IETF 123
CBOR side meeting
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A Formal Model and Verified Implementation for CBOR, CDDL and COSE

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Verified End-to-End Secure Transport

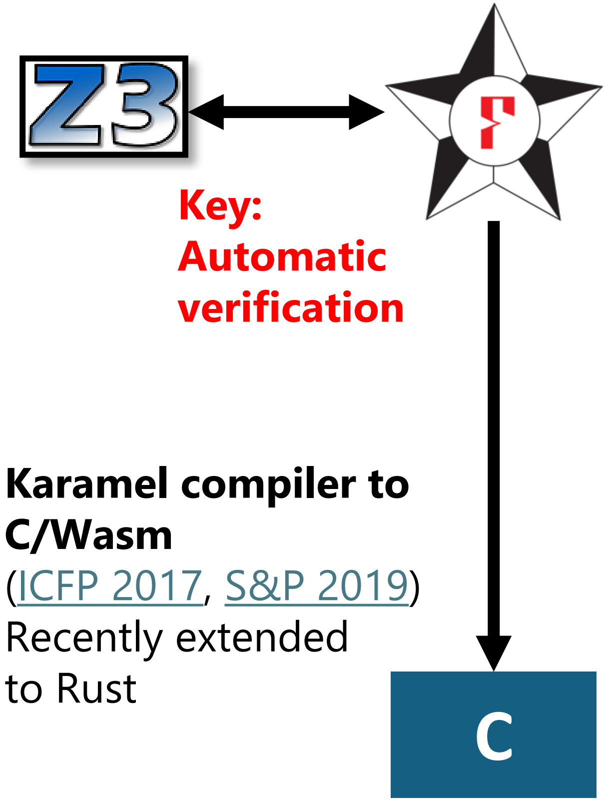
Overview

- EverCBOR: Verified parser and serializer for CBOR
  - Written and proven correct in F*
  - Extracts to C or Rust

- EverCDDL: Verified code generator for CDDL
  - Written and proven correct in F*
  - User provides a CDDL data format description
  - EverCDDL generates C or Rust:
    - Datatype
    - Parser
    - Serializer
  - Enough for COSE and other protocols

- ACM CCS 2025 (accepted for publication, to appear)
- Open-source: https://github.com/project-everest/everparse

Our Vehicle: F*, a proof-oriented language for verified low-level programming



Key: Automatic verification

F* implementation and specification

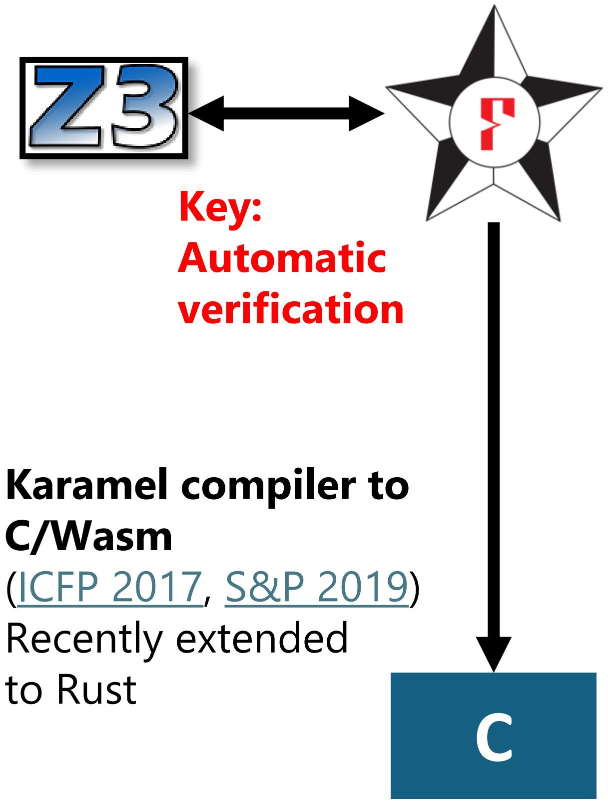
```
let multiply_by_9 (a:uint32) : Pure uint32
  (requires 9 * a <= MAX_UINT_32)
  (ensures λ result -> result == 9 * a)
  =
  let b = a << 3ul in
  a + b
```

