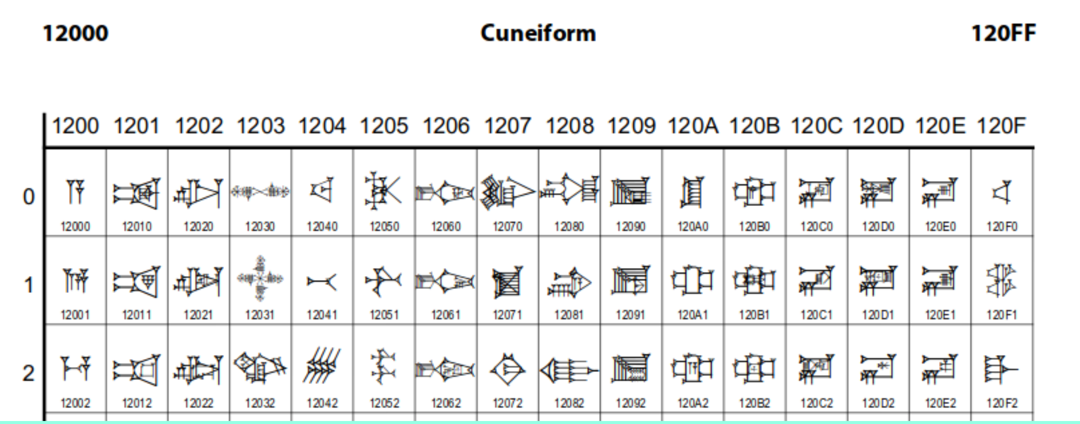
Using DFDL and

APACHE Daffodil™



12000 Cuneiform 120FF

	1200	1201	1202	1203	1204	1205	1206	1207	1208	1209	120A	120B	120C	120D	120E	120F
0	𒀀 12000	𒀐 12010	𒀠 12020	𒀰 12030	𒁀 12040	𒁐 12050	𒁠 12060	𒁰 12070	𒂀 12080	𒂐 12090	𒂠 120A0	𒂰 120B0	𒃀 120C0	𒃐 120D0	𒃠 120E0	𒃰 120F0
1	𒀁 12001	𒀑 12011	𒀡 12021	𒀱 12031	𒁁 12041	𒁑 12051	𒁡 12061	𒁱 12071	𒂁 12081	𒂑 12091	𒂡 120A1	𒂱 120B1	𒃁 120C1	𒃑 120D1	𒃡 120E1	𒃱 120F1
2	𒀂 12002	𒀒 12012	𒀢 12022	𒀲 12032	𒁂 12042	𒁒 12052	𒁢 12062	𒁲 12072	𒂂 12082	𒂒 12092	𒂢 120A2	𒂲 120B2	𒃂 120C2	𒃒 120D2	𒃢 120E2	𒃲 120F2

License

Goals of this Training

- Learn how to self-teach about DFDL
  - What are the sources of information?
  - How to find things in the DFDL Spec
  - How structure a DFDL Schema project
    - setting it up for testing
    - composing schemas together
  - Where to get help

- Manipulate and learn DFDL schemas

- Learn enough DFDL properties to create an interesting and real DFDL Schema
  - We will build one, for NTP, on Day 3.

Day 1

- Intro and Motivation
  - Why is DFDL Needed?
  - The DFDL Standard
  - DFDL for Cybersecurity
  - DFDL Limitations
    - What Kinds of Data Suitable for DFDL
- Intro to XML
  - Challenges of using XML as a Data Language
- Intro to XML Schema (as a basis for DFDL)
- DFDL for CSV - deep dive - line-by-line review
  - XML Schema concepts - namespaces, targetNamespace, include/import, annotations
  - DFDL Top level formats, reusing a named format
  - Lookup and discuss each of the DFDL Properties
  - Run it from CLI (Lab 0)
  - Examine Tests built into the CSV schema

- CSV - change data to break it
  - Understanding diagnostics (Lab 1)
    - Schema Definition Error
    - Parse Error / Unparse Error
  - Improved Diagnostics (Lab 2)
  - Capture as a negative test case in TDML
  - Built-in-Self-Test (BIST)
  - TDML - a way of life when test is everything
  - Standard schema project layout
- CSV - evolve it in new directions (Start on Day 1)
  - Multiple delimiters (Lab 3)
    - Canonical form
    - Rount trip tests
  - Specific element names and types
    - dfdl:calendarPattern
  - Escape schemes (Lab 4)
  - Looking for DFDL Information
  - Runtime-valued delimiters (Lab 5)

Day 2

- CSV - evolve it in new directions (Finish on Day 2)
  - Multiple delimiters (Lab 3)
    - Canonical form
    - Rount trip tests
  - Specific element names and types
    - dfdl:calendarPattern
  - Escape schemes (Lab 4)
  - Looking for DFDL Information
  - Runtime-valued delimiters (Lab 5)

- Binary Data - 1
  - Alignment
  - Bit order, Byte order
  - Fill Byte
  - Optional Elements using Presence bits (Lab 6)

- Binary Data - 2
  - Unparsing
    - Computed elements (Lab 7)
  - hidden groups
  - Stored Length

Day 3

- Create a Real DFDL Schema: NTP
  - Starting from the spec
  - Example test data
  - Network Time Protocol
    - NTP (RFC 5905)
  - With TDML tests, etc.
  - Divide and Conquer as a Team

- Advanced Topics (If there is time)
  - Other lengthKinds
  - New things we're doing with DFDL - Unit normalization for VMF
  - Dealing with giant data format specs - spec scrapers.

- DFDL Schemas
  - where are they? how many are there?
  - what is their status?

- Wrap-up / Conclusions
  - Don't forget to provide feedback

Why is DFDL Needed?

There are *hundreds* of ad-hoc data format description systems

Every Enterprise Software Company

- IBM (10+)
- Oracle(10+)
- SAP(10+)
- Microsoft
- SAS
- SyncSort
- AbInitio
- Pervasive
- Qlik/Expressor
- .... Dozens more

Every kind of software that takes in data:

- data directed routing
- database
- data analysis and/or data mining
- data cleansing
- master data management
- application integration
- data visualization

All these data format descriptions are:

- ***proprietary***
- ***ad-hoc***
- ***incompatible***

Even within products of the same company!

Why DFDL is Needed?

- Hundreds of data format description systems… means:
- Investment is spread too thin
  - Tools for creating data formats are inadequate
  - No product is comprehensive enough
    - Difficulty is grossly underestimated
  - Some products aren’t fast enough
- Customer lock in
- Inflexible packaging
  - Not libraries - must embed some product in your application data flow

Solving the Data Format Problem

- An Open Standard for DFDL
  - Multiple implementations that interoperate
    - Commercial & Open Source
  - Long-term sponsors
    - IBM – has their own DFDL implementations
    - US DoD, Canada DND
      - Cybersecurity as motivating use case
  - Available DFDL schemas for important data formats
- A High-Quality Open Source Library Implementation
  - With a supporting community of developers
  - With available commercial support

Why is DFDL Needed?

- But what about...
  - Apache Avro
  - Apache Thrift
  - Google Protocol Buffers
  - ASN.1 BER (or PER/DER/XER)
- Those are great, but are *prescriptive*.
  - They don't describe formats, they *are* data formats themselves.
  - We need a *descriptive* language.

DFDL = Data Format Description Language

- A standard from Open Grid Forum (OGF)
- Started 2001, Ratified 2022
- Big - 200+ pages

- DFDL is not a data format.
- Write a DFDL Schema to describe a format.

- DFDL is sometimes pronounced "DaFfoDiL"
- "Daffodil" and "DaFfoDiL" are not the same thing
  - DFDL = a language standard
    - a document
  - Daffodil = an open-source implementation of DFDL
    - a software library component

- DFDL is mostly not new
- Standardizes practice of data integration tools available commercially 1995 - 2010
- DFDL has some innovations - especially for unparsing binary data

GFD-R-P.240
OGF DFDL WG
dfdl-wg@ogf.org

Michael J Beckerle, Owl Cyber Defense/Tresys
Stephen M Hanson, IBM
February 2021

Data Format Description Language (DFDL) v1.0
Specification

Status of This Document
Grid Final Draft (GFD)

Obsoletes
This document incorporates all errata and clarifications to earlier DFDL v1.0 specification documents and therefore obsoletes both:

- GFD-P-R.207 dated September 2014 [OBSOLETE_DFDL_207]
- GFD-P-R.174 dated January 2011 [OBSOLETE_DFDL_174].

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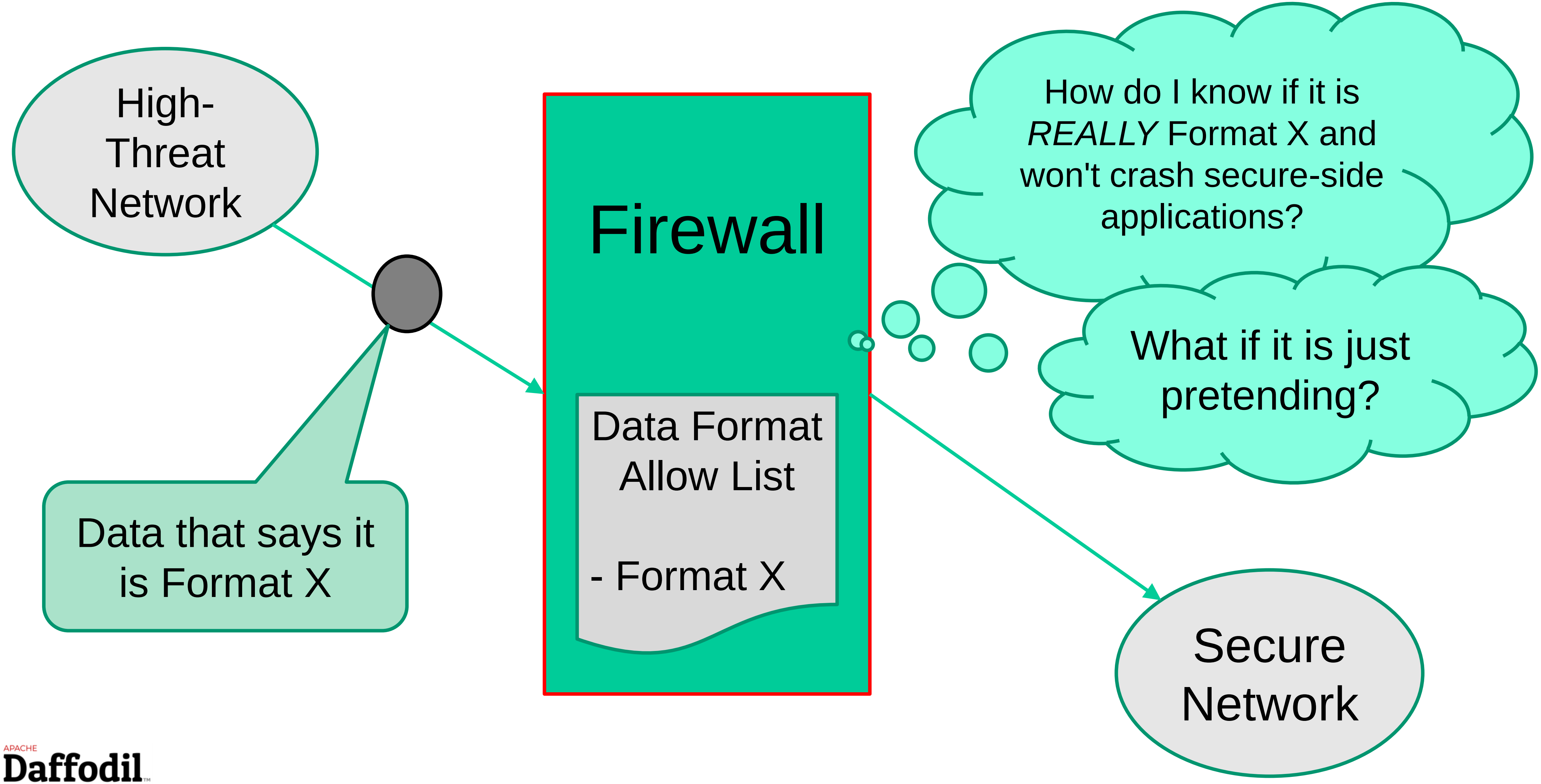
Abstract
This document provides a definition of a standard Data Format Description Language (DFDL). This language allows description of text, dense binary, and legacy data formats in a vendor-neutral declarative manner. DFDL is an extension to the XML Schema Description Language (XSD).

