if the value of a component with the DEFAULT qualifier is the default value, then the encoding of that component may or may not be included in the contents octets

DER encoding. Constructed. Contents octets are the same as for the BER encoding, except that:

1. If the value of a component with the DEFAULT qualifier is the default value, the encoding of that component is not included.

2. There is an order to the components, namely ascending order by tag (care: the CONSTRUCTED bit is not part of the tag value, see below). By ascending order, imagine every set element's encoding is padded with zeroes so that every encoding is the same length and then each padded encoding is treated as an INTEGER with the smallest encodings sorted to the start of the SET.

A simple pseudo-code version of the sort (in-place) would look like: ''' Sort(ASN1Object[] elements) { boolean swapped = true; while (swapped) { swapped = false; for (var i = 0; i != Length(elements) - 1; i++) { if (!LessThanOrEqual(DER(elements[i]), DER(elements[i+1]))) { swapped = true; var ei = elements[i]; elements[i] = elements[i + 1]; elements[i+1] = ei; } } } }

```
LessThanOrEqual(byte[] encA, byte[] encB)
{
    // clear CONSTRUCTED bit in tag byte if set
    var a0 = encA[0] & ~CONSTRUCTED
    var b0 = encB[0] & ~CONSTRUCTED
    if (a0 != b0)
    {
        return a0 < b0;
    }

    var last = Min(Length(encA), Length(encB)) - 1;

    for (var i = 1; i < last; ++i) {
        if (encA[i] != encB[i])
            return encA[i] < encB[i]
    }

    return encA[last] <= encB[last]
} ''' Where Length() returns the length of an array, Min returns the mathematical minimum
 of two values and DER() returns the DER encoding of the ASN1Object passed to it, and the
 ~ operator provides the ones compliment of a value, as it does in languages like C, Java
, and C#. Likewise for & - the bitwise AND.
```

NOTE: As you can see from the LessThanOrEqual function, SET elements in DER encodings are ordered first according to their tags (class and number), but the CONSTRUCTED bit is not part of the tag.

Links to examples of different implementations of the DER SET sort can be found in Section 7.

For SET-OF (see below), this is unimportant. All elements have the same tag and DER requires them to either all be in constructed form or all in primitive form, according to that tag. The elements are effectively ordered according to their contents octets.

For SET, the elements will have distinct tags, and each will be in constructed or primitive form accordingly. Failing to ignore the CONSTRUCTED bit could therefore lead to ordering inversions, so in general it is best to make sure it is not present in the encoding of the tag.

5.16. SET OF

The SET OF type denotes an unordered collection of zero or more occurrences of a given type.

The SET OF type is used for sets of attributes in PKCS #9 [RFC2985]. The SET OF type is used for sets of message-digest algorithm identifiers, signer information, and recipient information in [RFC5652].

ASN.1 notation:

```
SET [SIZE ({size | size1..size2})] OF Type
```

where Type is a type, and where size, size1, and size2 are optional size constraints. In the SET SIZE (size1..size2) OF form, the SET must have between size1 and size2 items present. In the SET OF form, the SET can have any number of items, including zero.

Example: The RelativeDistinguishedName type [RFC5280] consists of one or more occurrences of the AttributeValueAssertion type, where the order is unimportant:

```
RelativeDistinguishedName ::=
  SET SIZE (1..MAX) OF AttributeTypeAndValue
```

BER encoding. Constructed. Contents octets are the concatenation of the BER encodings of the values of the occurrences in the collection, in any order.

DER encoding. Constructed. Contents octets are the same as for the BER encoding, except that there is an order, namely ascending lexicographic order of BER encoding. Lexicographic comparison of two different BER encodings is done as follows: Logically pad the shorter BER encoding after the last octet with dummy octets that are smaller in value than any normal octet. Scan the BER encodings from left to right until a difference is found. The smaller-valued BER encoding is the one with the smaller-valued octet at the point of difference.

