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# The Computerate Specifying Paradigm
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## Abstract

This document specifies a paradigm named Computerate Specifying, designed to simultaneously document and formally specify communication protocols. This paradigm can be applied to any document produced by any Standard Developing Organization (SDO), but this document targets specifically documents produced by the IETF.

## Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

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## 1. Introduction

If, as the unofficial IETF motto states, we believe that "running code" is an important part of the feedback provided to the standardization process, then as per the Curry-Howard equivalence [Curry-Howard] (that states that code and mathematical proofs are the same), we ought to also believe that "verified proof" is an equally important part of that feedback. A verified proof is a mathematical proof of a logical proposition that was mechanically verified by a computer, as opposed to just peer-reviewed.

The "Experiences with Protocol Description" paper from Pamela Zave [Zave] gives three conclusions about the usage of formal specifications for a protocol standard. The first conclusion states that informal methods (i.e. the absence of verified proofs) are inadequate for widely used protocols. This document is based on the assumption that this conclusion is correct, so its validity will not be discussed further.

The second conclusion states that formal specifications are useful even if they fall short of the "gold standard" of a complete formal specification. We will show that a formal specification can be incrementally added to a standard.

The third conclusion from Zave's paper states that the normative English language should be paraphrasing the formal specification. The difficulty here is that to be able to keep the formal specification and the normative language synchronized at all time, these two should be kept as physically close as possible to each other.

To do that we introduce the concept of "Computerate Specifying" (note that Computerate is a British English word). "Computerate Specifying" is a play on "Literate Computing", itself a play on "Structured Computing" (see [Knuth92] page 99). In the same way that Literate Programming enriches code by interspersing it with its own documentation, Computerate Specifying enriches a standard specification by interspersing it with code (or with proofs, as they are the same thing), making it a computerate specification.

Note that computerate specifying is not specific to the IETF, just like literate computing is not restricted to the combination of Tex and Pascal described in Knuth's paper. What this document describes is a specific instance of computerate specifying that combines

[AsciiDoc] as formatting language and [Idris] as programming language with the goal of formally specify IETF protocols.

## 2. Overview of Operations

Nowadays specifications at the IETF are written in a format named xml2rfc v3 [RFC7991] but unfortunately making that format "Computerable" is not trivial, mostly because there is no simple solution to mix code and XML together in the same file. Instead, we chose the AsciiDoc format as the basis for computerate specifications as it permits to generate specifications in the xml2rfc v3 format (among other formats) and also because it can be enriched with code in the same file.

[I-D.ribose-asciirfc] describes a backend for the [Asciidoctor] tool that converts an AsciiDoc document into an xmlrfc3 document. The AsciiRFC document states various reasons why AsciiDoc is a superior format for the purpose of writing standards, so we will not discuss these further. Note that the same team developed Asciidoctor backends for other Standard Developing Organizations (SDO) [Metanorma], making it easy to develop computerate specifications targeting the standards developed by these SDOs.

The code in a computerate specification uses the programming language Idris in literate programming [Literate] mode using the Bird-style, by having each line of code starting with a ">" mark in the first column.

That same symbol was also used by AsciiDoc as an alternate way of defining a blockquote [Blockquotes], way which is no longer available in a computerate specification. Bird-style code will simply not appear in the rendered document.

The result of Idris code execution can be inserted inside the document part by putting that code fragment in the document between the "{`" string and the "`}" string.

A computerate specification is processed by an Asciidoctor preprocessor that do the following:

1. Load the whole document as an Idris program, including importing modules.

2. For each instance of an inline code fragment, evaluate that fragment and replace it (including the delimiters) by the result of that evaluation.

3. Continue with the normal processing of the modified document.

For instance the following computerate specification fragment taken from the computerate specification of STUNbis:

```
<CODE BEGINS>
> rto : Int
> rto = 500
>
> rc : Nat
> rc = 7
>
> rm : Int
> rm = 16
>
> -- A stream of transmission times
> transmissions : Int -> Int -> Stream Int
> transmissions value rto = value :: transmissions (value + rto)
>   (rto * 2)
>
> -- Returns a specific transmission time
> transmission : Int -> Nat -> Int
> transmission timeout i = index i $ transmissions 0 timeout
>
> a1 : String
> a1 = show rto
>
> a2 : String
> a2 = concat (take (rc - 1) (map (\t => show t ++ " ms, ")
>   (transmissions 0 rto))) ++ "and " ++ show (transmission rto
>     (rc - 1)) ++ " ms"
>
> a3 : String
> a3 = show $ transmission rto (rc - 1) + rto * rm
```

For example, assuming an RTO of {`a1`}ms, requests would be sent at times {`a2`}.
If the client has not received a response after {`a3`} ms, the client will consider the transaction to have timed out.
<CODE ENDS>

is rendered as:

"                                          For example, assuming an RTO of 500ms, requests would be sent at times 0 ms, 500 ms, 1500 ms, 3500 ms, 7500 ms, 15500 ms, and 31500 ms.  If the client has not received a response after 39500 ms, the client will consider the transaction to have timed out."

Appendix A explains how to install the command line tools to process a computerate specification.