A Use Case

DFDL and Cyber Security

Cyber-Security Use Case: Bad Data DoS Attack



High-Threat Network

Data that says it is Format X

Firewall

Data Format Allow List

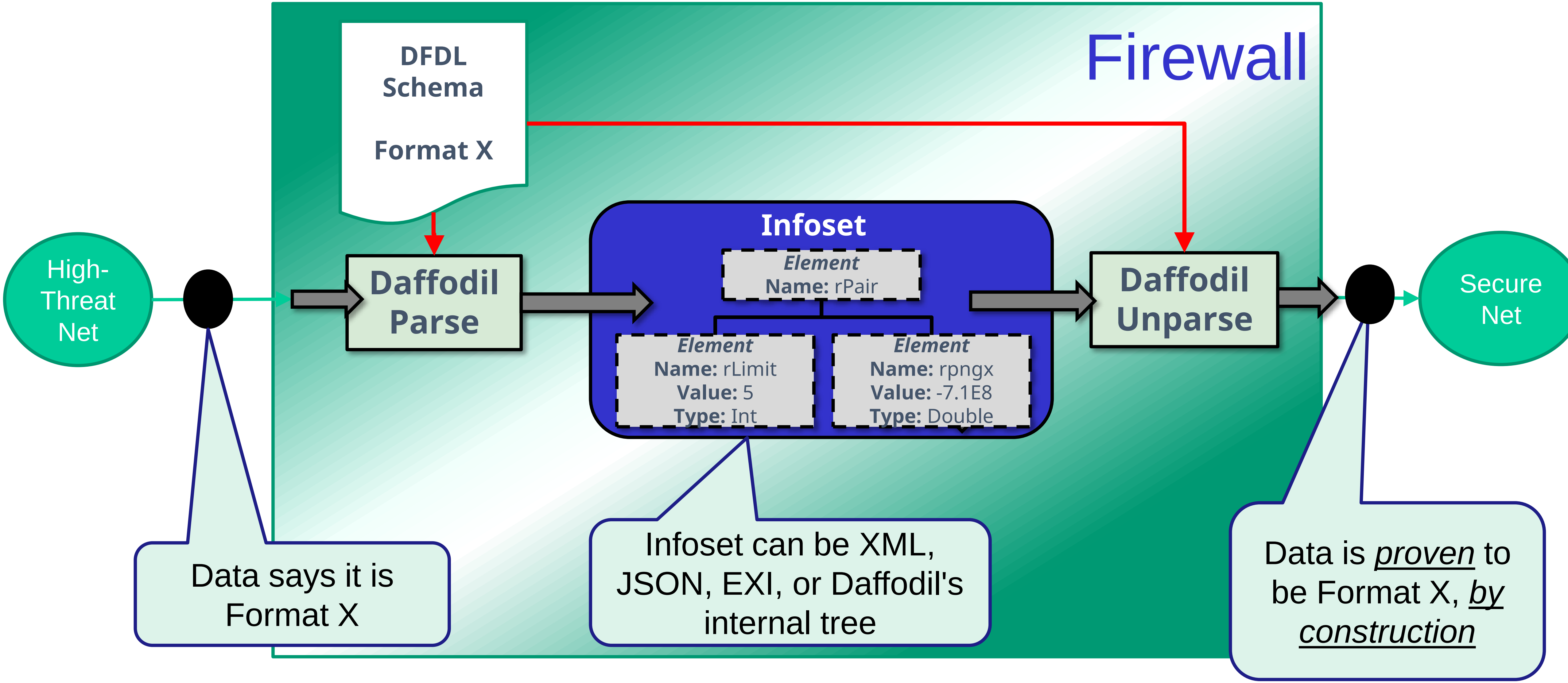
- Format X

How do I know if it is *REALLY* Format X and won't crash secure-side applications?

What if it is just pretending?

Secure Network

Cyber-Security Use Case: Full Protocol Break



Data says it is Format X

Infoset can be XML, JSON, EXI, or Daffodil's internal tree

Data is *proven* to be Format X, *by construction*

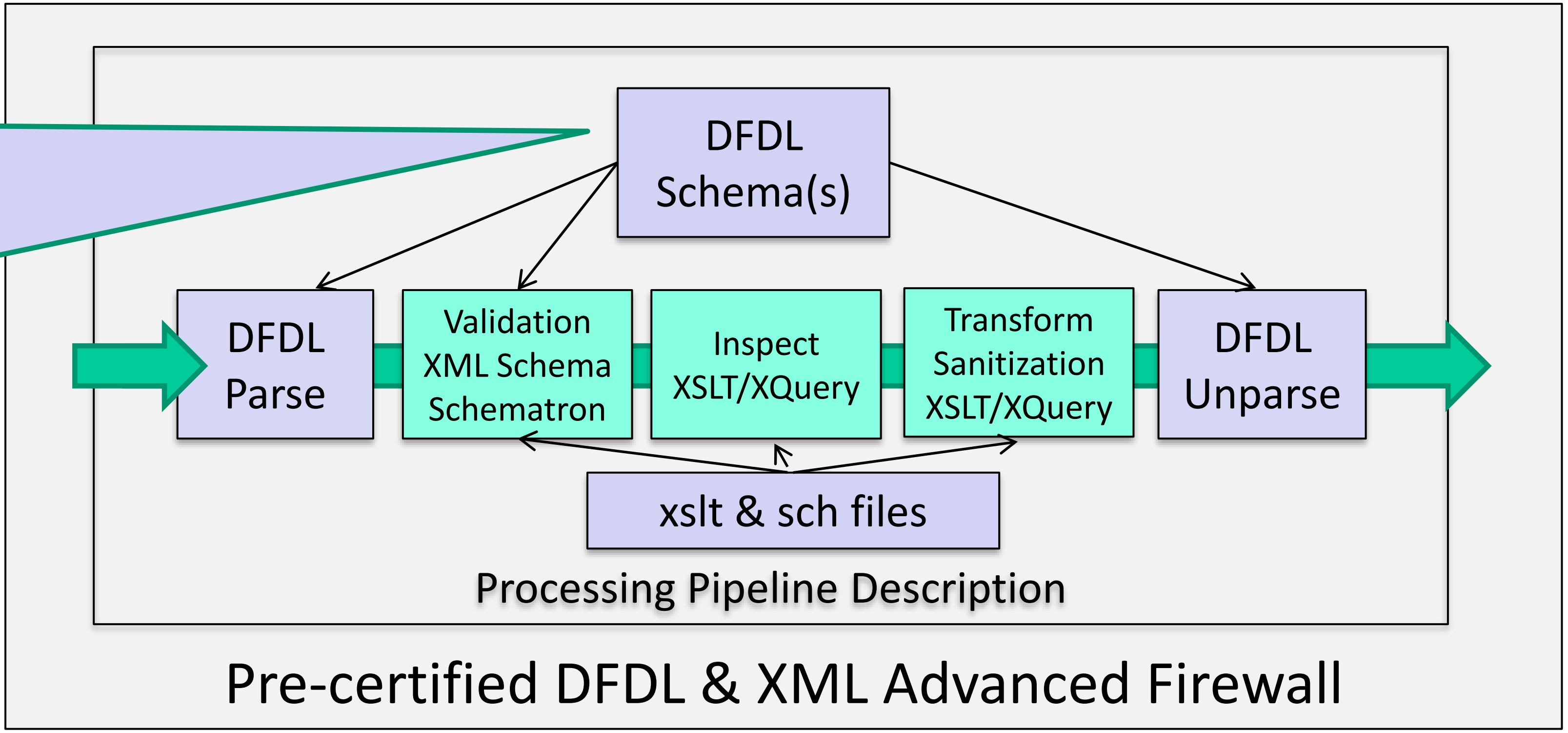
Reducing Cyber Security Cost for Everyone

- Some Network Boundary Protection Devices have to be Lab-Certified.
- Costly, Time-to-Market
- Software modules must be scrutinized carefully.
- With DFDL & XML Filtering, adding a new data type is just configuration