Karamel compiler to C/Wasm
(ICFP 2017, S&P 2019)
Recently extended to Rust

Efficient C/Wasm/Rust implementation
Verification imposes no runtime performance overhead

```
uint32_t multiply_by_9(uint32_t a)
{
  uint32_t b = a << (uint32_t)3;
  return a + b;
}
```

Our Vehicle: F*, a proof-oriented language for verified low-level programming



Key: Automatic verification

Karamel compiler to C/Wasm
(ICFP 2017, S&P 2019)
Recently extended to Rust

Implementation in the Pulse DSL embedded in F* **and specification** using separation logic (PLDI 2025)

```
fn inc (r: ref uint32_t)
  (requires r |-> ‘vr * pure (vr + 2 <= MAX_UINT_32))
  (ensures r |-> (‘vr + 2))
{
  let v = !r;
  r := v + 2
}
```

Efficient C/Wasm/Rust implementation
Verification imposes no runtime performance overhead

```
void inc(uint32_t *r)
{
  uint32_t v = *r;
  *r = v + 2;
}
```

Proof-Oriented Programming At Scale

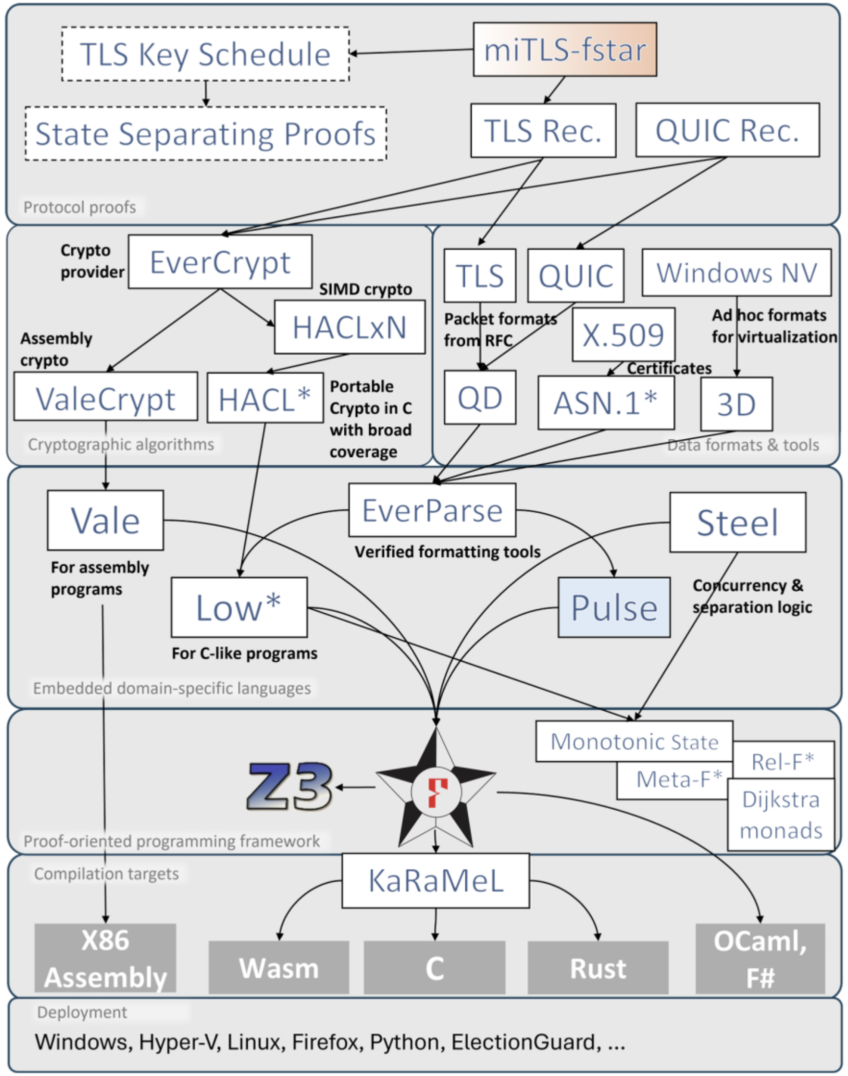
Project Everest (2016-2021)