There are some widely used ASN.1 specifications that define an OPTIONAL SET OF component without a size constraint. In this case, the sender can encode either an empty SET, or it can elect to not encode the SET. Absent some requirement established in the prose of the specification, it is preferable to not encode the empty SET OF, as it minimizes the size of the message.

5.17. T61String

The T61String type denotes an arbitrary string of T.61 characters. T.61 is an eight-bit extension to the ASCII character set. Special "escape" sequences specify the interpretation of subsequent character values as, for example, Japanese; the initial interpretation is Latin. The character set includes non-printing control characters. The T61String type allows only the Latin and Japanese character interpretations, and implementors' agreements for directory names exclude control characters [NIST92]. A T61String value can have any length, including zero. This type is a string type.

The T61String type is used in PKCS #9 unstructured-address and challenge-password attributes [RFC2985], and in several attributes documented in [RFC5280].

ASN.1 notation:

T61String

BER encoding. Primitive or constructed. In a primitive encoding, the contents octets give the characters in the T.61 string, encoded in ASCII. In a constructed encoding, the contents octets give the concatenation of the BER encodings of consecutive substrings of the T.61 string.

Example: The BER encoding of the T61String value "cl迪s publiques" (French for "public keys") can be any of the following, among others, depending on the form of length octets and whether the encoding is primitive or constructed:

```
14 0f                                          DER encoding
   63 6c c2 65 73 20 70 75 62 6c 69 71 75 65 73

14 81 0f                           long form of length octets
   63 6c c2 65 73 20 70 75 62 6c 69 71 75 65 73

34 15      constructed encoding: "cl迪s" + " " + "publiques"
   14 05 63 6c c2 65 73
   14 01 20
   14 09 70 75 62 6c 69 71 75 65 73
```

The eight-bit character c2 is a T.61 prefix that adds an acute accent (’) to the next character.

DER encoding. Primitive. Contents octets are as for a primitive BER encoding.

Example: The DER encoding of the T61String value "cl’es publiques" is

```
14 0f 63 6c c2 65 73 20 70 75 62 6c 69 71 75 65 73
```

5.18. UTCTime

The UTCTime type denotes a "coordinated universal time" or Greenwich Mean Time (GMT) value. A UTCTime value includes the local time precise to either minutes or seconds, and an offset from GMT in hours and minutes. It takes any of the following forms:

YYMMDDhhmmZ
YYMMDDhhmm+hh'mm'
YYMMDDhhmm-hh'mm'
YYMMDDhhmmssZ
YYMMDDhhmmss+hh'mm'
YYMMDDhhmmss-hh'mm'

where:

YY is the least significant two digits of the year (00 to 99)

MM is the month (01 to 12)

DD is the day (01 to 31)

hh is the hour (00 to 23)

mm are the minutes (00 to 59)

ss are the seconds (00 to 59)

Z indicates that local time is GMT, + indicates that local time is later than GMT, and - indicates that local time is earlier than GMT

hh' is the absolute value of the offset from GMT in hours

mm' is the absolute value of the offset from GMT in minutes

This type is a string type.

The UTCTime type is used for signing times in PKCS #9 signing-time attribute [RFC2985] and for certificate validity periods in Validity type [RFC5280].

ASN.1 notation:

UTCTime

BER encoding. Primitive or constructed. In a primitive encoding, the contents octets give the characters in the string, encoded in ASCII. In a constructed encoding, the contents octets give the concatenation of the BER encodings of consecutive substrings of the string. (The constructed encoding is not particularly interesting, since UTCTime values are so short, but the constructed encoding is permitted.)

Example: The time this sentence was originally written was 4:45:40 p.m. Pacific Daylight Time on May 6, 1991, which can be represented with either of the following UTCTime values, among others:

"910506164540-0700"

"910506234540Z"

These values have the following BER encodings, among others:

17 0d 39 31 30 35 30 36 32 33 34 35 34 30 5a

17 11 39 31 30 35 30 36 31 36 34 35 34 30 2D 30 37 30 30

DER encoding. Primitive. Contents octets are as for a primitive BER encoding.

