Specification-Based Verification and Testing of Internet Protocols

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Summary

A research project funded by NICT
From October 2010 to March 2013
(Jointly with Lepidum, Inc.)

Objective:

Design a methodology to certify implementation of Internet protocols

Leader:

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AIST Participants:

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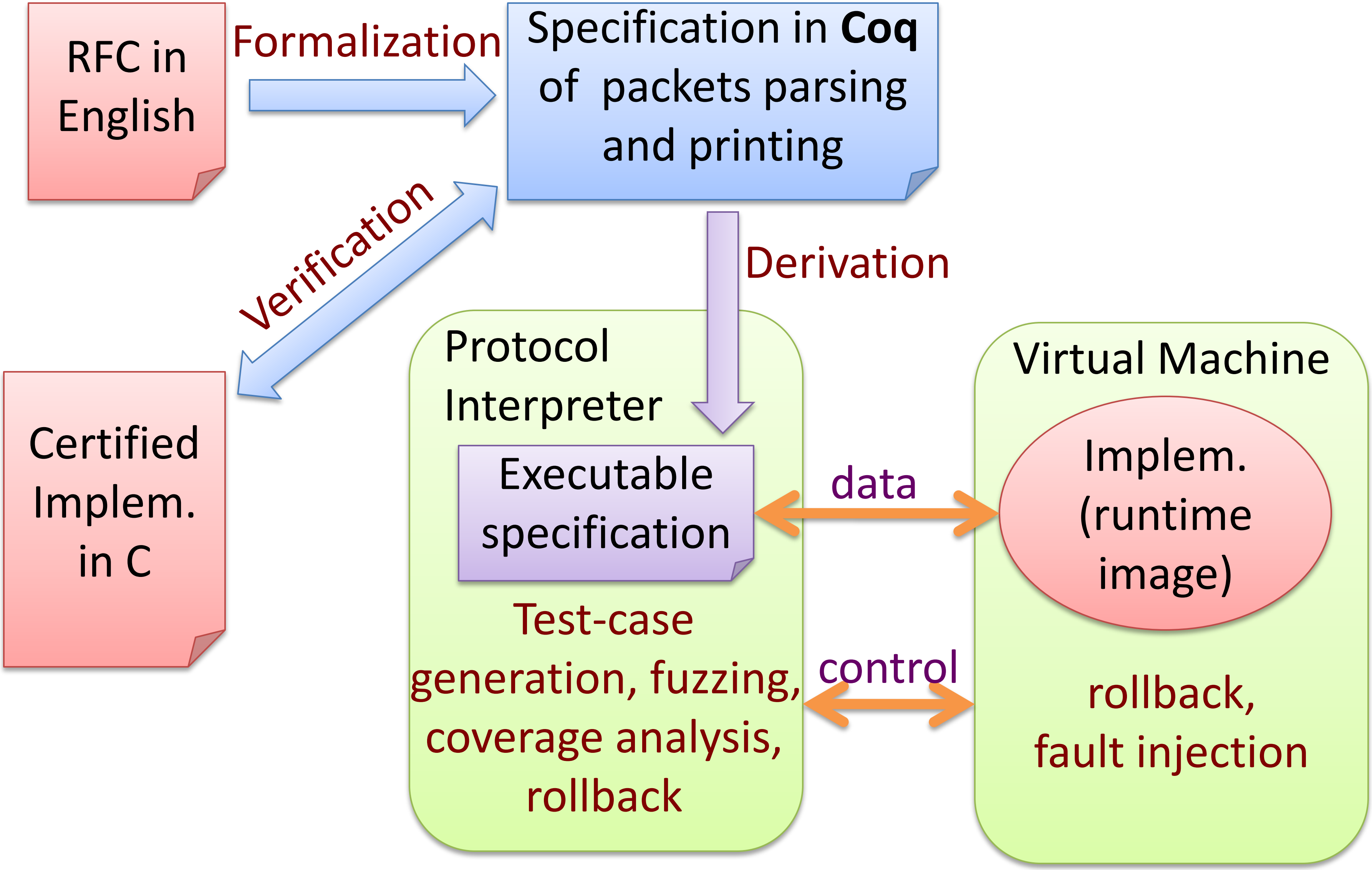
- Kuniyasu Suzaki (AIST)

Complementarity of formal verification and testing

We combine theorem proving and testing.