The Idris programming language has been chosen because its type system supports dependent and linear types, and that type system is the language in which formal specifications are written.

Following Zave's second conclusion, a computerate specification does not have to be about just formally specifying a protocol and proving properties about it. There is a whole spectrum of formalism that can be introduced in a specification, and we will present them in the remaining sections by increasing order of complexity. Note that because the formal language is a programming language, these usages are not exhaustive, and plenty of other usages can and will be found after the publication of this document.

## 2.1. Libraries

A computerate specification does not disappear as soon the standard it describes is published. Quite the opposite, each specification is designed to be used as an Idris module that can be imported in subsequent specifications, reducing over time the amount of code that needs to be written. At the difference of an RFC that is immutable after publication, the code in a specification will be improved over time, especially as new properties are proved or disproved. The latter will happen when a bug is discovered in a specification and a proof of negation is added to the specification, paving the way to a revision of the standard.

This document is itself a computerate specification that contains data types and functions that can be reused in future specifications, and as a whole can be considered as the standard library for computerate specifying.

For convenience each public computerate specification, including the one behind this document, will be made available as an individual git repository. Appendix B explains how to gain access to these computerate specifications.

## 2.2. Retrofitting Specifications

RFCs, Internet-Drafts and standard documents published by other SDOs did not start their life as computerate specifications, so to be able to use them as Idris modules they will need to be progressively retrofitted. This is done by converting the document into an AsciiDoc document and then enriching it with code, in the same way that would have been done if the standard was developed directly as a computerate specification.

Converting the whole document in AsciiDoc and enriching it with code, instead of just maintaining a library of code, seems a waste of resources. The reason for doing so is to be able to verify that the rendered text is equivalent to the original standard, which will validate the examples and formal languages.

Retrofitted specification will also be made available as individual git repositories as they are converted.

Because the IETF Trust does not permit to modify an RFC as a whole (excepted for translation purpose), a retrofitted RFC uses transclusion, which is a mechanism that include parts of a separate document at runtime. This way a retrofitted RFC is distributed as two separate files, the original RFC in text form, and a computerate specification that contain only code and transclusions.

Transclusion is a special form of AsciiDoc include that takes a range of lines as parameters:

```
[abstract]
include::rfc5234.txt[lines=26..35]
```

Here the "include" macro will be replaced by the content of lines 26 to 35 (included) of RFC 5234.

The "sub" parameter permits to modify the copied content according to a regular expression. For instance the following converts references into the AsciiDoc format:

```
include::rfc5234.txt[lines=121..131,sub="/\[([^\]])\]/<<\1>>/"]
```

In the following example, the text is converted into a note:

```
include::rfc5234.txt[lines=151,sub="/^.*$/NOTE: \0/"]
```

## 2.3. Revision of Standards

Standards evolve but because RFCs are immutable, revisions for a standard are done by publishing new RFCs.

The matching computerate specifications need to reflect that relationship by extending the data type of syntax and semantics in the new version, instead of recreating new data types from scratch. There is two diametrically opposed directions when extending a type:

- The new standard is adding constraints. This is done by indexing the new type over the old type.

- The new standard is removing constraints. This is done by defining the new type as a sum type, with one of the alternative being the old type.

NOTE

This is correct in theory, but in practice creating new specifications from old ones as described above is not very convenient. Maybe an alternate solution is to define the new specifications from scratch, and use an isomorphism proof to precisely define the differences between the two. An Idris elaboration script may permit to duplicate a type and modify it without having to manually copy it.

## 2.4. Content of a Computerate Specification

Communication protocols specifications are generally split in two distinct parts, syntax (the data layout of the messages exchanged) and semantics (the rules that drive the exchange of messages).

Section 3 will discuss in details the application of computerate specifying to syntax descriptions, and Section 4 will be about specifying semantics.

# 3. Syntax

The syntax of a communication protocol determines how data is laid out before be sent over a communication link. Generally the syntax is described only in the context of the layer that this particular protocol is operating at, e.g. an application protocol syntax only describes the data as sent over UDP or TCP, not over Ethernet or Wi-Fi.

Syntaxes can generally be split into two broad categories, binary and text, and generally a protocol syntax falls completely into one of these two categories.

Syntax descriptions can be formalized for at least three reasons, reasons that will be presented in the following sections.

## 3.1. Syntax Examples

Examples in protocols documentation are frequently incorrect, which should not be that much of an issue but for the fact that most developers do not read the normative text when an example is available. Moving the examples into appendices or adding caution notices have shown limited success in preventing that problem.

[NOTE: citation needed]

So ensuring that examples match the normative text seems like a good starting point for a computerate specification. This is done by having the possibility of adding the result of a computation directly inside the document. If that computation is done from a type that is (physically and conceptually) close to the normative text, then we gain some level of assurance that both the normative text and the derived examples will match. Note that examples can be inserted in the document as whole block of text, or as inline text.

### 3.1.1. Data Type

The first step is to define an Idris type that completely defines the layout of the messages exchanged. By "completely define" we mean that the type checker will prevent creating any invalid value of this type. That ensures that all values are correct by construction.