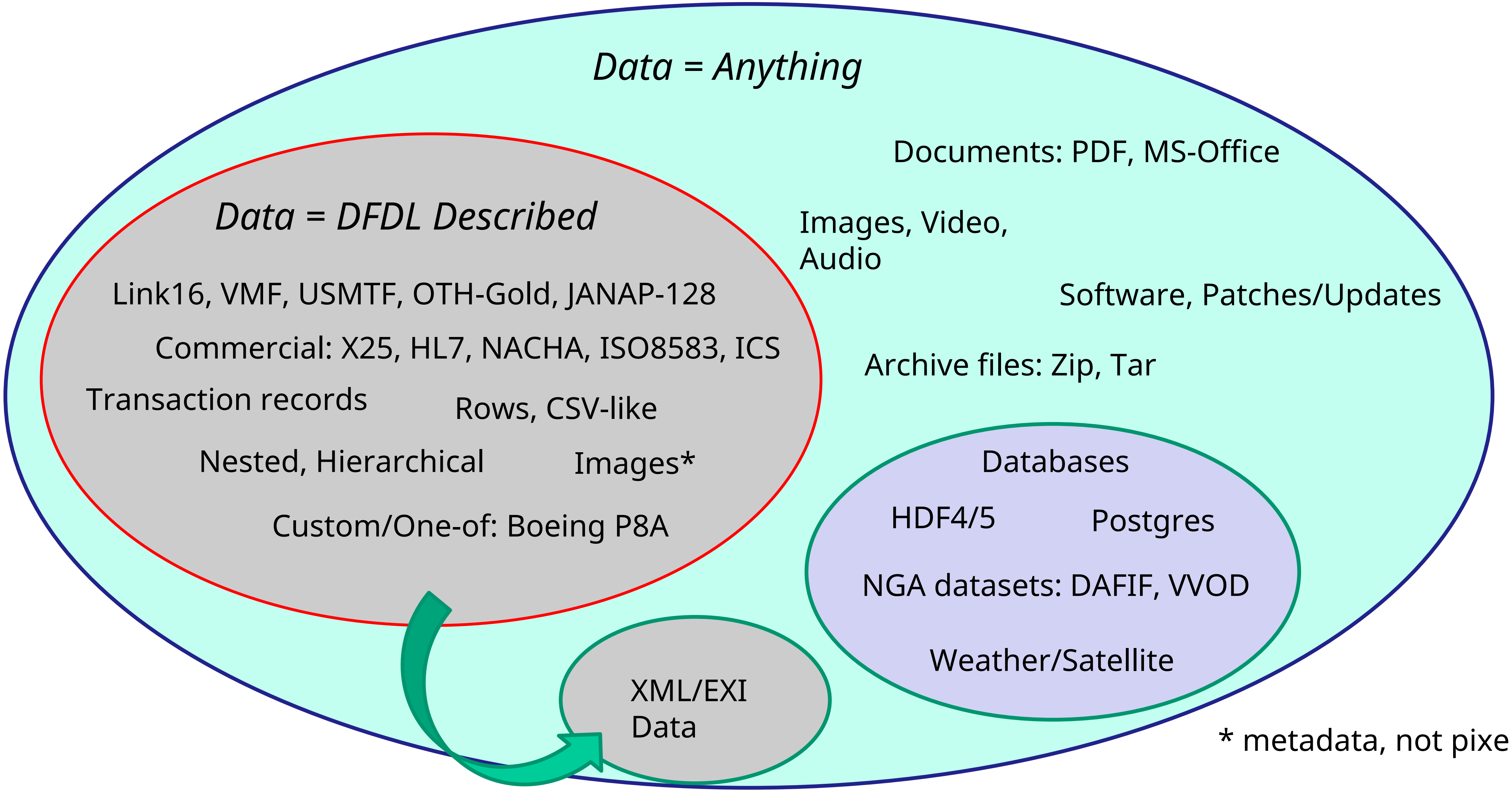
These are NOT new software modules

They're simple compared to software

No Lab-Based Security Assessment (LBSA) Required to add a new data type


DFDL Schema(s)
DFDL Parse
Validation XML Schema Schematron
Inspect XSLT/XQuery
Transform Sanitization XSLT/XQuery
DFDL Unparse
xslt & sch files
Processing Pipeline Description
Pre-certified DFDL & XML Advanced Firewall

Q: What Kinds of Data is DFDL Good For?
A: Not everything



Data = Anything

Documents: PDF, MS-Office

Images, Video, Audio

Software, Patches/Updates

Archive files: Zip, Tar

Data = DFDL Described

Link16, VMF, USMTF, OTH-Gold, JANAP-128

Commercial: X25, HL7, NACHA, ISO8583, ICS

Transaction records

Rows, CSV-like

Nested, Hierarchical

Images*

Custom/One-of: Boeing P8A

XML/EXI Data

Databases

HDF4/5

Postgres

NGA datasets: DAFIF, VVOD

Weather/Satellite

* metadata, not pixels

Q: What Kinds of Data is DFDL Good For?
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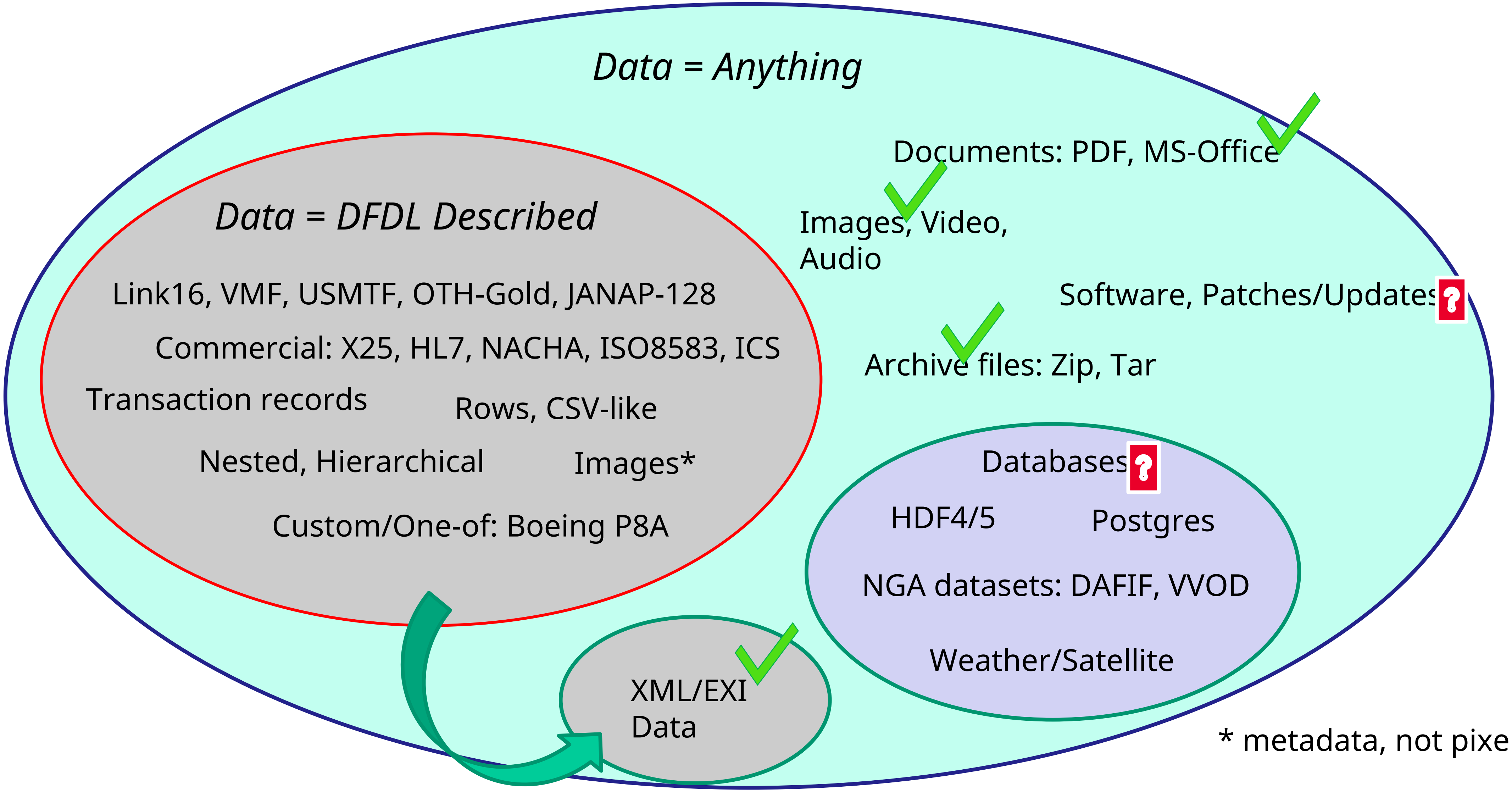

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Documents: PDF, MS-Office ✓

Images, Video, Audio ✓

Software, Patches/Updates ?

Archive files: Zip, Tar ✓

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Current DFDL v1.0 Language Limitations

- Recursive types
  - DFDL v1.0 not a Turing-Complete language
  - On purpose - it's a feature, not a bug
- Position of elements "by offset"
  - Random jumping around data
  - Ex: TIFF file format
    - TIFF cannot be described in DFDL v1.0

Thanks to http://langsec.org/occupy/

Data Format Description Language

- Core Concepts
- Leverage XML Schema (XSD or XSDL)
  - Grammar scaffolding
  - Describes the logical data model
  - DFDL uses only a subset of XML schema
  - Provides *standard ways to annotate*
- Add annotations
  - Describe the physical representation.
- Read and write from same DFDL Schema

- Because Developers [Love | Hate] XML
- The DFDL Schema is based on XSD
- The Infoset created when parsing data does NOT have to be XML
  - Can be EXI
  - Can be JSON
  - Can be directly connected to NiFi Records, Spark Structs, etc.

XML as a Data Language

Introduction To XML

XML - eXtensible Markup Language

- originally intended for human authoring/reading
- textual
- mostly whitespace *insensitive*
- copies syntax principles from HTML

```
<elementName
     childName1="attribute value text"
     childName2="more attribute value text">
  value text <subElementName>sub element value</subElementName>
  more element value text
</elementName>
```

XML - eXtensible Markup Language

- WWW Consortium (w3c) standard
  - Versions 1.0 and 1.1 exist.
  - Almost all usage is version 1.0
- Designed to handle large and complex *documents*
  - namespaces to handle naming conflicts

XML - Love it/Hate it

- Reasons people love XML
  - Standard, robust, versioned, familiar (to those who have seen HTML)
  - Textual - with standard way to specify charset encoding
    - Standard file preamble/first-line - optional but recommended
    - <?xml version="1.0" encoding="utf-8"?>
  - Has a robust schema language
  - Precise specification of syntax and infoset (data model), excellent interoperability

- Reasons people hate XML
  - inefficient, verbose as a data language
    - ex: no real *arrays*, just repeating elements
  - two kinds of child nodes (element children, attribute children)
    - they can have the same name - two different child namespaces
    - note: I know of no other data structure system that has/allows this.
  - namespace mechanism *seems* too complex
  - whitespace problems
  - text character restrictions

XML - Whitespace Mostly Insignificant

```
<title kind="draft 1">iso lorem txt facto</title>

<title kind="draft
1">
  iso lorem
  txt facto
</title>
```

- Order of multiple attributes is not significant
- Whitespace (other than single spaces) is *normally* not significant
  - For attributes: gets collapsed to single spaces
  - XML tools will often wrap or unwrap lines

XML - Prefixes, Qualified Names (QName)

```
<ex:myEnclosingElement
  xmlns:ex="http://example.com"
  xmlns:pre="urn:foo.com/data1">

   ...
   <pre:myTextItem
     ex:myAttr="a value">
     this text is the element content
   </pre:myTextItem>
   ...

</ex:myEnclosingElement>
```

`xmlns` is an XML *keyword*

These URIs are just unique IDs.

They are never fetched.

XML - Default Namepace

```
<enclosingElement
  xmlns="http://example.com">
  ...
  <foo><bar>6.847</bar></foo>
  ...
</enclosingElement>
```

`xmlns` with no prefix defines the default namespace

This element and enclosed elements with no prefix are in the default namespace.

http://example.com is a reserved URI for examples in XML.

XML - No Namepace

```
<enclosingElement
   xmlns="">
    ...
    <foo><bar>6.847</bar></foo>
    ...
</enclosingElement>
```

In XML data with no xmlns attributes the elements have *no namespace*

Or you can explicitly shut off default namespace

`xmlns` with no prefix AND no URL removes the default namespace

Contained elements with no prefix have no namespace

XML - Quoting, Character Entities

```
<elementName
  attributeName='a "value" with quotes'>
  ... element content ...
</elementName>

<elementName
  attributeName="a &quot;value&quot; with quotes">
  ... element content ...
</elementName>
```

- &quot; "
- &apos; '
- &amp; &
- &gt;   >
- &lt;   <
- &#13; decimal numeric character entity (13 is Carriage Return aka CR)
- &#x0D; hex numeric character entity (x0d is Carriage Return aka CR)

- XML 1.0 does not allow any ASCII control characters (00 to 1F) except TAB, LF, CR
- XML 1.0 converts CRLF to LF, and CR (alone) to LF.