- ~1 million lines of F* code
- Cryptography, verified parsers, …
- Deployed in Linux, Firefox, Python, Windows, Azure, …
- https://project-everest.github.io/

Everest offspring (including F*, EverParse) grown up as active standalone projects

EverCBOR, EverCDDL are part of EverParse

- Broader talk at UFMRG on Thursday 7/24



EverCBOR Formal Guarantees

- Specification
  - Non-ambiguity: serialization parses back to the same CBOR object
  - CBOR§4.2 is non-malleable: unique binary representation
- Implementation
  - Memory-safe, absence of panics or integer overflows/underflows
  - Functionally correct wrt. specification

EverCBOR implementation

- Definite-length
- Current status
  - Deterministic encoding (CBOR§4.2)
  - No support for floating-point

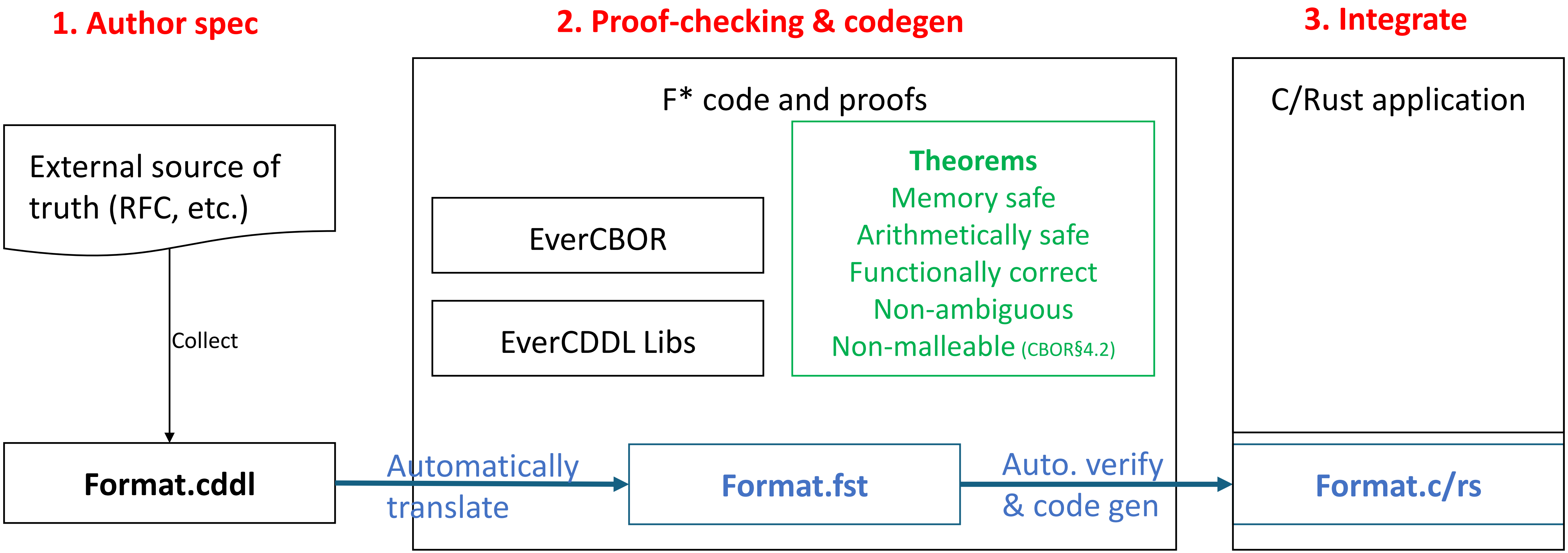
- No heap allocation

- API: constructor and destructor functions
  - Constructor for maps takes mutable map entry array, reorders it wrt. deterministic encoding *before* serialization
  - Sorting at the level of objects instead of bytes