E.g. here is the definition of a DNS label per [RFC1034]:

<CODE STARTS>
```
> data PartialLabel' : List Char -> Type where
>   Empty : PartialLabel' []
>   More : (c : Char) -> (prf1 : isAlphaNum c || c == '-' = True) ->
>     PartialLabel' s -> (prf2 : length s < 61 = True) ->
>     PartialLabel' (c :: s)
>
> data Label' : List Char -> Type where
>   One : (c : Char) -> (prf1 : isAlpha c = True) -> Label' [c]
>   Many : (begin : Char) -> (prf1 : isAlpha begin = True) ->
>     (middle : PartialLabel' xs) ->
>     (end : Char) -> (prf2 : isAlphaNum end = True) ->
>     Label' ([begin] ++ xs ++ [end])
>
> data Label : {a : Type} -> a -> Type where
>   MkLabel : {xs : String} -> Label' (unpack xs) -> Label xs
```
<CODE ENDS>

NOTE

Find an example that cannot be completely expressed in ABNF.

### 3.1.2. Serializer

The second step is to write a serializer from that type into the wire representation. For a text format, it is done by implementing the Show interface:

```
<CODE STARTS>
> Show (Label xs) where
> show _ = xs
<CODE ENDS>
```

NOTE

Define binary serializer.

### 3.1.3. Presentation Format

The IETF canonical format can be converted into a text format or a graphical format (HTML, PDF, Epub). The main issue here is that the text format limits a line length to 72 columns, so some additional formatting rules needs to be applied in that case. To support both formats at the same time, all AsciiDoc blocks will be converted into an <artwork> element that contains both the 72 columns formatted text and an equivalent SVG file, even for code source (instead of using the <sourcecode> element).

NOTE

Under development.

## 3.2. Formal Syntax Language

Some specifications use a formal language to describe the data layout. One shared property of these languages is that they cannot always formalize all the constraints of a specific data layout, so they have to be enriched with comments. One consequence of this is that they cannot be used as a replacement for the Idris data type described in Section 3.1.1, data type that is purposely complete.

The following sections describe how these formal languages have been or will be themselves formalized with the goal of using them in computerate specifications.

### 3.2.1. Augmented BNF (ABNF)

Augmented Backus-Naur Form [RFC5234] (ABNF) is a formal language used to describe a text based data layout.

The [RFC5234] document has been retrofitted as a computerate specification to provide an internal Domain Specific Language (DSL) that permits to specify an ABNF for a specification. The encoding of an example from Section 2.3 of [RFC5234] looks like this:

<CODE BEGINS>

```
> rulename : Rule
> rulename = "rulename" "Eq" (Concat (TermDec 97 []) (TermDec 98 [])
>   [TermDec 99 []])
<CODE ENDS>
```

A serializer, also defined in the same specification, permits to convert that description into a proper ABNF text that can be inserted into the document such as in the following fragment:

```
<CODE BEGINS>
[source,abnf]
----
{ `show rulename`}
----
<CODE ENDS>
```

is rendered as

```
rulename = %d97 %d98 %d99
```

See Appendix B.2.1 for access to the source of the retrofitted specification for [RFC5234].

### 3.2.2. Augmented ASCII Diagrams (AAD)

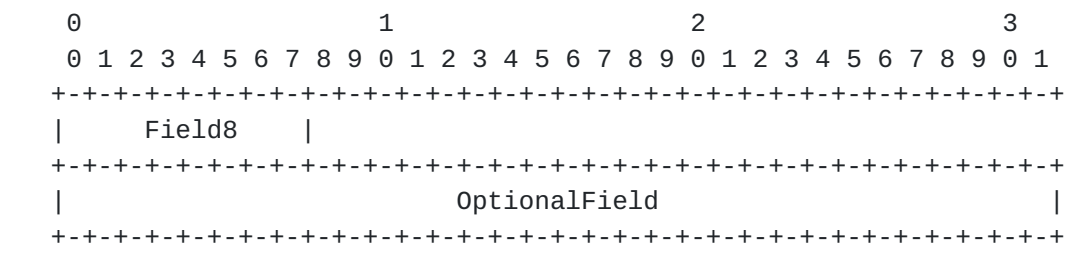
Augmented ASCII Diagram [I-D.mcquistin-augmented-ascii-diagrams] (AAD) is a formal language to describe binary data layouts and represent them as ASCII diagrams.

The conversion of the AAD language into an actual ASCII diagram will be done by an Asciidoctor block processor, so both a text representation and an SVG representation can be generated in the xmlrfc3 file.

Here's a fragment of a specification using AAD:

```
<CODE BEGINS>
[aad]
....
AAD code goes there
....
<CODE ENDS>
```

is rendered as




Like for ABNF, the computerate specification for [I-D.mcquistin-augmented-ascii-diagrams] will define a DSL for the AAD language, a serializer that generates the AAD code, and an elaborator script that generates a type. The serializer will be used to generate the content of the AsciiDoc block so the code above can be replaced by the following and still be rendered identically:

```
<CODE BEGINS>
> myOptionalTest : Rule
> myOptionalTest = something something

[aad]
....
{ "show myOptionalTest"}
....
<CODE ENDS>
```

NOTE

Update the examples when the AAD language is available.