XML - Element Quoting

```
<malformedXML>
  This content uses XML syntax literally
  in the element value to <emphasize>
  & generally mess with things.
</malformedXML>

<wellFormed1>
  This content uses XML syntax literally
  in the element value to &lt;emphasize&gt;
  &amp; generally mess with things.

  Note the whitespace is not guaranteed to be preserved.
</wellFormed1>

<wellFormed2><![CDATA[
  This content uses XML syntax literally
  in the element value to <emphasize>
  & generally mess with things.

  But now the space, tab, and lines are preserved. Even for pretty printed XML.
  (Except line endings CRLF/CR still become LF)
  Character entities cannot be used at all.
]]></wellFormed2>
```

XML data and CR (0x0D) line endings

- XML does not round-trip CR

  <foo>mydata&#x0D;</foo>

  6 characters for the character entity

- Read by XML you get
  - an element with a string of length 8 as contents
  - the string contains "mydata" plus a single CR character.

- Write it out with default writer you get in output:

  <foo>mydata␍</foo>

  A single CR character with code point 0x0D

- Read by XML again, and you get in memory:

  <foo>mydata␊</foo>

  A single LF character with code point 0x0A

- Because XML converts CRLF *and isolated CR* to LF !!!
  - XML wants data to be whitespace insensitive
  - But REAL data often is very particular about whitespace, control-chars, etc.

- To preserve CR
  - Special writer always writes out "&#x0D;", but must be aware of quoting context.
  - ✓ Special reader/writer always converts CR to some other character that is preserved.

- Daffodil uses 0xE00D in the *Unicode Public Use Area* (PUA)
  - See "Daffodil and the DFDL Infoset" at https://daffodil.apache.org/infoset/

XML data and the NUL character

- XML documents cannot contain NUL.
  - No way, No how.
  - Not even as &#x0;
- Daffodil uses 0xE000 in the *Unicode Public Use Area* (PUA)
  - See "Daffodil and the DFDL Infoset" at https://daffodil.apache.org/infoset/

XML - Whitespace, Pretty Print and CDATA

- For XML data to be human accessible, must be pretty-printed (indented)

- Beware pretty-printing of XML.
  - It does not necessarily preserve string data.
- Consider this string element:

```
<callSign>BB823<callSign>

<callSign>
   BB823
</callSign>

<callSign><![CDATA[BB823]]><callSign>
```

Pretty print at deep indent level might do this

- Most (All?) Pretty printers respect CDATA and will not corrupt this.

- Note: xml:space='preserve' does *NOT* fix this.

XML as a Data Language

- Requires some effort
- Map XML Illegal chars to PUA (Especially NUL)
- Map CR to PUA
- Pretty printing can cause trouble
  - CDATA bracketing needed around all xs:string elements
  - Protects significant whitespace from being harmed

XML - Element Content Types

- Element with Simple Type Content

```
<courseNum>6.847</courseNum>
<courseDesc>Intro to Computer Science</courseDesc>
```

- Element with Simple Type Content with Attributes
  - *Not used by DFDL v1.0* when value is non-empty

```
<courseNum creditHours="9">6.847</courseNum>
```

XML - Element Content Types

- Element with Empty Content

```
    <middleName/>

equivalent to

    <middleName></middleName>
```

- Element with Empty Content with Attribute

```
<middleName xsi:nil='true'/>
```

- This is XML's very clumsy way of expressing 'null' or 'nilled' values.

XML - Element Content Types

- Element with Element-only Complex Type Content
  - Complex Type in XML means "may contain child elements"

```
<book>
 <title>Plants of the Amazon</title>
 <isbn>1-2345678-90123</isbn>
</book>
```

- Element with Mixed Content (for real text+markup cases)
  - Mixture of text and elements
  - HTML-like
  - *Not used by DFDL v1.0*

```
<bookReview>
As entertaining as the tome <title>Plants of the Amazon</title>
is, I found it full of errors. You can find this book using its
<isbn>1-2345678-90123</isbn> at your favorite online bookstore.
</bookReview>
```

XML Schema Description Language (XSD or XSDL)

INTRODUCTION TO XML Schema (XSD)

Review: Formal Grammars

- When we describe languages we use a grammar
- Typically use a Backus-Naur Form (BNF) Grammar
- Ex: US Postal Address

John Doe IV
8840 Stanford Blvd Ste 200
Columbia MD 12345

postal-address ::= name-part street-address zip-part

name-part ::=

    personal-part *last-name* opt-suffix-part *EOL*

personal-part ::= *first-name* | *initial* "."

street-address ::= *house-num street-name* opt-apt-num *EOL*

zip-part ::= *town-name* "," *state-code ZIP-code EOL*

opt-suffix-part ::= "Sr." | "Jr." | roman-numeral | ""

opt-apt-num ::= *apt-num* | ""

XML Schema is a Formal Grammar

- Grammar of an XML document
- In a very verbose notation
- Assumes XML document is well-formed

postal-address ::= name-part street-address zip-part

```
<element name="postal-address">
  <complexType>
   <sequence>
     <group ref="name-part"/>
     <element name="street-address"
              type="street-address-type"/>
     <group ref="zip-part"/>
   </sequence>
  </complexType>
</element>
```

```
<postal-address>
  <first-name>John</first-name>
  <last-name>Doe</last-name>
  <name-suffix>IV</name-suffix>
  <street-address>
    <street>8840 Stanford Blvd</street>
    <apt-num>Ste 200<apt-num>
    <city>Columbia</city>
    <state>MD</state>
  </street-address>
  <zipcode>12345</zipcode>
</postal-address>
```

XML Schema as a Formal Grammar

personal-part ::= *first-name* | *initial* "."

```
<group name="personal-part">
  <choice>
    <element name="first-name" type="xs:string"/>

    <element name="initial">
      <simpleType>
        <restriction base="xs:string">
          <pattern value="[A-Z]\."/>
        </restriction>
      </simpleType>
    </element>

  </choice>
</group>
```

XML Schema Defining Forms

XSD Terminology:
Elements have *declarations*.
Types and Groups have *definitions*.

- An XML Schema is a collection of *Defining Forms*
- Element
  - always named, can be *nillable*
- SimpleType - int, boolean, string, float, date, time, etc.
  - named or anonymous (inline)
- ComplexType - contains child elements
  - named or anonymous (inline)
- Group
  - named for reuse or anonymous (inline)
  - Sequence
  - Choice

XML Schema (XSD) is Verbose

Compare this BNF:

personal-part ::= *first-name* | *initial* "."

To this XSD:

```
<group name="personal-part">
  <choice>

    <element name="first-name" type="xs:string"/>

    <element name="initial">
      <simpleType>
        <restriction base="xs:string">
          <pattern value="[A-Z]\."/>
        </restriction>
      </simpleType>
    </element>

  </choice>
</group>
```

XSD is Verbose for One Good Reason

- *Standardized Annotation Syntax*
  - non-native attributes
  - appinfo annotations

- Every part of the XML Schema has these. Consider:

```
<group name="personal-part">
  <choice dfdl:choiceLengthKind='implicit'>
    <annotation>
      <appinfo source="http://www.ogf.org/dfdl/">
        <dfdl:choice choiceDispatchKey='{
              ....
        }'/>
      </appinfo>
    </annotation>
    ...
```

- BNF provides noplace to hang annotations. It is too dense notationally. No flexibility.

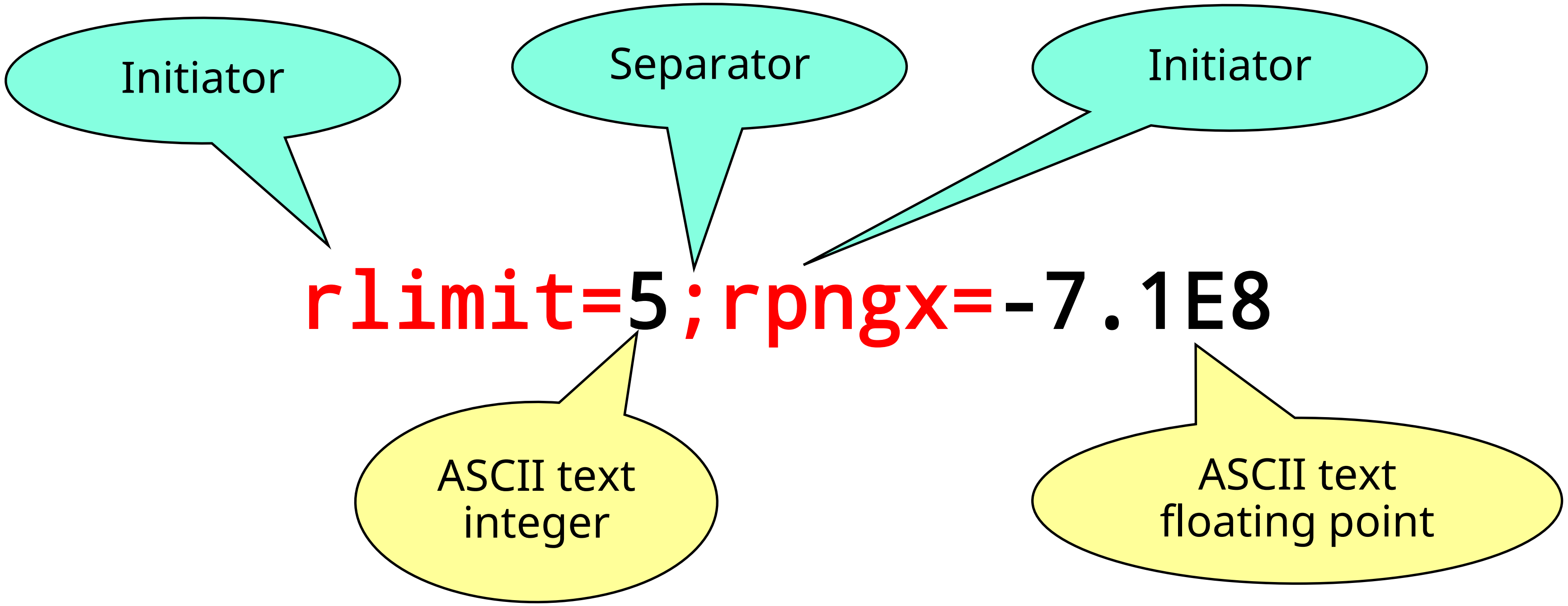
personal-part ::= *first-name* | *initial* "."

