Challenges and Possibilities for Safe and Secure ASN.1 Encoders and Decoders

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Outline

About This Talk

- Primarily a "position paper" : *Secure ASN.1 IMHO*

- For technical details, see our CAV 2018 paper
  - *Formal Verification of a Vehicle-to-Vehicle (V2V) Messaging System*

What is ASN.1?

- ASN.1 is *not*
  - a format
  - a single specification
  - a library (that we can implement once)
- ASN.1 is
  - a language by which we define hundreds of protocols and data-formats!

The Importance (& Risks) of ASN.1

- ASN.1 pervasive
- Decoding ASN.1-defined messages: definitely on the *attack surface*

ASN.1 is Abstract

ASN.1 does not limit us to

- a single implementation language
- nor to a single de facto representation of the "abstract" values

```
T ::= SEQUENCE (SIZE(1..4)) OF INTEGER
```

One may have different *concrete* values/representations:

```
typedef int T[4];     // probably not if SIℤE(1..10000)
typedef int *T;       // length elsewhere, or special encode of "last"
typedef struct node *T;  // i.e., a linked-list
```

ASN.1 is Highly Expressive (for describing data)

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```
Address::= SEQUENCE {
  street          VisibleString (SIℤE (5 .. 50)) OPTIONAL,
  city            VisibleString (SIℤE (2..30)),
  state           VisibleString (SIℤE(2) ^ FROM ("A".."ℤ")),
  zipCode         NumericString (SIℤE(5 | 9))
}
ListOfItems ::= SEQUENCE (SIℤE (1..100)) OF Item
Item ::= SEQUENCE {
  itemCode      INTEGER (1..99999),
  power         INTEGER (110 | 220),
  deliveryTime  INTEGER (8..12 | 14..19),
  isTaxable     BOOLEAN
}
```

ASN.1 is Compositional

I.e., we can compose small data definitions to create larger ones.

- Has a real module system.
- Can refer to modules outside the current system.
- Can embed data of undetermined types, safely and sanely.
  - With Information Objects . . . even more elegantly

ASN.1 is Versatile: Multiple Encoding Schemes

- Allows for a variety of encoding methods, each specified separately from the definition of abstract values.
- E.g., Basic Encoding Rules (BER), Distinguished Encoding Rules (DER), XML Encoding Rules (XER), Canonical XML Encoding Rules (CXER), Packed Encoding Rules (PER, unaligned: UPER, canonical: CPER, canonical unaligned: CUPER), Octet Encoding Rules (OER, canonical: COER), etc.

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- Self-describing: BER, DER, etc.
- Highly bit-efficient: *OER, *PER (must know ASN.1 type to decode)
- *Canonical* signifies that a given value has only a single valid encoding
  - E.g., for X.509, DER is used (canonical)

ASN.1 is Extensible: Features for Protocol Evolution

- Provides mechanisms for extensibility to allow protocols and formats to evolve gracefully.

```
MyCoffeeShopMenu ::=
  SEQUENCE { coffee   Price,
             tea      Price,
             ...!1,            -- extensible, exception-marker!
             [[ sandwich Price,     -- Version2
                dessert Price ]]
           }
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- This data specification
  - marked as extensible
  - has evolved
- The bits on the wire indicate if the data is in the base or extension
  - Thus, *Version1* encoders/decoders work on *Version2* data.

Obstacles to Secure ASN.1

Following Frederick Brooks—and Aristotle—in the use of these terms:

- Obstacles, *Essential* (intrinsic, "of the essence")
- Obstacles, *Accidental* (historical, poor design, etc.)

Essential Obstacles

- The *Five Things to Like* each creates some degree of
  - complexity in the ASN.1 definition language itself
  - non-trivial learning curve for users and implementers
  - complexity for an ASN.1 compiler
  - complexity in (and multiplicity of) the encode/decode routines
  - etc.
- Thus, a large effort to fully support the language
  - Unsurprisingly, fully compliant compilers are expensive & proprietary
- There *will* be a loss of abstraction in the concrete types: room for errors in the interfacing code. (The cost of *Things to Like* 1, 2, 5.)
- With new & improved (bit-efficient) encoding schemes (PER, UPER, OER, etc.),
  - Previous—and simpler—library-based solutions inadequate
  - Compiler that uses global knowledge and "constraint solving": recommended!

Accidental Obstacles

- Evolutionary artifacts
  - Complicate the language
  - Force us to support old features and old specs
  - E.g.,
    - explicit TAGs / AUTOMATIC TAGS
    - newer encoding schemes that *fix* old ones
    - methods to encode unknowns or parameters
- Over-complexity
  - Information Objects
  - Encoding scheme details
    - e.g., long tags vs. long lengths vs. long values
    - Many closely related encoding schemes (is there a canonical encoding or not)
  - The ASN.1 Language itself
    - Literally thousands of grammar rules to parse the language.

The Unfortunate Outcome

- ASN.1's complex and evolving language features, as well as its complex and evolving encoding schemes, together
  - hinder adoption
  - increase the complexity of tools & compilers,
  - and necessitate large and complex encoder/decoder implementations.

