

MTAT.07.017

Applied Cryptography

Abstract Syntax Notation One (ASN.1),
Distinguished Encoding Rules (DER)

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Abstract Syntax Notation One

“ASN.1 is a standard interface description language for defining data structures that can be serialized and deserialized in a cross-platform way. It is broadly used in telecommunications and computer networking, and especially in cryptography.”

Notation to describe *abstract* types and values
Describes *information* – not representation

Similar to XML schema, however:

- ASN.1 is rich with built-in data types
- ASN.1 is not tied to a particular encoding mechanism

ASN.1 example

```
-- ASN.1 module
MyQAProtocol DEFINITIONS ::= BEGIN
    MyQuestion ::= SEQUENCE {
        id INTEGER (0..999),
        text UTF8String
    }

    MyAnswer ::= SEQUENCE {
        id INTEGER (0..999),
        text UTF8String
    }
    -- new type defined
END
```

ASN.1 simple types

NULL -- only possible value is Null
BOOLEAN -- True or False
INTEGER -- whole numbers -infinity..+infinity
REAL -- mantissa, base, exponent
OCTET STRING -- values 0x00..0xFF
BIT STRING -- 0-s and 1-s
UTF8String -- UTF-8 characters
NumericString -- [space]0123456789
PrintableString -- printable ASCII chars
IA5String -- ASCII chars 0x00..0x7F
UTCTime -- time in the form 'YYMMDDhhmmssZ'

There are more...

ASN.1 structured types

```
YearInfo ::= SEQUENCE {  
    year      INTEGER (0..9999),  
    isLeapYear BOOLEAN  
}
```

```
Person ::= SET {  
    name      IA5String,  
    age       INTEGER,  
    female    BOOLEAN  
}
```

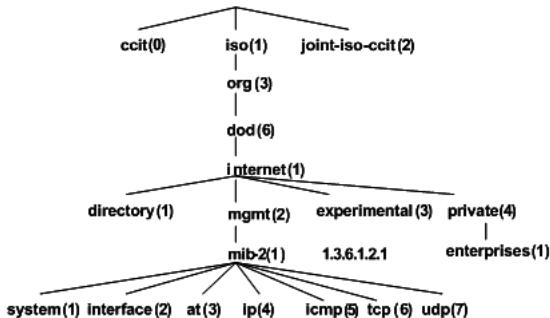
```
Prize ::= CHOICE {  
    car        IA5String,  
    cash       INTEGER,  
    nothing    NULL  
}
```

ASN.1 OBJECT IDENTIFIER

Algorithm ::= OBJECT IDENTIFIER

rsa Algorithm ::= {1.2.840.113549.1.1.1}

OID tree:



iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1) pkcs-1(1) rsaEncryption(1)

<http://oid-info.com>

ASN.1 encodings

```
-- ASN.1 type definition
Question ::= SEQUENCE {
    id INTEGER,
    questionText UTF8String
}
```

How do we encode (serialize) this structure for transmission?

The standard ASN.1 encoding rules:

- Basic Encoding Rules (BER)
- Distinguished Encoding Rules (DER)
- Packed Encoding Rules (PER)
- XML Encoding Rules (XER)
- JSON Encoding Rules (JER)

XML Encoding Rules (XER)

```
-- ASN.1 type definition
Question ::= SEQUENCE {
    id INTEGER,
    questionText UTF8String
}
```

```
<!-- XER-encoded object -->
<Question>
  <id>42</id>
  <questionText>Why is it so?</questionText>
</Question>
```

- Human readable
- Inefficient encoding
- Canonicalization needed

Distinguished Encoding Rules (DER)

- Efficient encoding
- A value can be encoded only in a single way
- Data is encoded as Type-Length-Value (TLV) element:

```
message UTF8String :: = "Hello"
```

Type: UTF8String

Length: 5 bytes

Value: "Hello"

DER encoded:

```
[0x0c] [0x05] [0x48 0x65 0x6c 0x6c 0x6f]
```

```
$ echo -e -n "\x0c\x05Hello" > hello.der
```

```
$ sudo apt install dumpasn1
```

```
$ dumpasn1 hello.der
```

```
0    5: UTF8String 'Hello'
```