INTRODUCTION TO DFDL

Example – Delimited Text Data

```
rlimit=5;rpngx=-7.1E8
```

Example – Delimited Text Data



Initiator

Separator

Initiator

`rlimit=5;rpngx=-7.1E8`

ASCII text
integer

ASCII text
floating point

Separators, initiators (aka tags), & terminators are all examples in DFDL of *delimiters*

DFDL Schema

```
<xs:complexType name=“rPair">
  <xs:sequence>
    <xs:element name=“rlim" type="xs:int"/>

     <xs:element name=“rpng" type="xs:float"/>

  </xs:sequence>
</xs:complexType>
```

Logical
Elements

DFDL schema

Top level format declaration block applies to this entire schema *file*.

```
<xs:annotation>
  <xs:appinfo source="http://www.ogf.org/dfdl/">
     <dfdl:format representation="text"
             textNumberRep="standard" encoding="ascii"
             lengthKind="delimited“ .../>
   </xs:appinfo>
</xs:annotation>

<xs:complexType name=“rPair">
  <xs:sequence dfdl:separator=";" ... >
    <xs:element name="rLim" type="xs:int"
                dfdl:initiator=“rLimit=" ... />
     <xs:element name=“rpng" type="xs:float"
                dfdl:initiator=“rpngx=" ... />
  </xs:sequence>
</xs:complexType>
```

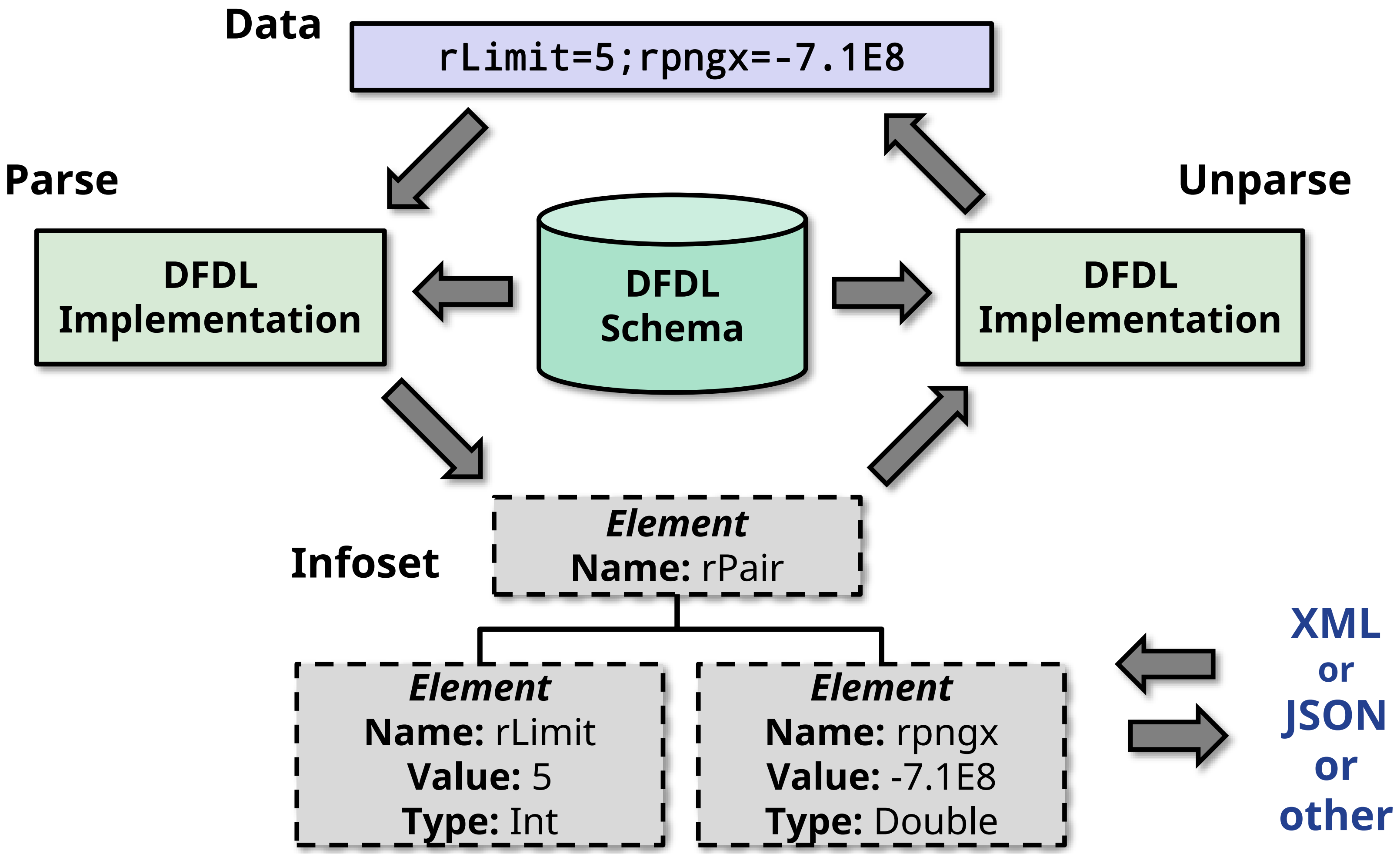
DFDL properties

;

rLimit=5

rpngx=-7.1E8

DFDL Data and Infoset Lifecycle



DFDL Schema

- A DFDL Schema is an XML Schema
- Minus
  - Only a subset of XML Schema is used
- Plus
  - Annotations that allow the schema to describe many data formats, not just XML.
- If you erase the annotations, a DFDL Schema IS an XML Schema
  - An XSD Validator will simply ignore the DFDL annotations

CSV Deep Dive

CSV Deep Dive

- Line-by-line review
- XML Schema concepts - namespaces, prefixes, NCName and QName, targetNamespace, include/import, DFDL annotations
- DFDL Top level formats, reusing a named format
  - org/apache/daffodil/xsd/DFDLGeneralFormat.dfdl.xsd
  - Found in daffodil-lib module:
    - shortcut https://s.apache.org/daffodil-DFDLGeneralFormat.dfdl.xsd
- Lookup and discuss each of the DFDL Properties
- Run it from CLI
  - Doc Link: https://daffodil.apache.org/cli/
- Examine Tests built into the CSV schema

DFDL Core Concepts

- Infoset - a Data Model
    - DFDL Spec - Section 4 Figure 1
    - parse into the DFDL Infoset
    - unparse from the DFDL Infoset
    - NOT the same as the XML infoset
        - There is a mapping to/from XML and the DFDL Infoset
        - Specific to Apache Daffodil
        - see: https://daffodil.apache.org/infoset/

- Simple Types - subset of XSD/XML types
    - DFDL Spec - Section 5.1 Figure 3

TEST/QA for DFDL Schemas

Test Data Markup Language (TDML)

- XML-based language for writing (and managing) DFDL tests
  - parserTestCase
  - unparserTestCase
  - tests can do round-trips - parse [unparse [parse [unparse]]]
- A TDML file glues together
  - DFDL schema
  - test data (text, binary files, hex, bits)
    - input for parse, expected result for unparse
  - test infoset (XML)
    - input for unparse, expected result for parse
  - Can be in separate files (e.g., test.bin, test.xml, schema.dfdl.xsd, tests.tdml)
  - Can all be expressed directly in the TDML file itself (self-contained test in one TDML file)
    - Perfect for bug reports, or to get help/support with DFDL properties you don't understand
- Doc Link: https://daffodil.apache.org/tdml/
- XML Schema for TDML:
  - https://s.apache.org/daffodil-tdml.xsd

Standard File System Layout

- link: https://daffodil.apache.org/dfdl-layout/
- There are two "standard" layouts now
  - simplified layout - no namespaces. For small projects, learning
    - src
    - test
  - namespaced layout - supports packaging very large schemas composed of multiple projects
    - src/main/resources/myOrg/formatName
    - src/test/resources/myOrg/formatName
    - src/test/scala/myOrg/formatName
- We will use simple layout at first. Later use namespaced layout.
- A template system 'giter8' can be used to create an empty schema project
  - https://github.com/apache/daffodil-schema.g8

Built-In Self Test (BIST)

- Every DFDL Schema should have BIST
- Standard tool 'sbt' - Simple Build Tool
  - 'sbt test' - verifies schema works - loads all dependencies
    - including scala
    - including Daffodil and everything it depends on
    - including other schemas that this one uses (if they are published)
  - Runs suite of TDML tests (Test Data Markup Language)

Lab 0

CSV-Like Data

CSV - Change it, break it

- Modify data - add an extra field to a row or remove a field so the row is too short.
- The basic csv.dfdl.xsd schema tolerates this!
- Let's fix that.
  - Edit csvHeaderEnforced.dfdl.xsd schema so it does not accept this.
- Add a TDML negative test that ensures your schema detects this error in the data
  - Read about negative tests on the TDML doc page
- Add a Junit 1-liner so your test runs with 'sbt test'
  - src/test/scala/.....

CSV - Enhancing it

- As is, the CSV schema is pretty flawed
  - Fields all come through as "item" elements
  - All fields are string type despite DOB is always a date.
  - Can't have a comma inside a field - no escaping mechanism
- Let's start fixing these

Lab 1

Named & Typed Elements

NameDOB1.dfdl.xsd

- Replace "item" element with 4 local element declarations
  - 3 of these with appropriate names

    ```
    <xs:element name="...." type="xs:string" ... />
    ```

  - 1 of these

    ```
    <xs:element name="DOB" type="xs:date"
        ... date properties go here .... />
    ```

- Study tests in TDML file that use new schema
  - Has 1 negative test to be sure incorrect date syntax is caught

NameDOB1.dfdl.xsd

- "Left over data"
- Parse created an infoset that ignores the final faulty data
- This is *correct* behavior
- Parser back-tracks to end the record array when the parse of a record fails.
- So the parse succeeds. It just doesn't consume all the data.
- Next lab will modify the schema to get better diagnostics and reject faulty dates.