EverCBOR implementation

- Validator
  - CBOR§4.2 validation in constant stack space
  - Definite-length validation in constant stack space if no maps in map keys
  - Unbounded stack in general
- Parser provides iterators for arrays and maps
- Serializer
  - Stack consumption linear in the nesting level
  - No further need for map sorting, since ordering maintained within the item

EverCDDL


1. Author spec
2. Proof-checking & codegen
3. Integrate
External source of truth (RFC, etc.)
Collect
Format.cddl
Automatically translate
F* code and proofs
EverCBOR
EverCDDL Libs
Theorems
Memory safe
Arithmetically safe
Functionally correct
Non-ambiguous
Non-malleable (CBOR§4.2)
Format.fst
Auto. verify & code gen
C/Rust application
Format.c/rs

EverCDDL Formal Guarantees

- Specification
  - Non-ambiguity: serialization parses back to the same value
  - Unique CBOR object representation
  - Translates to non-malleability (unique binary representation) with CBOR§4.2
- Generated code
  - Memory-safe, absence of panics or integer overflows/underflows
  - Functionally correct

EverCDDL Implementation

- Generates:
  - program datatypes
  - parsers from CBOR objects to program datatype values
  - serializers from program datatype values directly to bytes
  - Currently serializes to CBOR§4.2
- Produces correct-by-construction F* code that extracts to C or Rust
- Enough for most COSE data structures from RFC 9052

EverCDDL: Validation and Parsing

Given a CDDL description:

- Validation: is a CBOR object valid with respect to that description?
- Parsing:
  - Generate a C/Rust datatype
  - Given a CBOR object valid wrt. that description, extract its fields into a value of that datatype
  - Generate iterators for arrays/tables
  - No heap allocation

EverCDDL: Serialization

Given a CDDL description:

- Given a value of the datatype generated by EverCDDL, write the deterministic encoding of the CBOR object that will parse back to that value
- Gracefully fails if it is not serializable:
  - Array/map sizes must be less than 2^64
  - Integer range / string size constraints must hold
  - A table must not contain entries whose keys match previous items
  - The output buffer must be large enough

EverCDDL: Serialization

- No additional heap allocation
  - Additional stack usage linear in the size of the spec, not the input
  - Write array/map entries, then shift to write the size
- For each map entry append, insertion sort with 1 swap
  - Establishes and maintains the order
  - Automatically detects duplicates

EverCBOR, EverCDDL Benchmarks

	EverCDDL		QCBOR		TinyCBOR	
	V/P	S	V/P	S	V/P	S
Rec (μs)	3.33	.57	1.91	.23	3.78	.29
Map (μs)	138		282		306	
Arr (s)	2.67/4.92	2.06	2.92/2.91	0.75	2.68/2.68	1.23

Table 1. Synthetic benchmarks for EverCDDL, QCBOR and TinyCBOR. Values are time (for Rec, for **V**alidation plus **P**arsing, or **S**erialization), lookup time (for Map), or time (for Arr).We distinguish validation from parsing in Arr, since iteration is involved.

- Results on Intel Xeon W-2255 with gcc 11.4 -O3
- Also: We pass the deterministic encoding test cases

EverCDDL for COSE

	C API & OpenSSL	Pulse API & HACL*
COSE_sign	39.0 μs/iter	53.3 μs/iter
COSE_verify	99.6 μs/iter	58.2 μs/iter
Ed25519_sign	36.8 μs/iter	51.9 μs/iter
Ed25519_verify	96.7 μs/iter	57.3 μs/iter
parse(Sign1)	2.4 μs/iter	
ser(Sign1)	1.0 μs/iter	
ser(Sig_structure)	1.0 μs/iter	

Table 2. Benchmarking results of our EverCDDL-based COSE signature implementation. We sign and verify a message with an 896 byte long payload using Ed25519. The benchmarks were compiled with clang 19.1.7 (-O3) and run on an Intel Xeon W-2255 CPU.