5.19. GeneralizedTime

The GeneralizedTime type consists of a calendar date and time. A GeneralizedTime value includes the local time precise to fractions of seconds. A GeneralizedTime value can include midnight at the start of a day, but it excludes midnight at the end of a day. A GeneralizedTime value uses one of the following three forms:

1. a local time of day;

2. a local time of day with the difference between local time and UTC; or

3. a UTC time of day.

Accuracy of the time takes one of the following three forms:

1. hours, minutes, and seconds, with fractions of a second to any number of decimal places;

2. hours and minutes, with fractions of a minute to any number of decimal places; or

3. hours, with fractions of an hour to any number of decimal places.

This type is a string type. It uses a subset of VisibleString.

The VisibleString starts with a four-digit representation of the year, a two-digit representation of the month, and a two-digit representation of the day, without use of separators.

The VisibleString continues with the time of day to an accuracy of one hour one minute, one second, or fractions of a second, using either comma or full stop as the decimal sign.

The VisibleString ends with upper-case letter Z to indicate a UTC time.

The VisibleString ends the signed difference between local time and UTC, with the minutes component optionally omitted if the difference is an integral number of hours.

All possible forms of GeneralizedTime cannot be enumerated, but it is worth noting that [RFC5280] requires dates after 2049 use the following form, which uses the same as above, except that a four digit year is provided:

YYYYMMDDhhmmssZ

The GeneralizedTime type is used for certificate validity periods in Validity type [RFC5280].

ASN.1 notation:

GeneralizedTime

BER encoding. Primitive or constructed. In a primitive encoding, the contents octets give the characters in the string, encoded in VisibleString. In a constructed encoding, the contents octets give the concatenation of the BER encodings of consecutive substrings of the string. (The constructed encoding is not particularly interesting, since GeneralizedTime values are usually very short, but the constructed encoding is permitted.)

Example: Local time 6 minutes, 27.3 seconds after 9 pm on 6 November 2050.

"20501106210627.3"

This value has the following BER encodings, among others:

18 10 31 39 38 35 31 31 30 36 32 31 30 36 32 37 2e 33

DER encoding. Primitive. Contents octets are as for a primitive BER encoding.

Example: [RFC5280] uses the GeneralizedTime value of "99991231235959Z" to indicate that a certificate has no well-defined expiration date.

This value has the following DER encodings:

18 10 31 39 38 35 31 31 30 36 32 31 30 36 32 37 2e 33

DER encoding. Primitive. Contents octets are as for a primitive BER encoding.

18 0f 39 39 39 39 31 32 33 31 32 33 35 39 35 39 5a

5.20. UTF8String

The UTF8String type supports the encoding of character sets which covers most of the world’s writing systems; see [RFC3629]. This type is a string type.

The UTF8String type is used with many naming attributes in [RFC5280].

ASN.1 notation:

UTF8String

BER encoding. Primitive or constructed. In a primitive encoding, the contents octets give the characters in the UTF-8 string. In a constructed encoding, the contents octets give the concatenation of the BER encodings of consecutive substrings of the UTF-8 string.

Example: The character sequence U+D55C U+AD6D U+C5B4 (Korean "hangugeo", meaning "the Korean language") is encoded in UTF-8, and then this value has the following DER encodings, among others:

0c 09 ed 95 9c ea b5 ad ec 96 b4

6. An example

This section gives an example of ASN.1 notation and DER encoding: the Name type [RFC5280].