### 3.2.3. Mathematical Formulas

AsciiDoc supports writing equations using either asciimath or latexmath. The rendered for RFCs will generate an artwork element that contains both the text version of the equation and a graphical version in an SVG file.

NOTE

Not sure what to do with inline formulas, as we cannot generate an artwork element in that case.

An Idris type will be used to described equations at the type level. An interpreter will be used to calculate and insert examples in the document.

A serializer will be used to generate the asciimath code that is inserted inside a stem block.

### 3.2.4. TLS Description Language

TBD

## 3.3. Proofs for Syntax

The kind of proofs that one would want in a specification are related to isomorphism, i.e. a guarantee that two or more descriptions of a data layout contains exactly the same information.

### 3.3.1. Isomorphism Between Type and Formal Language

We saw above that when a data layout is described with a formal language, we end up with two descriptions of that data layout, one using the Idris dependent type (and used to generate examples) and one using the formal language.

Proving isomorphism requires to generate an Idris type from the formal language instance, which is done using an Idris elaborator script.

In Idris, Elaborator Reflection [Elab] is a metaprogramming facility that permits to write code that generates type declarations and code (including proofs) automatically.

For instance the ABNF language is itself defined using ABNF, so after converting that ABNF into an instance of the Syntax type (which is an holder for a list of instances of the Rule type), it is possible to generates a suite of types that represents the same language:

```
<CODE BEGINS>
> abnf : Syntax
> abnf = MkSyntax [
>   "rulelist" "Eq" (Repeat (Just 1) Nothing (Group (Altern
>     (TermName "rule") (Group (Concat (Repeat Nothing Nothing
>     (TermName "c-wsp")) (TermName "c-nl") [])) [])))),
>     ...
>   ]
>
> %runElab (generateType "Abnf" abnf)
<CODE ENDS>
```

The result of the elaboration can then be used to construct a value of type Iso, which requires four total functions, two for the conversion between types, and another two to prove that sequencing the conversions results in the same original value.

The following example generates an Idris type "SessionDescription" from the SDP ABNF. It then proves that this type and the Sdp type contains exactly the same information (the proofs themselves have been removed, leaving only the propositions):

```
<CODE BEGINS>
> import Data.Control.Isomorphism
>
> sdp : Syntax
> sdp = MkSyntax [
>   "session-description" "Eq" (Concat (TermName "version-field")
>     (TermName "origin-field") [
>       TermName "session-name-field",
>       Optional (TermName "information-field"),
>       Optional (TermName "uri-field"),
>       Repeat Nothing Nothing (TermName "email-field"),
>       Repeat Nothing Nothing (TermName "phone-field"),
>       Optional (TermName "connection-field"),
>       Repeat Nothing Nothing (TermName "bandwidth-field"),
>       Repeat (Just 1) Nothing (TermName "time-description"),
>       Optional (TermName "key-field"),
>       Repeat Nothing Nothing (TermName "attribute-field"),
>       Repeat Nothing Nothing (TermName "media-description")
>       ]),
>   ...
>   ]
>
> %runElab (generateType "Sdp" sdp)
>
> same : Iso Sdp SessionDescription
> same = MkIso to from toFrom fromTo
>   where
>     to : Sdp -> SessionDescription
>
>     from : SessionDescription -> Abnf
>
>     toFrom : (x : SessionDescription ) -> to (from x) = x
>
>     fromTo : (x : Sdp) -> from (to x) = x
>
<CODE ENDS>
```

As stated in Section 3.2, the Idris type and the type generated from the formal language are not always isomorphic, because some constraints cannot be expressed in that formal language. In that case isomorphism can be used to precisely define what are the information that are missing in the formal language type. To do so, the generated type is augmented with a delta type, like so:

```
<CODE BEGINS>
> data DeltaSessionDescription : Type where
> ...
>
> same : Iso Sdp (SessionDescription, DeltaSessionDescription)
> ...
<CODE ENDS>
```

Then the DeltaSessionDescription type can be modified to include the missing information until the same function type checks. After this we have a guarantee that we know all about the constraints that cannot be encoded in that formal language, and can check manually that each of them is described as comment.

### 3.3.2. Data Format Conversion

For specifications that describe a conversion between different data layouts, having a proof that guarantee that no information is lost in the process can be beneficial. For instance, we observe that syntax encoding tends to be replaced each ten years or so by something "better". Here again isomorphism can tell us exactly what kind of information we lost and gained during that replacement.

Here is for example the definition of a function that would verify an isomorphism between an XML format and a JSON format:

```
<CODE BEGINS>
> isXmlAndJsonSame: Iso (XML, DeltaXML) (JSON, DeltaJson)
> ...
<CODE ENDS>
```

Here DeltaXML expresses what is gained by switching from XML to JSON, and DeltaJson expresses what is lost.

### 3.3.3. Interoperability with Previous Versions

The syntax of the data layout may be modified as part of the evolution of a standard. In most case a version number prevents the old format to be used with the new format, but in cases where that it is not possible, the new specification can ensure that both formats can co-exist by using the same techniques as above.