Different Kinds of Errors

- Schema Definition Error
  - the DFDL schema has an error
  - usually detected at schema compilation time (before parse/unparse begins)
  - sometimes detected at runtime
    - ex: if dfdl:lengthKind="delimited" dfdl:terminator="{ ../terminatorField }" but that expression returns "" (empty string).
- Parse Error
  - the data has an error or doesn't match the schema
  - causes backtracking to try other choice alternatives
  - causes optional elements/variable-length array elements to stop parsing more elements
  - only fatal if there are no alternatives for the parser to try
- Unparse Error
  - always fatal - unparsing fails
- Validation Error
  - if Daffodil is run with validation options selected
  - These do not cause backtracking
- Left-over data - warning (error if occurs in a TDML test)
  - parse succeeded, but did not consume all the data
  - This can be correct behavior if we are calling parse via API in a loop.
- TDML negative tests can expect any of these

Lab 2

Discriminators
More-Specific Diagnostics

DFDL discriminators

- Discriminators are used to "cut off possibilities"
- They discriminate a DFDL "point of uncertainty"
- Let's add one to nameDOB2.dfdl.xsd
  - A pattern discriminator takes a regex, and matches it against the data stream.

```
<dfdl:discriminator
  testKind="pattern"
  testPattern="."/>
```

  - Boilerplate: Must be wrapped in a sequence (so you can put it wherever you want)

```
<xs:sequence>
  <xs:annotation><xs:appinfo source='http://www.ogf.org/dfdl/'>
    <dfdl:discriminator testKind="pattern" testPattern="."/>
  </xs:appinfo></xs:annotation>
</xs:sequence>
```

NameDOB2.dfdl.xsd

- Add discriminator at start of record.
  - Suggest: Use a group definition and group reference to declutter.

```
<group name="discriminateAnyData">
  <sequence>
    <annotation><appinfo source="http://www.ogf.org/dfdl/">
      <dfdl:discriminator testKind="pattern" testPattern="."/>
    </appinfo></annotation>
  </sequence>
</group>

....to use the discriminator just...

<group ref="ex:discriminateAnyData"/>
```

- Do we get a more-specific error?
  - not "left over data"

Do we need dot-matches newline mode? (?s)

NameDOB2.dfdl.xsd

- Adding discriminator makes it possible to get more specific errors that mention the specific element and type
- discriminators provide format clarity about what deciding factor is that selects among alternatives
- discriminators can improve performance
  - for formats that do backtracking
  - backtracking aka "speculative parsing"

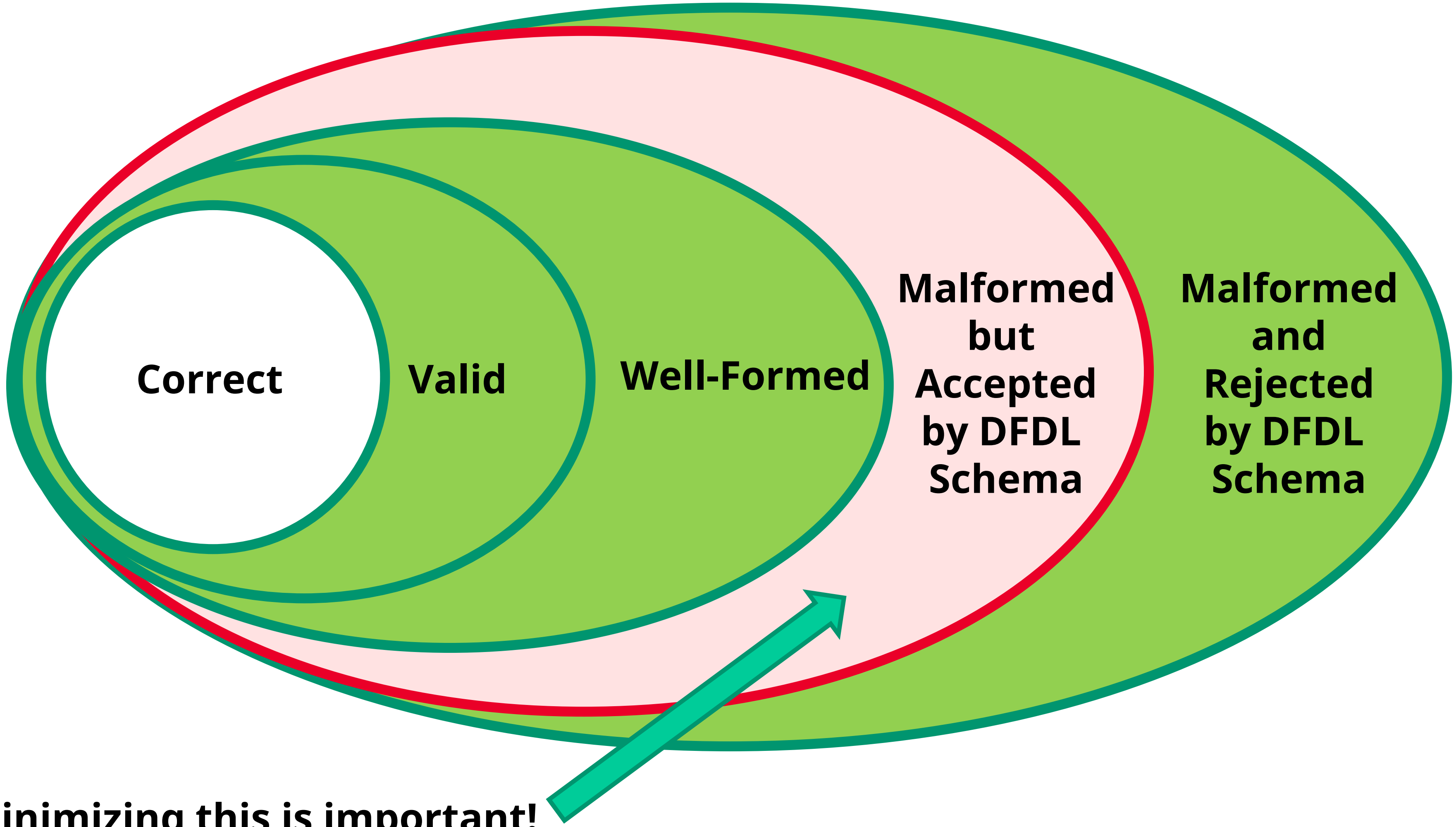
Well-Formed vs. Valid vs. Correct

Negative Testing

Quality Scale for Data

- Correct
  - Data that is perfect and suitable for all uses by intended applications
  - Blameless: If an application fails, that's its fault, not the fault of this data
- Valid
  - Data that satisfies "validity checks"
  - Establishes a policy about values in the data
  - Cares about values of numbers, patterns of text, co-existence constraints,.....
- Well-Formed
  - Data that has some value.
  - Applications may still want to use it even if it is not suitable for many things
  - "Worth talking about"
  - Cares that numbers are numbers, text is text, dates are dates
  - Can find and isolate all the pieces of the data
- Malformed
  - Data that shouldn't be considered.
  - Don't even want to bring it into memory
  - Might not even be what it says it is.
  - Dangerous data: Likely to crash applications - maybe even those trying to tolerate invalid data.

Don't Accept Malformed Data


Correct
Valid
Well-Formed
Malformed but Accepted by DFDL Schema
Malformed and Rejected by DFDL Schema

Minimizing this is important!

Design to Exclude Malformed Data

- Schema should admit well-formed data
- Schema should exclude malformed data
  - And provide a good diagnostic.
  - True regardless of the fact that most data format documentation does not call out the diagnostic behavior.

- These goals are consistent with the DFDL schema being a good declarative specification of the format
  - Providing a good diagnostic makes it clearer what aspect of the specification is not being obeyed.

Well-Formed vs. Valid vs. Correct

- All these are a spectrum of how suitable is a given piece of data for the expected applications that consume it.
- DFDL schemas should be about parsing well-formed data, and rejecting malformed data.
  - Similarly they should be about unparsing well-formed infosets into well-formed data
- Sometimes constraints need to be expressed as part of well-formedness checking
  - DFDL Assertions may not be expressive enough.
  - Schematron rules could be used here
- But…this is still about well-formed data, not validity.

How to tell apart Well-Formed from Valid?

- Could you ever want the data available with this erroneous content in it?
    - For applications that want to tolerate some data mistakes?
    - For applications that want to help humans correct mistakes manually?
  - If so then you want that data to be considered well-formed, though invalid.
- Simple rule about Well-Formed
  - If it's not well-formed, you won't even get it into memory, so you can't touch it.
- DFDL Schemas can be designed to be strict or lax about what they accept.

Well-formed vs. Valid vs. Correct

- Test/QA needs can provide hints
  - Do you want to use your DFDL schema to generate erroneous data for test purposes?
  - If so by definition, that data will be well-formed according to your DFDL Schema
    - Because otherwise you can't use your DFDL Schema to generate it!
  - Such data will be Incorrect or Invalid, but Well-Formed.

Is it Well-Formed If.....?

- There is left-over data at the end of the file?
  - Maybe yes: if there is up to a few KBytes of it
    - A reasonable thing some file formats may allow
  - Clearly no: if there is 3 gigabytes of it.

- Sometimes it is a matter of degree!

Lab 3

Multiple Delimiters Canonical Form

Allowing Commas inside Comma-sep data

- Data formats use a variety of ways to fix this
  - Allow multiple terminators
    - Tab, | (aka pipe or vbar), or "//"
  - Escaping
  - Dynamic Terminator per row

Using Multiple Terminators: nameDOB3

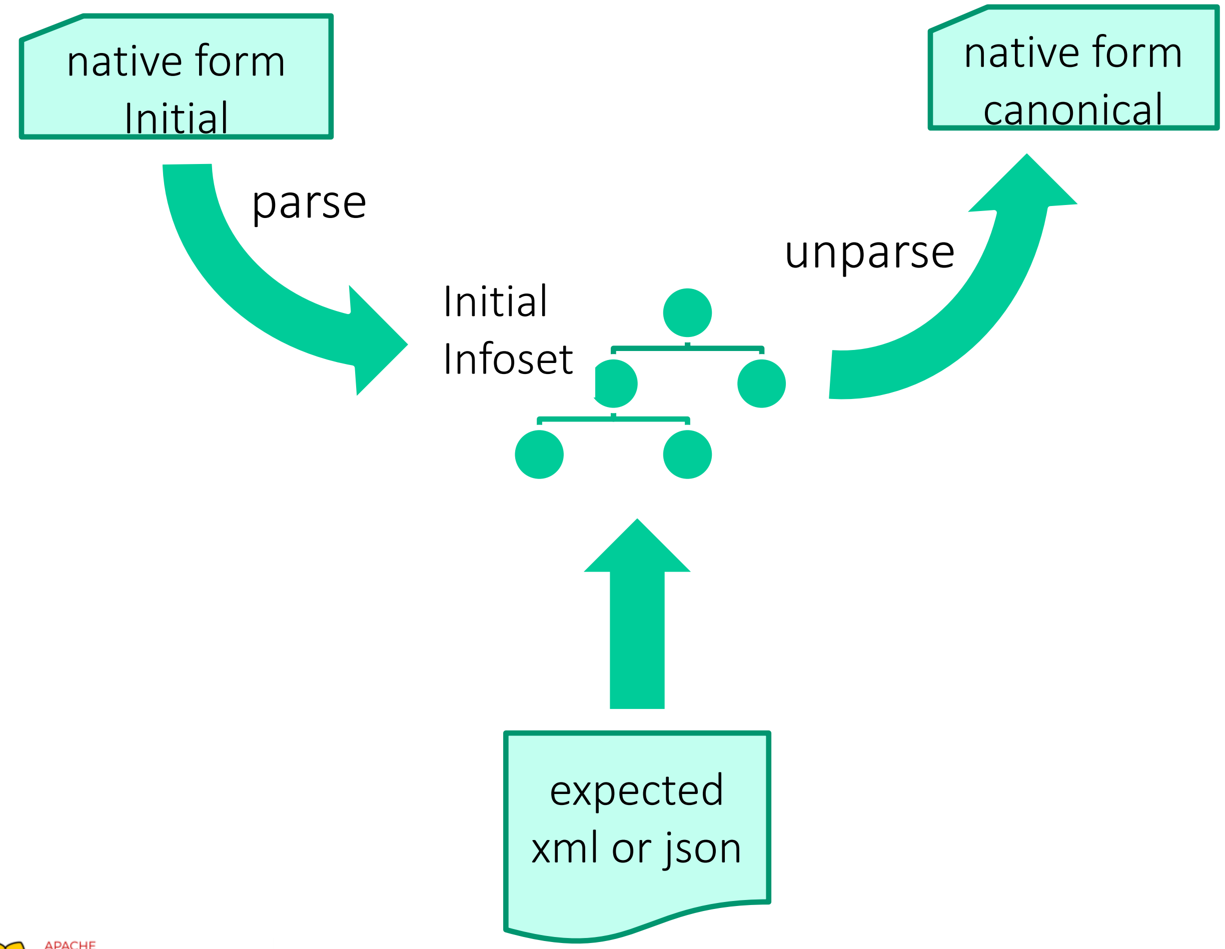
- Change `dfdl:terminator=","` to allow TAB, |, and // as terminators
  - Look at DFDL spec's description of terminator property
    - List of DFDL String Literals or DFDL Expression
    - XMLism - List means "whitespace separated list".
  - Lookup DFDL String Literal
    - A Tab is whitespace. So….use a DFDL Character Entity
- Study TDML Test that uses a mixture of terminators
- Issue: Unparse does NOT recreate the input data!
  - You get *Canonical Form* data out