6.1. Abstract notation

This section gives the ASN.1 notation for the Name type [RFC5280].

```
Name ::= CHOICE {
  RDNSequence }

RDNSequence ::= SEQUENCE OF RelativeDistinguishedName

RelativeDistinguishedName ::=
  SET OF AttributeValueAssertion

AttributeValueAssertion ::= SEQUENCE {
   AttributeType,
   AttributeValue }

AttributeType ::= OBJECT IDENTIFIER

AttributeValue ::= ANY
```

The Name type identifies an object in an X.500 directory. Name is a CHOICE type consisting of one alternative: RDNSequence. (Future revisions of X.500 may have other alternatives.)

The RDNSequence type gives a path through an X.500 directory tree starting at the root. RDNSequence is a SEQUENCE OF type consisting of zero or more occurrences of RelativeDistinguishedName.

The RelativeDistinguishedName type gives a unique name to an object relative to the object superior to it in the directory tree. RelativeDistinguishedName is a SET OF type consisting of zero or more occurrences of AttributeValueAssertion.

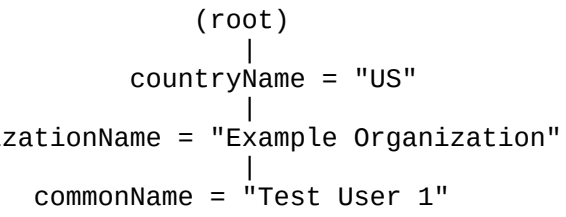
The AttributeValueAssertion type assigns a value to some attribute of a relative distinguished name, such as country name or common name. AttributeValueAssertion is a SEQUENCE type consisting of two components, an AttributeType type and an AttributeValue type.

The AttributeType type identifies an attribute by object identifier. The AttributeValue type gives an arbitrary attribute value. The actual type of the attribute value is determined by the attribute type.

6.2. DER encoding

This section gives an example of a DER encoding of a value of type Name, working from the bottom up.

The name is that of the Test User 1. The name is represented by the following path:



Each level corresponds to one RelativeDistinguishedName value, each of which happens for this name to consist of one AttributeValueAssertion value. The AttributeType value is before the equals sign, and the AttributeValue value (a printable string for the given attribute types) is after the equals sign.

The countryName, organizationName, and commonUnitName are attribute types defined in [RFC5280] as:

```
attributeType OBJECT IDENTIFIER ::= { joint-iso-ccitt(2) ds(5) 4 }

countryName OBJECT IDENTIFIER ::= { attributeType 6 }

organizationName OBJECT IDENTIFIER ::= { attributeType 10 }

commonUnitName OBJECT IDENTIFIER ::= { attributeType 3 }
```

Note: joint-iso-ccitt and joint-iso-itu-t are interchangeable for (2).

6.2.1. AttributeType

The three AttributeType values are OCTET STRING values, so their DER encoding follows the primitive, definite-length method:

```
06 03 55 04 06                                    countryName

06 03 55 04 0a                                organizationName

06 03 55 04 03                                     commonName
```

The identifier octets follow the low-tag form, since the tag is 6 for OBJECT IDENTIFIER. Bits 8 and 7 have value "0," indicating universal class, and bit 6 has value "0," indicating that the encoding is primitive. The length octets follow the short form. The contents octets are the concatenation of three octet strings derived from subidentifiers: 40 * 2 + 5 = 85 = 55 (hexadecimal); 4; and 6, 10, or 3.

6.2.2. AttributeValue

The three AttributeValue values are PrintableString values, so their encodings follow the primitive, definite-length method:

```
13 02 55 53                                                 "US"

13 14                                    "Example Organization"
   45 78 61 6d 70 6c 65 20 4f 72 67 61 6e 69 7a 61
   74 69 6f 6e

13 0b                                                "Test User 1"
   54 65 73 74 20 55 73 65 72 20 31
```

The identifier octets follow the low-tag-number form, since the tag for PrintableString, 19 (decimal), is between 0 and 30. Bits 8 and 7 have value "0" since PrintableString is in the universal class. Bit 6 has value "0" since the encoding is primitive. The length octets follow the short form, and the contents octets are the ASCII representation of the attribute value.