Conversely these techniques can be used during the design phase of a new version of a format, to check if a new version number is warranted.

### 3.3.4. Postel's Law

> Be conservative in what you do, be liberal in what you accept from others.
>
> -- Jon Postel, RFC 761

One of the downside of formal specifications is that there is no wiggle room possible when implementing it. An implementation is either conform to the specification or is not.

One analogy would be specifying a pair of gears. If one decides to have both of them made with too small tolerances, then it is very likely that they will not be able to move when put together. A bit of slack is needed to get the gear smoothly working together but more importantly the cost of making these gears is directly proportional to their tolerance. There is an inflexion point where the cost of an high precision gear outweighs its purpose.

We have a similar issue when implementing a formal specification, where having an absolutely conform implementation may cost more money than it is worth spending. On the other hand a specification exists for the purpose of interoperability, so we need some guidelines on what to ignore in a formal specification to make it cost effective.

Postel's law proposes an informal way of defining that wiggle room by actually having two different specifications, one that defines data layout for the purpose of sending it, and another one that defines a data layout for the purpose of receiving that data layout.

Existing specifications express that dichotomy in the form of the usage of SHOULD/SHOULD NOT/RECOMMENDED/NOT RECOMMENDED [RFC2119] keywords. For example the SDP spec says that "[t]he sequence CRLF (0x0d0a) is used to end a line, although parsers SHOULD be tolerant and also accept lines terminated with a single newline character." This directly infers two specifications, one used to define an SDP when sending it, that enforces using only CRLF, and a second specification, used to define an SDP when receiving it (or parsing it), that accepts both CRLF and LF.

Note that the converse is not necessarily true, i.e. not all usages of these keywords are related to Postel's Law.

To ensure that the differences between the sending specification and the receiving specification do not create interoperability problems, we can use a variant of isomorphism, as shown in the following example (data constructors and code elided):

```
<CODE BEGINS>
> data Sending : Type where
>
> data Receiving : Type where
>
> to : Sending -> List Receiving
>
> from : Receiving -> Sending
>
> toFrom : (y : Receiving) -> Elem y (to (from y))
>
> fromTo : (y : Sending) --> True = all (== y) [from x | x <-- to y]
<CODE ENDS>
```

Here we define two data types, one that describes the data layout that is permitted to the sent (Sending) and one that describes the data layout that is permitted to be received (Receiving). For each data layout that is possible to sent, there is one or more matching receiving data layouts. This is expressed by the function "to" that takes as input one Sending value and returns a list of Receiving values.

Conversely, the "from" function maps a Receiving data layout unto a Sending data layout. Note the asymmetry there, which prevents to use a standard proof of isomorphism.

Then the "toFrom" and "fromTo" proofs verify that there is no interoperability issue by guaranteeing that each Receiving value maps to one and only one Sending instance and that this mapping is isomorphic.

All of this will provide a clear guidance of when and where to use a SHOULD keyword or its variants, without loss of interoperability.

As an trivial example, the following proves that accepting LF character in addition to CRLF characters as end of line markers does not break interoperability:

```
<CODE BEGINS>
> data Sending : Type where
>   S_CRLF : Sending
>
> Eq Sending where
>   (==) S_CRLF S_CRLF = True
>
> data Receiving : Type where
>   R_CRLF : Receiving
>   R_LF : Receiving
```

```
>
>to : Sending --> List Receiving
>to S_CRLF = [R_CRLF, R_LF]
>
>from : Receiving --> Sending
>from R_CRLF = S_CRLF
>from R_LF = S_CRLF
>
>toFrom : (y : Receiving) --> Elem y (to (from y))
>toFrom R_CRLF = Here
>toFrom R_LF = There Here
>
>fromTo : (y : Sending) --> True = all (== y) [from x | x <-- to y]
>fromTo S_CRLF = Refl
<CODE ENDS>
```

## 4. Semantics

The semantics of a communication protocol determines what messages are exchanged over a communication link and the relationship between them. The semantics are generally described only in the context of the layer that this particular protocol is operating at.

### 4.1. Typed Petri Nets

The semantics of a specification requires to define an Idris type that strictly enforces these semantics. This can be done in an ad hoc way [Type-Driven], particularly by using linear types that express resources' consumption.

But a better solution is to design these graphically, particularly by using Petri Nets. This specification defines a DSL that permits to describe a Typed Petri Net (TPN) which is heavily influenced by Coloured Petri Nets [CPN] (CPN). A CPN adds some restriction on the types that can be used in a Petri Net because of limitation is the underlying programming language, SML. The underlying programming used in TPN, Idris, does not have these limitations, so any well-formed Idris type (including polymorphic, linear and dependent types) can be directly used in TPN.

NOTE

A graphical editor for TPN is planned as part of the integration tooling. The graphical tool will use the document directly as storage.