	Proof Assistant	Model checking	Testing
Technique	Mathematical proof	Abstraction, State-space exploration	Sampling
Result	Correctness proof	Correctness proof, Bug discovery	Bug discovery
Object	Source code	Abstracted source code	Runtime behavior
Scalability	Low	Medium	High
Expressivity	High (Higher-order logic)	Low (Temporal logic)	Medium

Overview of the project



RFC in English

Formalization

Specification in **Coq** of packets parsing and printing

Verification

Certified Implem. in C

Derivation

Protocol Interpreter

Executable specification

Test-case generation, fuzzing, coverage analysis, rollback

data

control

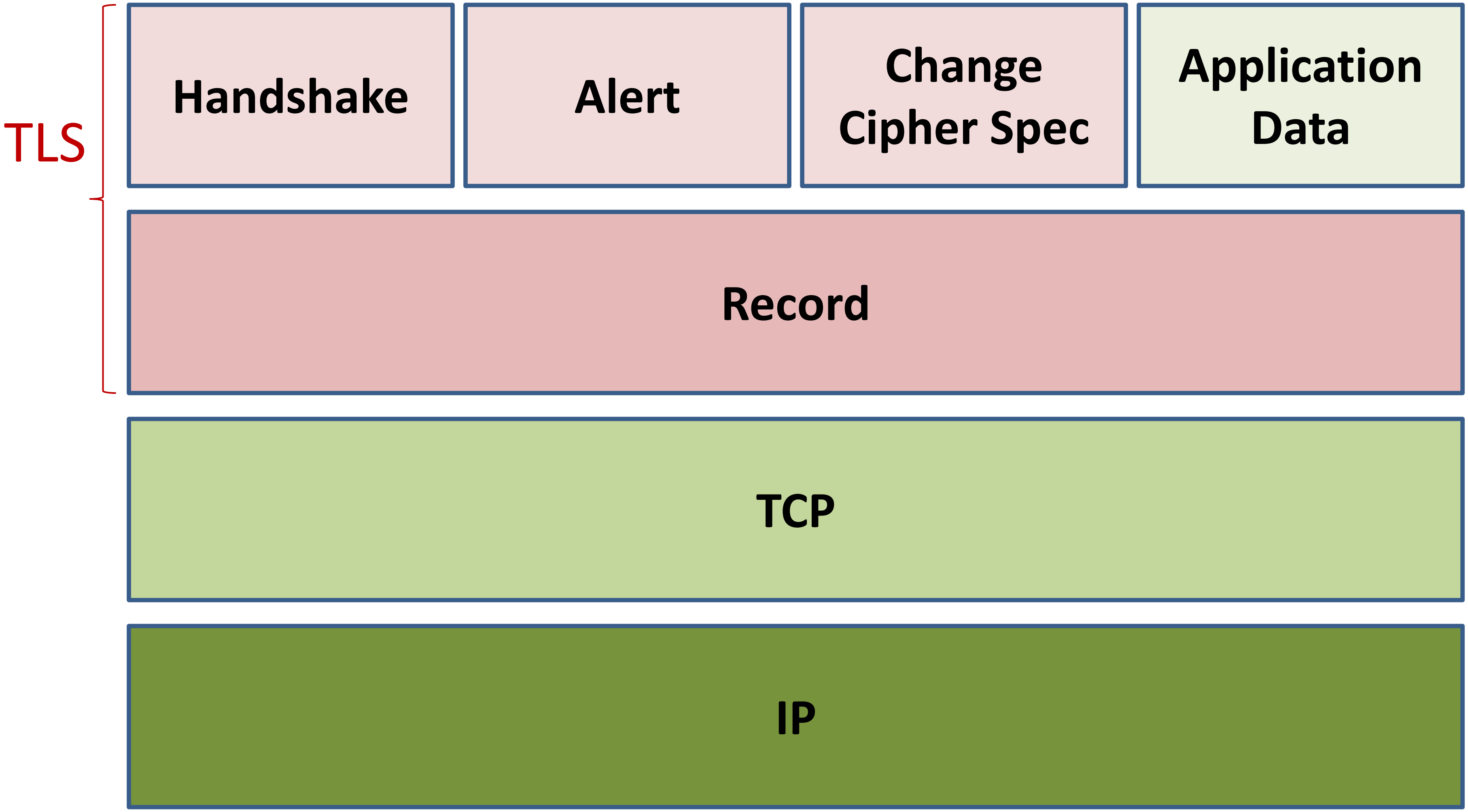
Virtual Machine

Implem. (runtime image)