6.2.3. AttributeValueAssertion

The three AttributeValueAssertion values are SEQUENCE values, so their DER encodings follow the constructed, definite-length method:

```
30 09                                       countryName = "US"
   06 03 55 04 06
   13 02 55 53

30 1b              organizationName = "Example Organizaiton"
   06 03 55 04 0a
   13 14 ... 6f 6e

30 12                               commonName = "Test User 1"
   06 03 55 04 0b
   13 0b ... 20 31
```

The identifier octets follow the low-tag-number form, since the tag for SEQUENCE, 16 (decimal), is between 0 and 30. Bits 8 and 7 have value "0" since SEQUENCE is in the universal class. Bit 6 has value "1" since the encoding is constructed. The length octets follow the short form, and the contents octets are the concatenation of the DER encodings of the attributeType and attributeValue components.

6.2.4. RelativeDistinguishedName

The three RelativeDistinguishedName values are SET OF values, so their DER encodings follow the constructed, definite-length method:

```
31 0b
   30 09 ... 55 53

31 1d
   30 1b ... 6f 6e

31 14
   30 12 ... 20 31
```

The identifier octets follow the low-tag-number form, since the tag for SET OF, 17 (decimal), is between 0 and 30. Bits 8 and 7 have value "0" since SET OF is in the universal class Bit 6 has value "1" since the encoding is constructed. The lengths octets follow the short form, and the contents octets are the DER encodings of the respective AttributeValueAssertion values, since there is only one value in each set.

6.2.5. RDNSequence

The RDNSequence value is a SEQUENCE OF value, so its DER encoding follows the constructed, definite-length method:

```
30 42
   31 0b ... 55 53
   31 1d ... 6f 6e
   31 14 ... 20 31
```

The identifier octets follow the low-tag-number form, since the tag for SEQUENCE OF, 16 (decimal), is between 0 and 30. Bits 8 and 7 have value "0" since SEQUENCE OF is in the universal class. Bit 6 has value "1" since the encoding is constructed. The lengths octets follow the short form, and the contents octets are the concatenation of the DER encodings of the three RelativeDistinguishedName values, in order of occurrence.

6.2.6. Name

The Name value is a CHOICE value, so its DER encoding is the same as that of the RDNSequence value:

```
30 42
   31 0b
      30 09
         06 03 55 04 06          attributeType = countryName
         13 02 55 53                   attributeValue = "US"
   31 1d
      30 1b
         06 03 55 04 0a     attributeType = organizationName
         13 14       attributeValue = "Example Organization"
            45 78 61 6d 70 6c 65 20 4f 72 67 61 6e 69 7a 61
            74 69 6f 6e

   31 14
      30 12
         06 03 55 04 03           attributeType = commonName
         13 0b                attributeValue = "Test User 1"
            54 65 73 74 20 55 73 65 72 20 31
```

Which if pretty-printed in strict order would provide an X.500 Name that looked like: countryName=US,organizationName=Example Organization,commonName=Test User 1 Occasionally, just occasionally you will also come across a '+' syntax in X.500 Names so instead the name might look like: countryName=US,organizationName=Example Organization+commonName=Test User 1 This case is interesting, the reason for this being that the '+' means the last two attribute value pairs end up in the same RDN, or more specifically the same SET as can be seen in the encoding below. 30 40 31 0b 30 09 06 03 55 04 06 13 02 55 53 31 31 30 1b 06 03 55 04 0a 0c 14 45 78 61 6d 70 6c 65 20 4f 72 67 61 6e 69 7a 61 74 69 6f 6e 30 12 06 03 55 04 03 0c 0b 54 65 73 74 20 55 73 65 72 20 31 That said, while the above is a correct definite-length encoding for the X.500 name we are looking at, it is not the correct DER encoding for the X.500 name we are looking at as the correct DER encoding looks like: 30 40 31 0b 30 09 06 03 55 04 06 13 02 55 53 31 31 30 12 06 03 55 04 03 0c 0b 54 65 73 74 20 55 73 65 72 20 31 30 1b 06 03 55 04 0a 0c 14 45 78 61 6d 70 6c 65 20 4f 72 67 61 6e 69 7a 61 74 69 6f 6e which, if pretty-printed directly, would give: countryName=US,commonName=Test User 1+organizationName=Example Organization The difference between the two encodings being that the SET has been correctly sorted for DER encoding in the final encoding.