Here's an example of TPN (from figure 2.10 in [CPN]):

```
<CODE BEGINS>
> NO : Type
> NO = Int
>
> DATA : Type
> DATA = String
>
> NOxDATA : Type
> NOxDATA = (NO, DATA)
>
> PTS : Place
> PTS = MkPlace "Packets To Send" NOxDATA (\() => [(1, "COL"),
>   (2, "OUR"), (3, "ED "), (4, "PET"), (5, "RI "), (6, "NET")])
>
> NS : Place
> NS = MkPlace "NextSend" NO (\() => [1])
>
> A : Place
> A = MkPlace "A" NOxDATA (\() => [])
>
> input1 : Input
> input1 = MkInput PTS (NO, DATA) pure
>
> input2 : Input
> input2 = MkInput NS NO pure
>
> output1 : Output
> output1 = MkOutput PTS (NO, DATA) pure
>
> output2 : Output
> output2 = MkOutput NS NO pure
>
> output3 : Output
> output3 = MkOutput A (NO, DATA) pure
>
> sendPacket : Transition
> sendPacket = MkTransition [input1, input2] [output1, output2,
>   output3] (\((n, d), n') => if n == n'
>                              then pure ((n, d), n, (n, d))
>                              else empty)
<CODE ENDS>
```

NOTE

The DSL is being currently designed, so the example shows the generated value.

From there it is easy to generate (using the non-deterministic monad in Idris) an interpreter for debugging and simulation purpose:

<CODE BEGINS>
```
> interpret : MS NOxDATA -> MS NO -> MS NOxDATA ->
>   ND (MS NOxDATA, MS NO, MS NOxDATA)
> interpret pts ns a = do
>   (pts1, pts2) <- sel pts
>   (ns1, ns2) <- sel ns
>   i1 <- input' input1 pts1
>   i2 <- input' input2 ns1
>   (pts3, ns3, a3) <- transition' sendPacket (i1, i2)
>   let o1 = output' output1 pts3
>   let o2 = output' output2 ns3
>   let o3 = output' output3 a3
>   pure (o1 ++ pts2, o2 ++ ns2, o3 ++ a)
```
<CODE ENDS>

NOTE

Replace by the generic variant of the interpreter.

A Petri Net has the advantage that the same graph can be reused to derive other Petri Nets, e.g., Timed Petri Nets (that can be used to collect performance metrics) or Stochastic Petri Nets.

NOTE

The traditional way of verifying a Petri Net is by using model checking. There is nothing in the design that prevents doing that, but because that takes quite some time to run and so cannot be part of the document processing, how do we store in the document a proof that the model checking was successful?

### 4.2. Semantics Examples

Semantics examples can be wrong, so it is useful to be sure that they match the specification.

#### 4.2.1. Data Type

As explained above, semantics can be described in an ad hoc manner, or using the TPN DSL.

#### 4.2.2. Serializer

At the difference of syntax, where there is more or less as many ways to display them than there are syntaxes, semantics examples generally use sequence diagram, eventually augmented with the content of the packets exchanged (and so using the techniques described in Section 3.1).

Similarly to what is done in Section 3.2.2, an Asciidoctor block processor similar to the "msc" type of diagram used by the asciidoctor-diagram extension will be designed.

NOTE

We unfortunately cannot reuse the asciidoctor-diagram extension because it cannot generate both text and SVG versions of a sequence diagram.

The serializer for an example derived from a TPN generates the content of the msc AsciiDoc block, by selecting one particular path and its associated bindings through the Petri Net.

NOTE

We probably want to use AsciiDoc callouts for these, although that would require a modification in AsciiRfc. In fact callout would be a far better technique for other diagrams, like AAD, as it will let the renderer take care of the best way to place elements depending on the output format.

#### 4.2.3. Presentation Format

TBD.

### 4.3. Formal Semantics Language

Some specifications use a formal language to describe the state machines. One shared property of these languages is that they cannot always formalize all the constraints of specific semantics, so they have to be enriched with comments. One consequence of this is that they cannot be used as a replacement for the Idris data type described in Section 4.1, data type that is purposely complete.

#### 4.3.1. Cosmogol

Cosmogol [I-D.bortzmeyer-language-state-machines] is a formal language designed to define states machines. The Internet-Draft will be retrofitted as a computerate specification to provide an internal

Domain Specific Language (DSL) that permits to specify an instance of that language. A serializer and elaborator script will also be defined.

Finally, an Asciidoctor block processor would be used to convert the language into both a text and a graphical view of the state machine.

NOTE

Add examples there.

### 4.4. Proofs for Semantics

Like for syntax formal languages, an elaborator script permits to generate a type from a TPN instance. That type can then be used to write proofs of the properties that we expect from the semantics.

#### 4.4.1. Isomorphism

An isomorphism proof can be used between two types derived from the semantics of a specification, for example to prove that no information is lost in the converting between the underlying processes, or when upgrading a process.

An example of that would be to prove (or more likely disprove) that the SIP state machines are isomorphic to the WebRTC state machines.

#### 4.4.2. Postel's Law

Like for the syntax, semantics can introduce wiggle room between the state machines on the sending side and the state machines on the receiving side. A similar isomorphism proof can be used to ensure that this is done without loss of interoperability.

#### 4.4.3. Termination

The TPN type can be used to verify that the protocol actually terminates, or that it always returns to its initial state. This is equivalent to proving that a program terminates.