- We interoperate with pycose

EverCDDL Applicability (IETF 123 Hackathon)

- We support most of:
  - COSE (RFC 9052)
  - CWT, EAT (RFC 9711)
  - draft-ietf-ace-edhoc-oscore-profile-08
  - draft-ietf-core-href-23
  - draft-ietf-core-observe-multicast-notifications-12
  - …
- Some manual rewrites due to currently unsupported features:
  - Syntactic transformations: ~, &
  - JC<_, _>, CBOR_ONLY<_>, other generics
  - Occurrence bounds
  - Disable floating-point
  - Unfold bounded recursion in COSE

No support for recursive CDDL descriptions

- May cause unbounded stack consumption during validation

- COSE (RFC 9052): COSE-Recipients
  - Bounded by 3 in Appendix B
  - Unfolded by hand
  - Maybe “tail-recursive”? Hard to generalize

- EAT (RFC 9711): nested Claims-Set
  - Nested tokens
  - Submodules

Some potential inaccuracies in existing CDDL descriptions?

```
header_map = {
  ?      1 => int / tstr,   ; algorithm identifier
  ?      2 => [+label],     ; criticality
  ?      3 => tstr / int,   ; content type
  ?      4 => bstr,         ; key identifier
  ?   ( 5 => bstr //        ; IV
        6 => bstr ),        ; Partial IV
  * label => values
}
```

- Missing cuts next to extension tables
  - COSE header_map
  - EDHOC_Information
  - DPE (DICE Protection Environment, Trusted Computing Group)
  - …
- PEG interpretation
  - COSE Sig_structure, etc.
- Some constraints can be added but are not
  - COSE header_map entries for keys 5 and 6 cannot appear together

Missing CDDL cuts in the wild

- COSE header_map

```
header_map = {
  ?      1 => int / tstr,   ; algorithm identifier
  ?      2 => [+label],     ; criticality
  ?      3 => tstr / int,   ; content type
  ?      4 => bstr,         ; key identifier
  ?    ( 5 => bstr //       ; IV
         6 => bstr ),       ; Partial IV
  * label => values
}
```

- Also: EDHOC_Information, etc.

Missing CDDL cuts in the wild

- COSE header_map

These should be cuts

: or ^=>

```
header_map = {
  ?      1 => int / tstr,   ; algorithm identifier
  ?      2 => [+label],     ; criticality
  ?      3 => tstr / int,   ; content type
  ?      4 => bstr,         ; key identifier
  ?    ( 5 => bstr //       ; IV
         6 => bstr ),       ; Partial IV
  * label => values
}
```

- Also: EDHOC_Information, etc.

CDDL is PEG

- Occurrence operators ?, * should be interpreted in a greedy way without backtracking
- COSE Sig_structure etc.

```
empty_or_serialized_map = bstr .cbor header_map / bstr .size 0
```

```
Sig_structure = [
    context : "Signature" / "Signature1",
    body_protected : empty_or_serialized_map,
    ? sign_protected : empty_or_serialized_map,
    external_aad : bstr,
    payload : bstr
]
```

CDDL is PEG

- Occurrence operators ?, * should be interpreted in a greedy way without backtracking
- COSE Sig_structure etc.

```
empty_or_serialized_map = bstr .cbor header_map / bstr .size 0
```

```
Sig_structure = [
    context : "Signature" / "Signature1",
    body_protected : empty_or_serialized_map,
    (
      sign_protected : empty_or_serialized_map,
      external_aad : bstr,
      payload : bstr
    ) // (
      external_aad : bstr,
      payload : bstr
    )
]
```

EverCBOR, EverCDDL Takeaways

- Interoperable, reasonable implementations with strong formal guarantees
  - No need to hand-write parsers/serializers for CDDL-defined formats anymore

- Improved understanding of the CBOR deterministic encoding and of CDDL

- Clarification may be needed in CDDL descriptions in some existing standards
  - For use with EverCDDL and other automated code generators

- https://github.com/project-everest/everparse
- Tahina Ramananandro, taramana@microsoft.com