There are a few morals to this particular tale. As you can imagine '+' in an X.500 name is best avoided as sometimes people forget about the sorting or insist on definite-length encoding to preserver order requiring DER encoding to be done every time for signature generation and verification. Ideally if you have to include a '+' (it really does happen) it is also better to write out the X.500 name in DER format at the start, so anyone else trying to verify a signature that might be associated with the use of the name will always get a

correct result. Where it is not possible to write out the X.500 name in DER format, so anyone checking the subsequent encoding will be presented with a definite-length encoding instead, special care must be taken to calculate and evaluate any signatures or MACs based on the name using the DER encoding, rather than the definite-length encoding, otherwise recipients will not be able to verify the data.

One final note, as Name is of type CHOICE, whenever it is tagged it will always encode as explicitly tagged, even if it's in a module with which starts with a definitions block reading "DEFINITIONS IMPLICIT TAGS ::=". This convention is followed as CHOICE encodings need to maintain the original encoding of the ASN.1 primitive, or structure, making up the CHOICE. Overwriting the tag by following the implicit tagging rule could change the meaning of the CHOICE item completely!

7. Useful Links

The following table provides alternate implementations of the DER SET sort for a variety of languages.

Language	Project	Link
C	OpenSSL	https://github.com/openssl/openssl/blob/3206bb708246a97b281133009a419fb7421971d9/crypto/asn1/tasn_enc.c#L399
C#	Bouncy Castle	https://github.com/bcgit/bc-csharp/blob/0c87b54b4b78e95eb80db716e1ac57f2e7875d21/crypto/src/asn1/Asn1Set.cs#L277C38-L277C44
Java	Bouncy Castle	https://github.com/bcgit/bc-java/blob/126ac9e14a0f56fae088973a777f1f90a521fd82/core/src/main/java/org/bouncycastle/asn1/ASN1Set.java#L500
Rust	Rust Crypto	https://github.com/RustCrypto/formats/blob/master/der/src/asn1/set_of.rs#L456

Table 6: Example Implementations of DER SET Sorting.

8. IANA Considerations

This document has no IANA actions.

9. Security Considerations

Security considerations are discussed throughout this memo. Implementations that employ ASN.1 need to take care when parsing and decoding data to avoid buffer overflows, denial of service through resource exhaustion, and arbitrary code execution. These considerations are not unique to ASN.1; they need to be considered by all data parsers and decoders.

In relation to resource exhaustion, while ASN.1 allows for arbitrary nesting of constructed objects and very large lengths of individual data objects, we recommend that limits for both these are enforced appropriate for the use-case the parser, or decoder, is used for. Such limits can provide a useful early warning of corrupted data while also (usually) providing a recoverable situation for the parser, or decoder, encountering the issue.

Implementers of ASN.1 parsers and decoders are encouraged to use fuzz testing to identify security vulnerabilities and other flaws.

10. References

10.1. Normative References

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TODO acknowledge.

Authors’ Addresses

Burton S. Kaliski Jr.
Verisign
12061 Bluemont Way
Reston, VA 20190
United States of America
Email: bkaliski@verisign.com
URI: https://www.verisignlabs.com/

Corey Bonnell
DigiCert, Inc.
United States of America
Email: Corey.Bonnell@digicert.com

David Hook
Keyfactor
Australia
Email: david.hook@keyfactor.com

Russ Housley
Vigil Security, LLC
United States of America
Email: housley@vigilsec.com