#### 4.4.4. Liveness

The TPN type can be used to verify that the protocol is productive, i.e. that it does not loop without making progress.

### 4.4.5. Verified Code

A TPN that covers a whole protocol (i.e. client, network, and server) is useful to prove the properties listed in the previous sections. But the TPN is also designed in a way that each of these parts can be defined separately from the others (making it a Hierarchical TPN). This permits to use the type generated from these (through an elaborator script) as a type for real code, and thus verifying that this code is conform to both the syntax and the semantics specification.

## 5. Acknowledgements

Thanks to Jim Kleck, Stephane Bryant, Eric Petit-Huguenin, Nicolas Gironi, and Stephen McQuistin for the comments, suggestions, questions, and testing that helped improve this document.

## 6. Informative References

[AsciiDoc]
"Curry-Howard correspondence",
<https://en.wikipedia.org/wiki/AsciiDoc>.

[Asciidoctor]
"Asciidoctor",
<https://asciidoctor.org/docs/user-manual/>.

[Blockquotes]
"Markdown-style blockquotes",
<https://asciidoctor.org/docs/user-manual/#markdown-style-blockquotes>.

[CPN] Jensen, K. and L. Kristensen, "Coloured Petri Nets: Modelling and Validation of Concurrent Systems", Springer, 2009.

[Curry-Howard]
"Curry-Howard correspondence",
<https://en.wikipedia.org/wiki/Curry%E2%80%93Howard_correspondence>.

[Elab] Christiansen, D. and E. Brady, "Elaborator reflection: extending Idris in Idris", In Proceedings of the 21st ACM SIGPLAN International Conference on Functional Programming. ACM Press-Association for Computing Machinery, 2016.

[I-D.bortzmeyer-language-state-machines]
Bortzmeyer, S., "Cosmogol: a language to describe finite state machines", draft-bortzmeyer-language-state-machines-01 (work in progress), November 2006.

[I-D.mcquistin-augmented-ascii-diagrams]
McQuistin, S., Band, V., and C. Perkins, "Fully Specifying Protocol Parsing with Augmented ASCII Diagrams", draft-mcquistin-augmented-ascii-diagrams-00 (work in progress), July 2019.

[I-D.ribose-asciirfc]
Tse, R., Nicholas, N., and P. Brasolin, "AsciiRFC: Authoring Internet-Drafts And RFCs Using AsciiDoc", draft-ribose-asciirfc-08 (work in progress), April 2018.

[Idris] "Idris: A Language with Dependent Types", <https://www.idris-lang.org/>.

[Knuth92] Knuth, D., "Literate Programming", Center for the Study of Language and Information, 1992.

[Literate]
"Literate programming", <http://docs.idris-lang.org/en/latest/tutorial/miscellany.html#literate-programming>.

[Metanorma]
"Metanorma", <https://www.metanorma.com/>.

[Postel] "Robustness principle", <https://en.wikipedia.org/wiki/Robustness_principle>.

[RFC1034] Mockapetris, P., "Domain names - concepts and facilities", STD 13, RFC 1034, DOI 10.17487/RFC1034, November 1987, <https://www.rfc-editor.org/info/rfc1034>.

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <https://www.rfc-editor.org/info/rfc2119>.

[RFC5234] Crocker, D., Ed. and P. Overell, "Augmented BNF for Syntax Specifications: ABNF", STD 68, RFC 5234, DOI 10.17487/RFC5234, January 2008, <https://www.rfc-editor.org/info/rfc5234>.

[RFC7991] Hoffman, P., "The "xml2rfc" Version 3 Vocabulary", RFC 7991, DOI 10.17487/RFC7991, December 2016, <https://www.rfc-editor.org/info/rfc7991>.

[Type-Driven] Brady, E., "Type-Driven Development with Idris", Manning, 2017.

[Zave] Zave, P., "Experiences with Protocol Description", Rigorous Protocol Engineering (WRiPE'11), October 2011, <http://www.pamelazave.com/wripe.pdf>.

# Appendix A. Command Line Tools

## A.1. Installation

The computerate command line tools are running inside a Docker image, so the first step is to install the Docker software or verify that it is up to date (<https://docs.docker.com/install/>).

Note that for the usage described in this document there is no need for Docker EE or for having a Docker account.

The following instructions assume a Unix based OS, i.e. Linux or MacOS. Lines ending with a "\" are meant to be executed as one single line, with the "\" character removed.

### A.1.1. Download the Docker Image

To install the computerate tools, the fastest is to download and install the Docker image using a temporary image containing the dat tool:

```
docker pull veggiemonk/dat-docker
mkdir computerate
cd computerate
docker run -u $(id -u):$(id -g) -v \
 $(pwd):/tools veggiemonk/dat-docker dat clone \
 dat://78f80c850af509e0cd3fd7bd6f5d0dd527a861d783e05574bbd040f0502da3c6 \
 tools
```

After this, the image can be loaded in Docker. The newly installed Docker image also contains the dat command, so there is no need to keep the veggiemonk/dat-docker image after this:

```
docker load -i tools.tar.xz
docker image rm --force veggiemonk/dat-docker
```

After this, running the following command in the computerate directory will pull any new version of the tool tar file.

```
docker run -u $(id -u):$(id -g) \
 -v $(pwd):/computerate computerate/tools dat pull --exit
```

The docker image can then be loaded as above.