rollback, fault injection

Case study: TLS

A cryptographic layer on top of existing communication protocols


TLS

Handshake

Alert

Change Cipher Spec

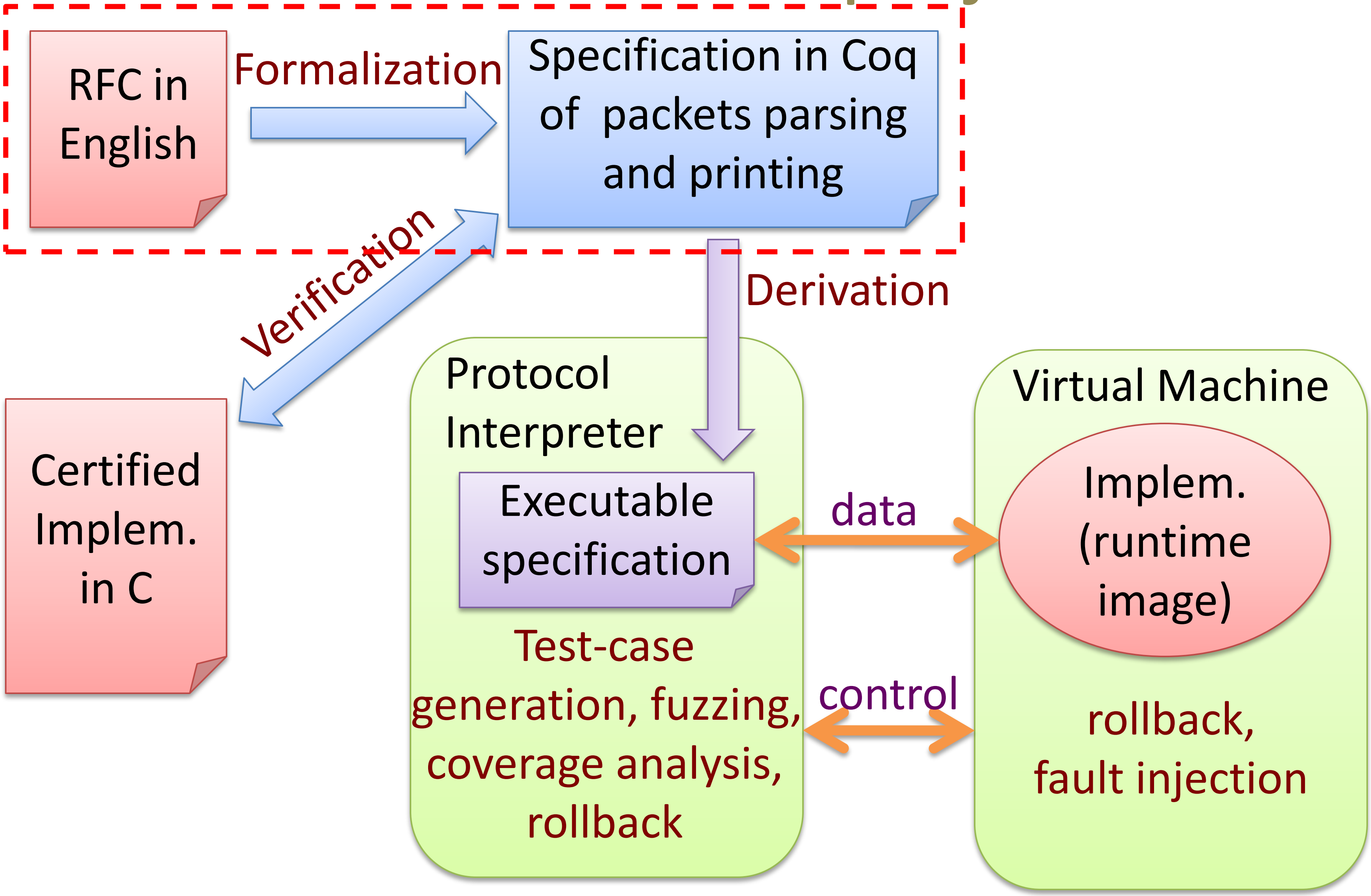
Application Data

Record

TCP

IP

Overview of the project



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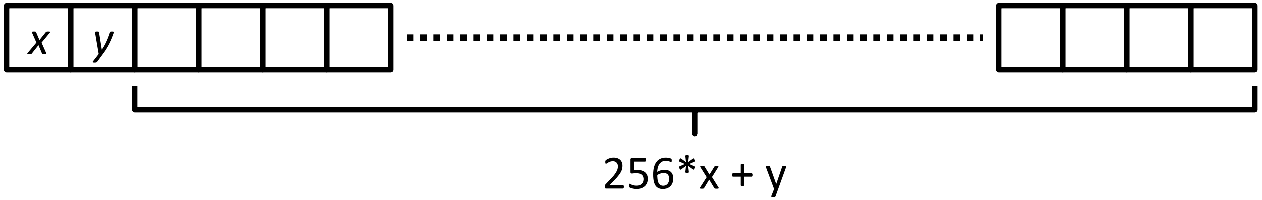
Data-dependent parsing for TLS

- To specify TLS packets, there is a need for dependent types.

Example:

```
Record Handshake : Set := {
  msg_type : HandshakeType ;
  body : HandshakeType_type msg_type
}.
```

- We also need dependent types to parse variable-length packets.



- We will use dependent types available in the proof assistant **Coq**.

Parsing monad

A monad is an abstract data type that allows to embed imperative features in a purely functional language (like Coq).

```
Definition state : Type :=
  in_channel * out_channel * nat.

Definition parser (A:Type) : Type :=
  state -> exception (A * state).

Definition ret {A:Type}(a:A) : parser A :=
  fun s => value (a,s).

Definition bind {A B:Type}(p:parser A)(f:A -> parser B) :
    parser B :=
  fun s =>
    match p s with
    | value (a,s') => f a s'
    | error msg => error msg
    end.
```

Dependent parsing monad

For data-dependent parsing, we need a dependently typed *bind*:

```
Definition bind_dep
    {A:Type}{B:A->Type}(p:parser A)(f:forall a:A, parser (B a)) :
    parser {a:A & B a} :=
  fun s =>
    match p s with
    | value (a,s') =>
        match f a s' with
        | value (b, s'') => value (existT (fun a => B a) a b, s'')
        | error msg => error msg
        end
    | error msg => error msg
    end.
```

Example: parsing handshake packets

We parse in order the packet’s type, its length and its body:

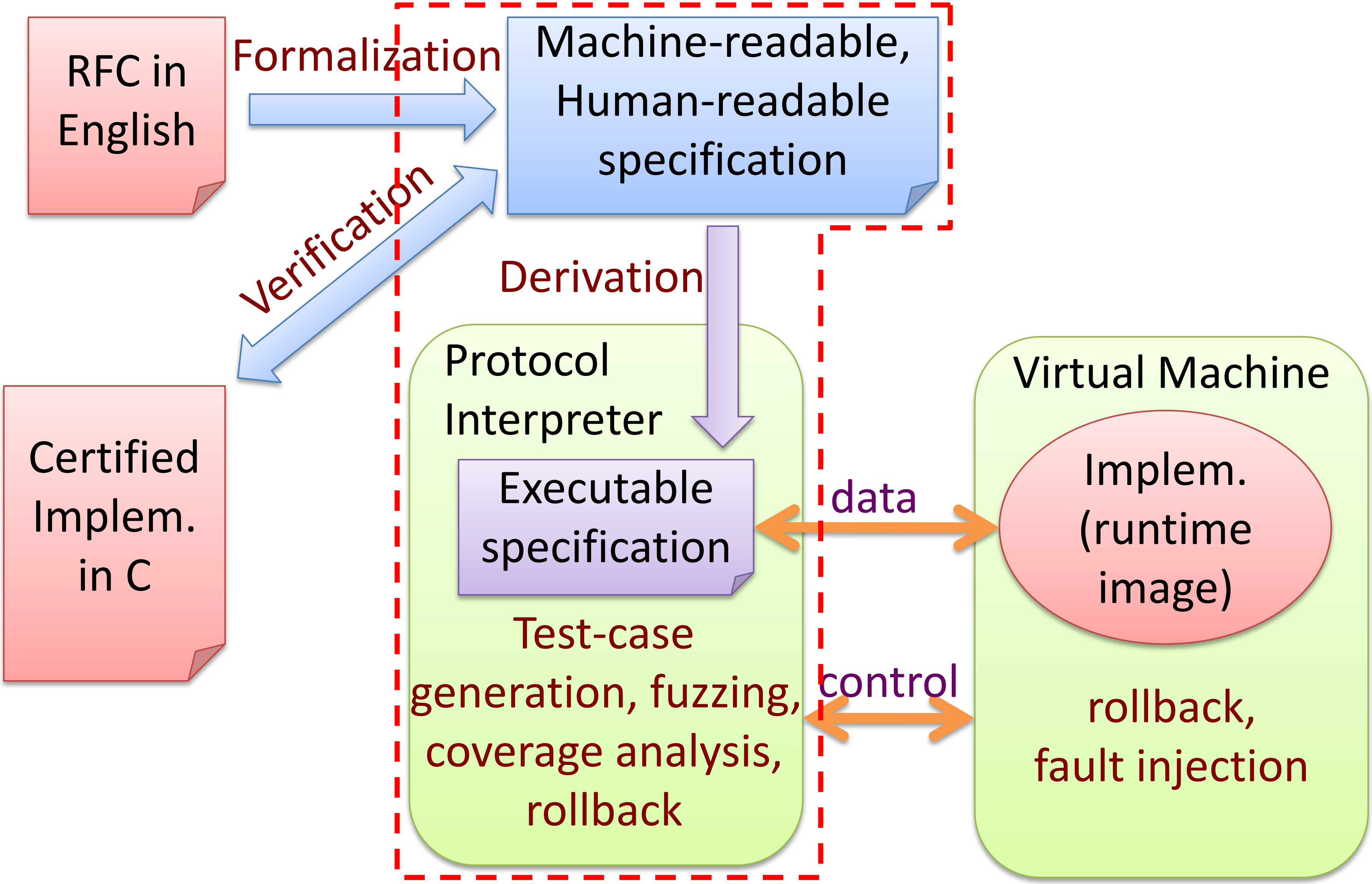
```
Definition parse_Handshake' :
    parser {ht : HandshakeType & HandshakeType_type ht} :=
  bind_dep parse_HandshakeType (
    fun ht =>
      len <<= parse_Z 3 ;
      match ht return parser (HandshakeType_type ht) with
      | hello_request => parse_exact (Zabs_nat len) parse_HelloRequest
      | client_hello => parse_exact (Zabs_nat len) parse_ClientHello
      | server_hello => parse_exact (Zabs_nat len) parse_ServerHello
      | certificate => parse_exact (Zabs_nat len) parse_Certificate
      | server_hello_done => parse_exact (Zabs_nat len) parse_ServerHelloDone
      end
  ).

Definition parse_Handshake : parser Handshake :=
  h <<= parse_Handshake' ;
  ret {| msg_type := projT1 h ; body := projT2 h |}.
```

Parsing/Printing monad

- In some sense, they are inverse to each other.
- Parsers and printers are often implemented separately.
  - → Redundancy
  - → Potential inconsistency
- We will use **invertible syntax descriptions**:
  a monadic approach that unifies parsing and printing

Overview of the project



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Machine-readable, Human-readable specification

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Roadmap of the following parts:

- To design a specification language that is:
  - Precise enough to extract parsing/encoding programs automatically
    - Parsing part done in work in the the previous slides
    - *This Coq work shows us how to do theoretic things here, very precisely!*