Canonical Form is more Secure

- When formats offer alternatives *canonicalization* (c14n) improves data security
- Blocks covert channels
- Ex:
  - Format allows any amount of whitespace around comma-separators
  - Transmit covert data via number of spaces before/after the commas
  - Canonical form " , " (one space either side of comma) blocks the channel
- Insisting that data output is bit-for-bit identical is a holdover from inspect-only pass/fail data security

TDML Round Trip Parse/Unparse

- By default TDML tests run in roundTrip = "onePass" mode



native form Initial

parse

Initial Infoset

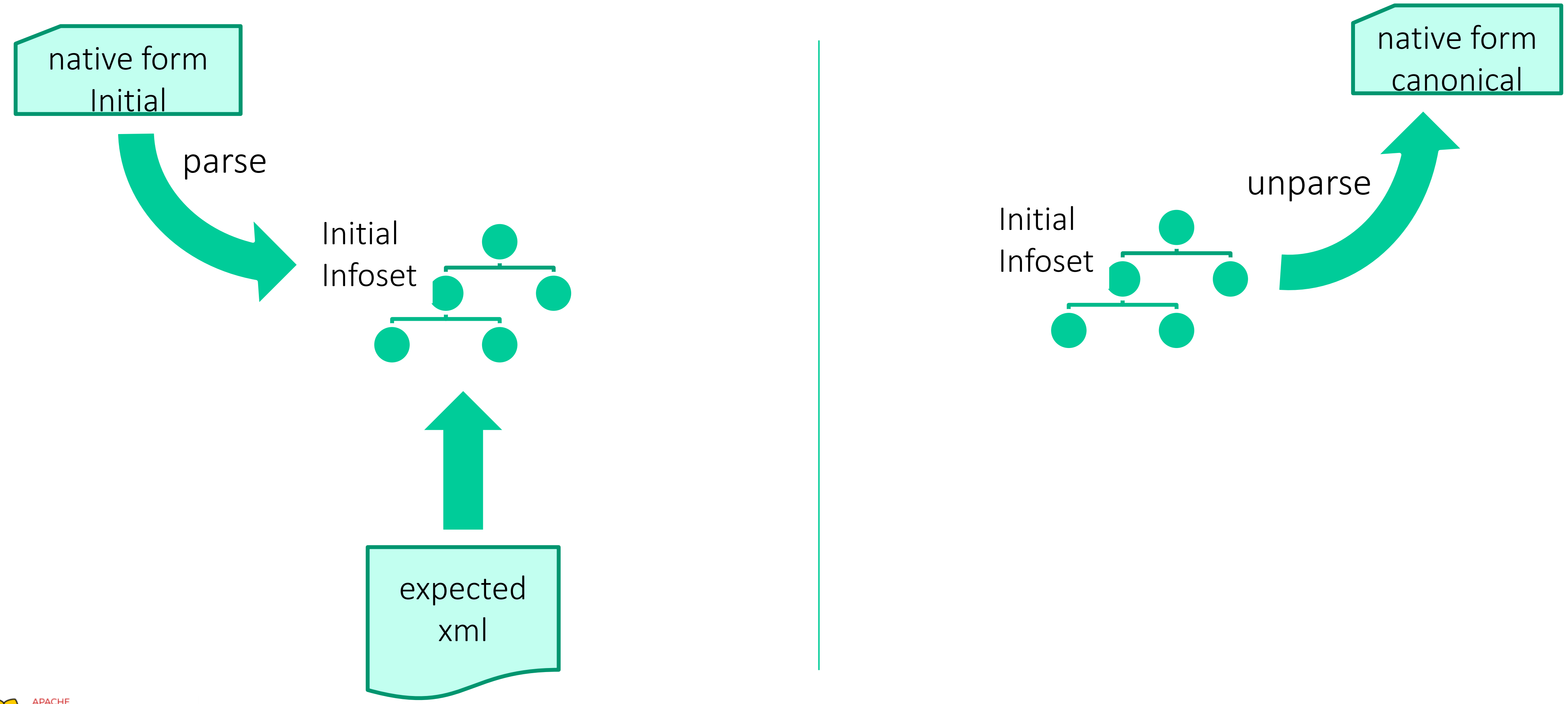
unparse

native form canonical

expected xml or json

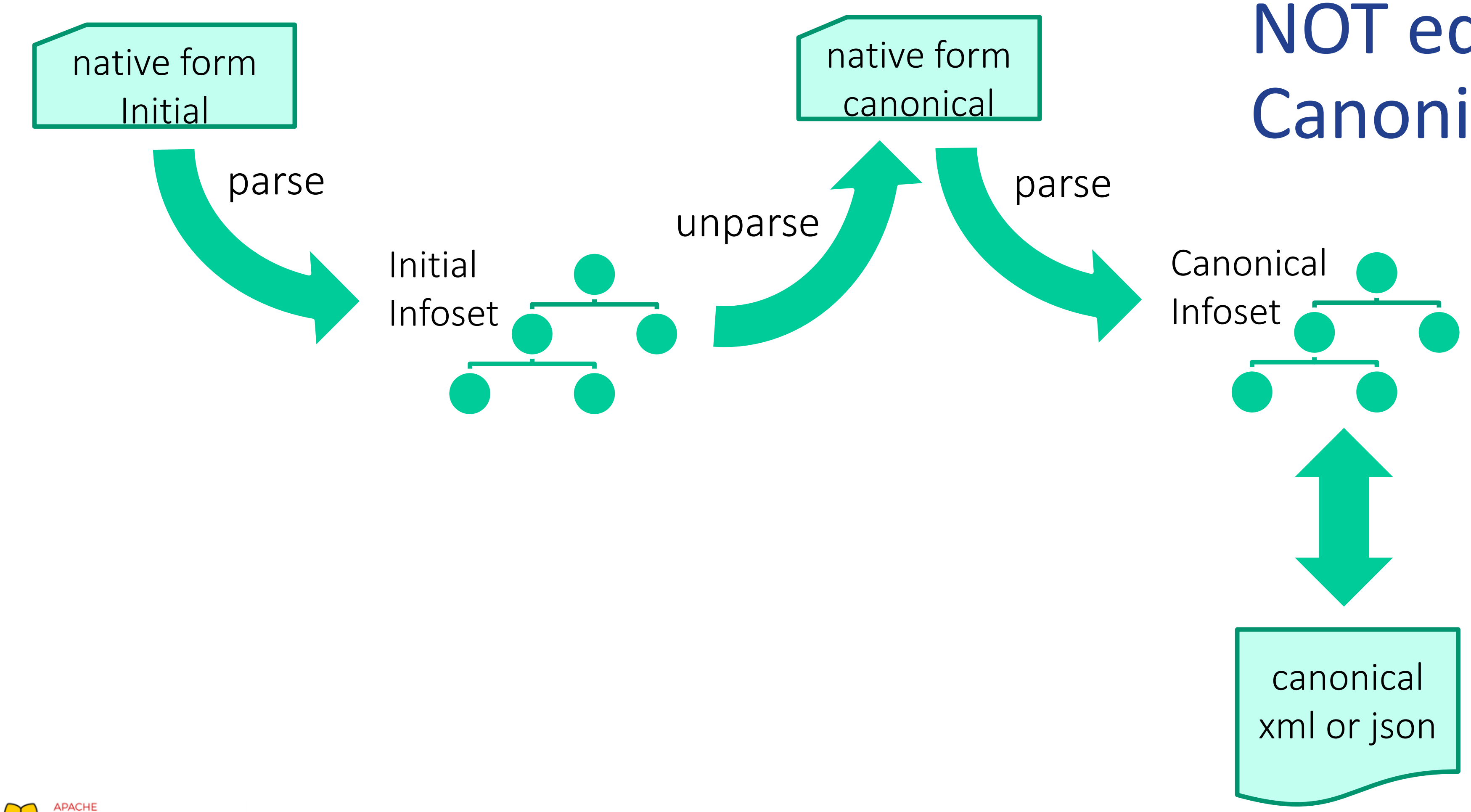
TDML Round Trip Parse/Unparse

- roundTrip="none"



TDML Round Trip Parse/Unparse

- roundTrip="twoPass"



- native form initial must NOT equal native form Canonical

Lab 4

Escape Schemes

Using Escape Schemes: nameDOB4

- DFDL has two kinds
  - escapeKind='escapeCharacter'
  - escapeKind='escapeBlock' (Let's use this one!)
- Lookup escape schemes in DFDL spec.
- Must add a top-level named escape scheme definition
  - Lookup defineEscapeScheme
- Must use it from the top-level default format via
  - escapeSchemeRef="..."
- Check out property dfdl:generateEscapeBlock
- XMLisms - how to embed " (double quote) into an XSD string literal?
  - escapeBlockStart='"' (that's single quote, double quote, single quote)
  - XML allows a string literal to start with single quotes or double quotes. Endings must match.
  - Or you could do escapeBlockStart="&quot;"

Lab 5

Dynamic Delimiter

Dynamic Terminator: nameDOB5

- Each row specifies its field terminator in first character
- Add element named "term" as new first column.
- dfdl:length="1" dfdl:lengthKind="explicit" dfdl:lengthUnits="characters"
- New xs:sequence for the 4 'real' elements
  - dfdl:terminator='{ ./term }'

Dynamic Terminator Variations

- Make the dynamic terminator be NUL (ascii 0)
- Working with NUL in DFDL is tricky
- XMLisms
  - XML documents cannot contain NUL. No way, No how.
  - Not even as &#x0;
  - Really
- TDMLisms
  - So a TDML file with embedded example data cannot have a literal NUL in it.
  - Fix 1: external data file, and <tdml:documentPart type="file">
  - Fix 2:
    - <tdml:documentPart replaceDFDLEntities="true">... %NUL;...
    - Use DFDL character entity for NUL which is %NUL;
    - Or Use DFDL numeric character entity %#x0;
    - Note: these create characters, not bytes. In a multi-byte character set it would matter!
- Expected Infoset
  - If you have Unicode, contains strange box characters. Like: So why?
  - See https://daffodil.apache.org/infoset/#xml-illegal-characters

dfdl:lengthKind and dfdl:lengthUnits

- Used frequently
  - delimited - what we've been using. Usually for text.
  - implicit
    - complex - length is sum of length of all children
    - simple - length depends on type (for binary data)
  - explicit - a constant or expression gives length
    - needs dfdl:lengthUnits
- Used in special cases
  - prefixed
    - needs dfdl:lengthUnits
  - pattern - uses regular expressions
  - endOfParent - not implemented (2022-06) by Daffodil
    - See https://daffodil.apache.org/unsupported/