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- None of which bode well for the task of creating robust & secure implementations.

The Goal

… creating robust & secure[1] encoder/decoder implementations.

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With *very high assurance*.

Provably secure?

With reasonable effort?

[1] secure: absence of software flaws

Generating Good Code?

- Roll your own ASN.1 encoder/decoder
  - Possible!
  - Isn't ASN.1 simple stuff: *just* serializing/deserializing?
- Open source compilers
  - Limited in features and support.
  - E.g., code *definitely* not optimized for clarity/verification
- Commercial compilers
  - Objective Systems compiler "bad memory bug"
  - Library flaws
    - Exploitable flaw in MS Windows library for years

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None of these can *guarantee* security.

Secure Code via Testing?

- Extensive testing
  - incomplete!
  - intelligent, expert, human testing: good idea

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- "Exhaustive Testing"?
  - Given this decode function with execution time of 1ms:

```
bool decode( uint64_t x, uint64_t y, uint64_t z) { .. }
```

  - Time to exhaustively test: 2×10^{47} years

Secure Code by Construction

- Develop a fully-compliant (open-source) ASN.1 compiler.
  - Make it a verified compiler
    - Remember to verify the libraries, ;-)
  - Make it certifying (generating proof of correctness/safety)

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- Immensely Large Effort

Secure Code by . . . Divide and Conquer? (1)

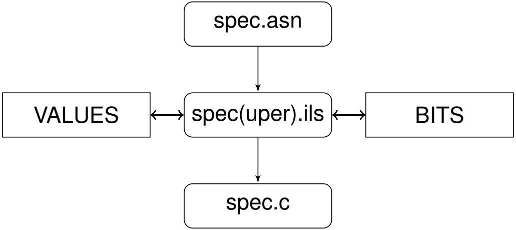
In order to reduce trusted computing base . . .

- Full ASN.1 to ASN.1-lite transformation tool.
    - Possibly remove 80% of the complexity of ASN.1
    - Allow for use of simpler, open-source ASN.1 tools/compilers
    - Much of the complexity of ASN.1 "goes away" in compilation.

Secure Code by . . . Divide and Conquer? (2)

Another approach to avoiding giant monolithic proofs . . .

- Use an Intermediate Language For Serialization (ILS)?
  - Just powerful enough to describe BER, DER, UPER, OER
  - TODO: What are the *key* primitives and combinators needed?



- Assurance & Verification?
  - can verify the parts separately!

Secure Code by Post-Hoc Verification

- For a given encode/decode pair on a given spec:
  - Formally verify encoder/decoder code
- However
  - Expertise? Effort?!
  - Every spec or code update requires redoing verification.
- What might we verify?
  - Full verification WRT ASN.1 semantics: highly infeasible
  - Verify encode/decode consistency (round trip property): feasible
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- We've done this: A *formal* verification of 1K+ lines of C
  - Basic Safety Message in V2V (part one, a subset of ASN.1)
  - Refer to our CAV 2018 paper

Secure Code by Intelligent Consensus Testing

Question: Are implementations A, B, C equivalent?

Method

1. Create intelligent test-generation capabilities
   - legal *and* illegal values
   - quickcheck/smallcheck like test generation (not just generating every number in `INTEGER(1..1000000)`)
2. Create the glue code to run tests on each implementation
   - Non-trivial: Every compiler (or library) has a different API for creating values, encoding, and decoding!
3. For each test, verify all implementations match.

Secure Code by Post-Hoc Verification

- Done
  - Accomplished verification of code for V2V Basic Safety Message (J2735.asn)
  - The *automatic* verification needed a bit of expert assistance
    - i.e., providing lemmas to allow SAW to terminate
  - Doesn't support all ASN.1 constructs
- Next Steps
  - Get the verification "automated"
    - generate lemmas/hints for SAW when we generate the C code
  - Support more ASN.1 features
- Future Goal
  - Given any ASN.1 specification, generate valid C code and sufficient lemmas/hints to *ensure* SAW will terminate.

Secure Code by Intelligent Consensus Testing

(New work the DOT is funding us to do.)

- Question: Are implementations A, B, C equivalent?
- Method
  1. Create intelligent test-generation capabilities
  2. Create the glue code to run tests on each implementation
     - Research: capture the commonality in a DSL
  3. For each test, verify all implementations match.
- Status
  - In progress.
  - Goal: consensus among 2-3, eventually . . .
  - Developing something like ILS so as to get results that apply to multiple encoding schemes.

Questions?

Back Up Slides:

Approach One: Abandon Ship?

- Forgo ASN.1: roll your own (or pick some trendy) data serializer/deserializer
  - E.g., protocol buffers, json, avro(json), xml(..), etc, etc.
- Nice
  - Could reduce the complexity issues
  - Relevant for a new, not-wanting-to-play-with-others format

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- But generally these
  - lack most of our *Five Things to Like*
  - have no separable "specification" of the data
    - are not primarily a data description language
  - are tied to implementation(s)
    - is there a *specification* for the encoding?
- And
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- And
  - we still have the verification effort,
  - can we just stop re-inventing the wheel!
    - we could be using and contributing to the library of ASN.1 defined formats