      - *Type design, dependent types, etc…*
      - *If it can be done in Coq, we can do it anywhere* :-)
  - Human-friendly enough to be read as document
    - Add some “human-friendly” nuts where needed
      - E.g. BNF, state machine description, etc…
    - Add hints for “fuzzing” in the next stage

Roadmap of the following parts:

- Extract “correct” testing program (reference impl.) from the specification
  - Just interprets the input specification
- Derive “incorrect” testing program, too
  - Mix the “fuzzings” with the extracted program
    - E.g. trailing garbage, data overrun,
      incorrect input for case branches…
    - Needs more hints in the input specification than above

Roadmap of the following parts:

- Build a black-box test program
    - Talk with black-box test targets
    - Non-deterministically choose several “correct” or “incorrect” behaviors on the fly
- Use program rollback to trace all possible cases to see what happens
    - Test all “correct” and “incorrect” cases thoroughly
    - Use VM to rollback execution of target program

Roadmap of the following parts:

- (Rough) Plans
  - *FY2010: explore design choices in Coq*
    - *See what will be needed to model parsing problems*
  - FY2011: Design spec language for “correct” cases
    - Auto-extract testing program from the spec
    - Build a test-bed system for black-box testing
  - FY2012: testing “incorrect” cases
    - Add fuzzing hints to the language
    - Integrates with VM roll-back control