Task: ASN.1 DER encoder

Implement ASN.1 DER encoder that can encode subset of ASN.1 types by implementing these functions:

```
def asn1_boolean(boolean):  
def asn1_integer(i):  
def asn1_bitstring(bitstr):  
def asn1_octetstring(octets):  
def asn1_null():  
def asn1_objectidentifier(oid):  
def asn1_sequence(der):  
def asn1_set(der):  
def asn1_utf8string(utf8bytes):  
def asn1_utctime(time):  
def asn1_tag_explicit(der, tag):  
def asn1_len(content): <-- helper function
```

Task: ASN.1 DER encoder

And encodes this artificial ASN.1 structure (test case):

```
$ dumpasn1 asn1.der
0 114: [0] { explicit tags
```

*NB! dumpasn1 fails to decode negative integers
and outputs bitstrings in reverse order.*

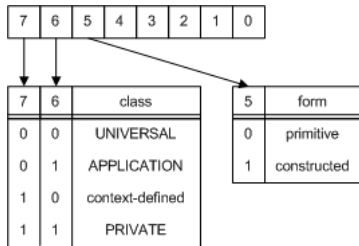
```
 2 112: SEQUENCE {
 4 16: SET {
 6 1: INTEGER 5
 9 4: [2] {
11 2: INTEGER 200
   : }
15 5: [11] {
17 3: INTEGER 65407
   : }
   : }
22 1: BOOLEAN TRUE
25 2: BIT STRING 5 unused bits
   : '110'B
29 51: OCTET STRING
   : 00 01 02 02 02 02 02 02 02 02 02 02 02 02 02
   : 02 02 02 02 02 02 02 02 02 02 02 02 02 02 02
   : 02 02 02 02 02 02 02 02 02 02 02 02 02 02 02
   : 02 02 02
82 0: NULL
84 7: OBJECT IDENTIFIER '1 2 840 113549 1'
93 6: UTF8String 'hello.'
101 13: UTCTime 23/02/2025 01:09:00 GMT
   : }
   : }
```

```
0 warnings, 0 errors.
```

```
asn1_tag_explicit(asn1_sequence(asn1_set(...)+asn1_boolean(true)+...), 0)
```

```
$ ./asn1_encoder.py asn1.der
```

Type-Length-Value: Type



Universal tags (Bits 4,3,2,1,0):

00001 (1) - BOOLEAN
00010 (2) - INTEGER
00011 (3) - BIT STRING
00100 (4) - OCTET STRING
00101 (5) - NULL
00110 (6) - OBJECT IDENTIFIER
01010 (10) - ENUMERATED
01100 (12) - UTF8String
10000 (16) - SEQUENCE
10001 (17) - SET
10011 (19) - PrintableString
10111 (23) - UTCTime

...

0x0c – 00 0 01100 (universal, primitive, UTF8String)

More on ASN.1 and DER:

<https://letsencrypt.org/docs/a-warm-welcome-to-asn1-and-der/>

<https://luca.ntop.org/Teaching/Appunti/asn1.html>

<https://www.itu.int/ITU-T/studygroups/com17/languages/X.690-0207.pdf>

Type-Length-Value: Length

- `asn1_len(value_bytes)`:
 - If the number of value bytes is < 128 then the length byte encodes the number of bytes in the value
 - Else the most significant bit of the first length byte is set to 1 and the remaining 7 bits encode the number of length bytes that follow
 - The following length bytes encode the number of value bytes (use `ib()` without the `length` parameter)

Example:

Length 126: 01111110

Length 127: 01111111

Length 128: 10000001 10000000

Length 1027: 10000010 00000100 00000011

(4 $\ll$ 8) | 3

= 1027

ASN.1 DER encoding

- `asn1_boolean(boolean)`:
 - Encodes a boolean value
 - Universal, primitive, tag 1 (00 0 00001)
 - Value byte contains 0x00 for FALSE and 0xff for TRUE
- `asn1_integer(int)`:
 - Encodes an integer (only positive integers must be supported)
 - Universal, primitive, tag 2
 - Two's complement integer encoding:
 - Convert integer to bytestring using `ib()` without the `length` parameter
 - If the most significant bit of the MSB for a positive integer is 1 then prepend zero (0x00) byte
 - Integer value 0 is encoded as zero byte (not empty bytestring)

INTEGER: 140

DER: 00000010	00000010	00000000	10001100
Type	Length	Padding	Integer

250,000 Estonian ID cards could be faulty

<https://news.err.ee/116849/250-000-estonian-id-cards-could-be-faulty>



A coding mistake made by the Certification Center, the company behind the software of ID cards, means 250,000 ID cards could cause problems for users in the future.