## A.2. Using the computerate Command

The Docker image main command is "computerate", which takes the same parameters as the "metanorma" command from the Metanorma tooling:

```
docker run -u $(id -u):$(id -g) -v $(pwd):/computerate \
  computerate/tools computerate -t ietf -x txt <file>
```

The differences with the "metanorma" command are:

- The "computerate" command can process Literate Idris files (files with a "lidr" extension, aka lidr files), in addition to AsciiDoc files (files with an "adoc" extension, aka adoc files). When a lidr file is processed, all embedded code fragments (text between prefix "{`" and suffix "`}") are evaluated in the context of the Idris code contained in this file. Each code fragment (including the prefix and suffix) are then substituted by the result of that evaluation.

- The "computerate" command can process included lidr files in the same way. The embedded code fragments in the imported file are processed in the context of the included lidr file, not in the context of the including file. Idris modules (either from an idr or lidr file) can be imported the usual way.

- The literate code (which is all the text that is starting by a ">" symbol in column 1) in a lidr file will not be part of the rendered document.

- The computerate command can process transclusions, as explained in Section 2.2.

- Lookup of external references is disabled. Use either raw XML references or an external directory.

- Instead of generating a file based on the name of the input file, the "computerate" command generates a file based on the ":name:" attribute in the header of the document.

The "computerate" command can also be used to generate an xmlrfc v3 file, ready for submission to the IETF:

```
docker run -u $(id -u):$(id -g) -v $(pwd):/computerate \
  computerate/tools computerate -t ietf -x xmlrfc3 <file>
```

### A.3. Using Other Commands

For convenience, the docker image provides the latest version of the xml2rfc, idnits, aspell, and languagetool tools.

```
docker run -u $(id -u):$(id -g) -v $(pwd):/computerate \
  computerate/tools xml2rfc
docker run -u $(id -u):$(id -g) -v $(pwd):/computerate \
  computerate/tools idnits --help
docker run -u $(id -u):$(id -g) -v $(pwd):/computerate \
  computerate/tools aspell
docker run -u $(id -u):$(id -g) -v $(pwd):/computerate \
  computerate/tools languagetool
```

lidr files can be loaded directly in the Idris REPL for debugging:

```
docker run -it -u $(id -u):$(id -g) -v $(pwd):/computerate \
  computerate/tools idris <lidr-file>
```

The Docker image also contains a extended version of git that will be used to retrieve the computerate specifications in Appendix B.

### A.4. Bugs and Workarounds

- Errors in embedded code do not stop the process but replace the text by the error message, which can be easily overlooked.

- backticks are not escaped in code fragments.

- The current version of Docker in Ubuntu fails, but this can be fixed with the following commands:

```
sudo apt-get install containerd.io=1.2.6-3
sudo systemctl restart docker.service
```

- The Asciidoctor processor does not correctly format the output in all cases (e.g. ++). The escaping can be done in Idris until this is fixed.

- Sometimes the Idris processing fails with an error "Module needs reloading". Deleting all the files with the ibc extension will solve that problem.

- Trying to fetch inexistant new commits on a git repository will block for 12 seconds.

- xml2rfc does not support PDF output.

### A.5. TODO List

- Embedded blocks.

- Test on Windows.

- Using recursive modules with Idris.

## Appendix B. Computerate Specifications Library

### B.1. Installation

As an hopeless tentative of restoring the end-to-end, fully distributed nature of the Internet, the git repositories that compose the Computerate Specification Library are distributed over a peer-to-peer protocol based on dat.

This requires an extension to git, extension that is already installed in the Docker image described in Appendix A. The following command can be used to retrieve a computerate specification:

```
docker run -u $(id -u):$(id -g) -v $(pwd):/computerate \
  computerate/tools git clone --recursive dat://<public-key> <name>
```

Here <public-key> is the dat public key for a specific computerate specification and <name> is it recommended name. Do not use the dat URIs given in Appendix A, as only the dat public keys listed in Appendix B.2 can be used with a git clone.

Updating the repository also requires using the Docker image:

```
docker run -u $(id -u):$(id -g) -v $(pwd):/computerate \
  computerate/tools git pull --recurse-submodules
```

All the git commands that do not require access to the remote can be run natively or from the Docker image.

Note that for the computerate specification library the "computerate" command must be run from the directory that is one level above the git repository. The name of the root document is always "Main.lidr" or "Main.adoc":

```
docker run -u $(id -u):$(id -g) -v $(pwd):/computerate \
  computerate/tools computerate -t ietf -x txt \
  <git-repository>/Main.lidr
```

### B.2. Catalog

For the time being this document will serve as a catalog of available computerate specifications.

#### B.2.1. RFC5234

Name: RFC5234
Public key:
994e52b29a7bf4f7590b0f0369a7d55d29fb22befd065e462b2185a8207e21f1

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