The problem concerns Estonian ID cards issued between September 2014 and September 2015, and if not fixed, will mean users will be unable to use ID cards with the new version of the Google Chrome browser.

“We let a fault slip through our software development process,” told the head of company.

The problem surfaced when Google worked out a new version of Chrome, which has more detailed checks.

ASN.1 DER encoding

- `asn1_bitstring(str_of_bits)`:
 - Encodes an arbitrary bitstring value (e.g. '010101')
 - Universal, primitive, tag 3
 - Bitstring is right-padded with zero bits to form a full byte string
 - The first byte of value bytes encodes the number of padding bits

BIT STRING: 010101

DER: 00000011 00000010 00000010 01010100

 Type Length Padding-length Padded-bitstring

- `asn1_octetstring(bytes)`:
 - Encodes an arbitrary string of octets
 - Universal, primitive, tag 4
- `asn1_null()`:
 - Encodes a null value
 - Universal, primitive, tag 5
 - No value bytes

ASN.1 DER encoding

- `asn1_objectidentifier(list_of_oid_components):`
 - Encodes an object identifier, which is a sequence of integer components
 - Universal, primitive, tag 6
 - The first value byte has value: $40 * \text{comp1} + \text{comp2}$
 - The following value bytes encode `comp3`, `comp4`, ...
 - Each component is encoded using the 7 right-most bits of the bytes
 - Each byte's left-most bit (except for the last) is 1

Example:

OBJECT IDENTIFIER: 1.2.840 (US (ANSII))

0000 0110	0000 0011	0010 1010	1 0000110	0 1001000
Type	Length	$40*1+2$	6	72
			$(6 \ll 7) \mid 72 = 840$	

- `asn1_sequence(der_bytes):`
 - Encodes an ordered collection of one or more types
 - Universal, **constructed**, tag 16
 - Value bytes contain DER encoded data

ASN.1 DER encoding

- `asn1_set(der_bytes):`
 - Encodes an unordered collection of one or more types
 - Universal, **constructed**, tag 17
 - Value bytes contain DER encoded data
- `asn1_utf8string(utf8bytes):`
 - Encodes UTF-8 encoded Unicode characters
 - Universal, primitive, tag 12
 - Value bytes contain UTF-8 encoded characters
- `asn1_utctime(date_str):`
 - Encodes “coordinated universal time”
 - Universal, primitive, tag 23
 - Value bytes contain string representation of time in the form “YYMMDDhhmmssZ”

ASN.1 Tagging

ASN.1 notation may be ambiguous:

```
Ambiguous ::= SEQUENCE {  
    value1 INTEGER OPTIONAL,  
    value2 INTEGER OPTIONAL  
}
```

Unable to decode if encoded structure contains only one value!

Fix is to tag the values:

```
unambiguous ::= SEQUENCE {  
    value1 [1] IMPLICIT INTEGER OPTIONAL,  
    value2 [2] EXPLICIT INTEGER OPTIONAL  
}
```

- IMPLICIT overwrites the existing TLV type byte
- EXPLICIT prepends type and length bytes (encapsulates original TLV)

ASN.1 DER encoding

- `asn1_tag_explicit(der, tag):`
 - Tags/encapsulates any data type
 - **Context-defined, constructed**, tag n (5 right-most bits)
 - No need to implement support for tag > 30
 - Value bytes contain DER-encoded data

```
>>> asn1 = asn1_tag_explicit(asn1_sequence(asn1_null()), 5)
>>> open('asn1.der', 'wb').write(asn1)
```

```
$ dumpasn1 asn1.der
0  4: [5] {
2  2:  SEQUENCE {
4  0:  NULL
   :  }
   :  }
```

Banned functions

Your solution must **not** use:

- functions: `bin()`, `hex()`, `str()`, `int()`, `bytearray()`, `divmod()`
- exponentiation: `**`, `pow()`
- division and modulus: `/`, `%` (unless needed for computing bitstring padding size)

Use bitwise operations as much as possible!

For example, to convert `str` containing bit representation to `int`:

```
i = 0
for bit in '010001':
    i<<=1
    if bit=='1':
        i|= 1
```

As a general rule for all homework tasks: encoding values to “bin” and “hex” representation is only allowed for printing out non-printable binary data.