Lab 6

Binary Data
Optional Elements with Flags
Packed Decimal

Binary Data Concepts

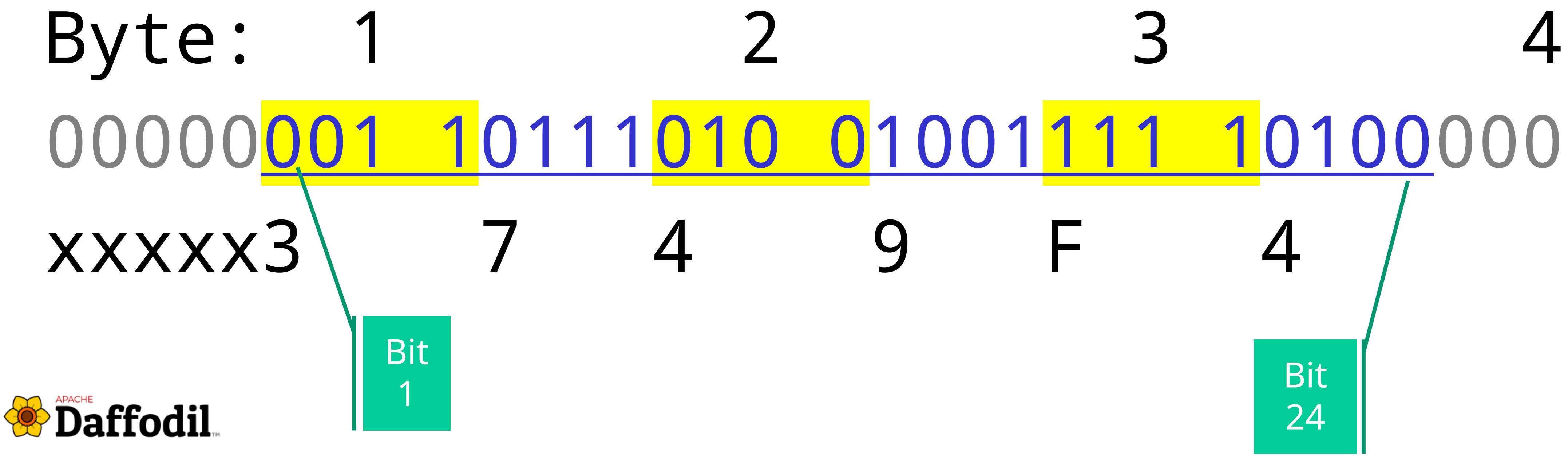
- Alignment, dfdl:alignmentUnits
- Mandatory Text Alignment
  - when text begins, we move to a boundary defined by the charset encoding.
  - Usually 8 bit boundary.
  - For 7-bit and smaller charsets no mandatory alignment (1-bit)
- dfdl:byteOrder
  - 'bigEndian' or 'littleEndian'
- dfdl:bitOrder
  - 'mostSignificantBitFirst' or 'leastSignificantBitFirst'
  - Not really order of the bits. Really just bit numbering scheme.

Binary Data Concepts

- dfdl:fillByte
  - Used to fill in unused space
    - DFDL Terminology:
      - "Padding" is about text
      - "Fill" is about binary
      - Lots of data formats use these terms in their own way however.
  - Commonly dfdl:fillByte="%#r00;" (zero byte)
    - %#rHH; notation is a DFDL Byte Entity aka a "raw byte".
  - Useful for debugging dfdl:fillByte="%#rFF;" (all 1's)
    - Filled data will show up in data more visibly.

Bit Order + Byte Order

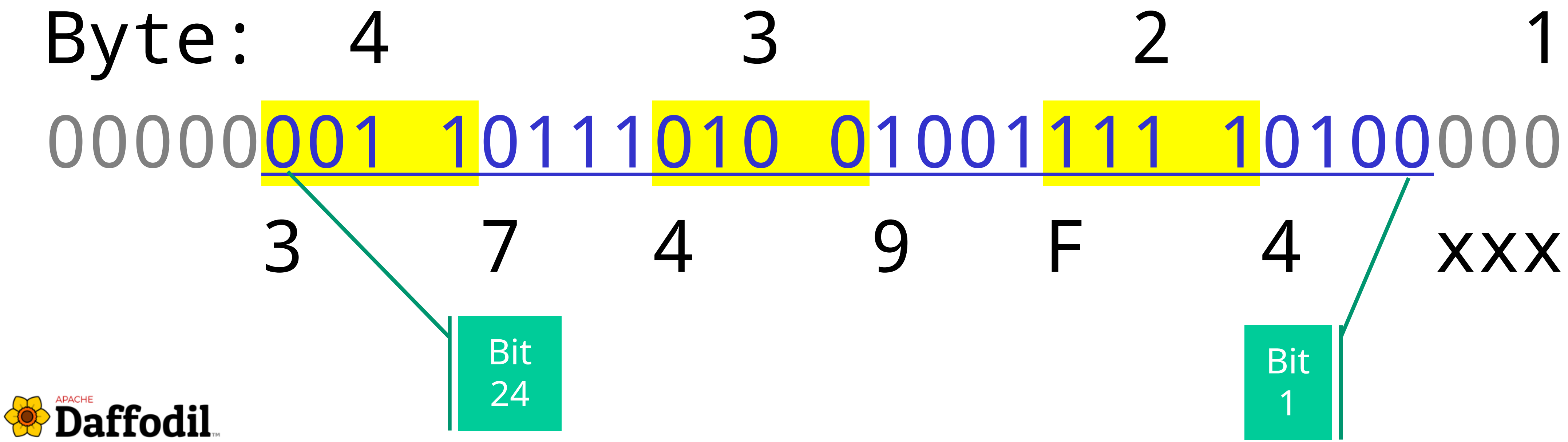
- Most Significant Bit First + Big Endian
- Use Left-to-Right numbering to best visualize
- Ex: Integer of 24 bits not byte aligned
- Starts at bit 6 of byte 1



```
Byte:  1        2        3        4
00000001 10111010 01001111 10100000
xxxxx3    7   4    9   F    4
```

Bit Order + Byte Order

- Least Significant Bit First + Little Endian
- Use *Right-to-Left* numbering to best visualize
- Ex: Integer of 24 bits not byte aligned
- Starts at bit 4 of byte 1



Byte: 4 3 2 1

00000001 10111010 01001111 10100000

3 7 4 9 F 4 xxx

Bit 24

Bit 1

More on Bit Order

- See: https://daffodil.apache.org/tutorials/bitorder.tutorial.tdml.xml

TDML Data via Bits and Bytes

- You can create binary data directly in TDML files
- Often needed to construct detailed tests

```
<document>
  <documentPart type="byte">01BA 4FA0</documentPart>
  <documentPart type="bits">
    00000001 10111010 01001111 10100000
  </documentPart>
</document>
```

- R-to-L order and LSBF are supported also

Binary Data 1: nameDOB6

- Turn our CSV data into binary data
  - Make all elements optional
  - 4 single-bit flags at start of each record indicate presence of corresponding element
  - DOB date - stored as packed decimal

Binary Data 1: nameDOB6

- Separate flag and data creates a new situation
- What would happen if we unparse with a flag and data in inconsistent state?

```
<lastNamePI>0</lastNamePI>
....
<lastName>smith, jr.</lastName>
```

Lab 7

Binary Data
Hidden Groups
Output Value Calc

Binary Data 2: nameDOB7

- Put flags into a hidden group - not part of the Infoset
- Compute flags at unparse-time with dfdl:outputValueCalc
  - based on fn:exists(../lastName)

- This provides STRONG separation of format considerations from application logic.
- Application logic doesn't have to know the representation or that the format even has presence indicator flags

- This is an innovation in DFDL - no prior-gen format description language has this.
  - Everything else in DFDL is just standardizing prior practice.
  - To date, only Apache Daffodil implements this capability (not IBM DFDL yet)

Use Best Practices to Create a Real DFDL Schema

Get REAL - DFDL Schema for NTP

NTP - Network Time Protocol Messages

- Common Setup
- Review/Study *RFC 5905*
- Break into groups
- Create a repository on github per team
- Use sbt giter8 template
  - https://github.com/apache/daffodil-schema.g8
  - Follow README.md instructions
  - Create "professional" (namespaced = yes) layout schema
- TDML - capture test data bytes in the TDML file directly
- Bottom up - tests for sub-types in the schema

NTP "Schema Project"

- Use github/open-source SDLC
  - Use tickets for features and issues and coordinate activity across the team(s)
  - Each contributor creates a "fork" of the repository
  - Create "Pull-requests" to review and merge changes
    - Sometimes called "Merge requests".
- Best practices for DFDL
  - BIST - built in self test using TDML tests
    - contributions only accepted with tests showing they work
  - Shared types.dfdl.xsd file
  - LengthKind 'explicit' types use base simple type
  - New Daffodil Enums feature (extension to DFDL v1.0)
- Self-Contained TDML Test files
  - especially for unit tests of the types

Git/Github/Gitlab Best Practice

- Git allows many workflows - none is built in
- A project must choose and stick with a git workflow process

We suggest:

- Maintain a linear history - use *rebase*, not pull
  - makes it far simpler to isolate where bugs were introduced
- All changes done on forks
- Use branches named for issues/ticket numbers - allows work in parallel on many things
  - e.g., git checkout -b bug-NNN
- One feature or bug fix per PR
- Squash multiple commits of a single change/fix and its review cycle into a single commit before merging - avoids commits that are in inconsistent states
- Commit comments should specify *rationale* of changes. Explain *why.*
- Review all PRs
  - 2nd set of eyes required for any good SDLC
  - Call for specific reviewers if particular knowledge is needed
- Big sweeping changes - always do these as a separate change from any fix/functional changes.
  - file renaming, directory structure changes
  - whitespace/indentation standards change
- Setup automated continuous integration (CI) regression testing
  - Part of review is all CI tests must pass
  - Can copy from an existing DFDL schema (see github DFDLSchemas mil-std-2045 in the ".travis.yml" file)

Git Cheat Sheet

OWL Cyber Defense

- Using browser
  - https://github.com/OpenDFDL/dfdl-training-ntp-2022-07-28-team1.git
- Fork the repository (buttons upper right)
- git clone your fork to your local workstation via
  - git clone https://github.com/mbeckerle/dfdl-training-ntp-2022-07-28-team1.git
- or via ssh (saves typing passwords, but must setup public key at github.com profile)
  - git clone git@github.com:mbeckerle/dfdl-training-ntp-2022-07-28-team1.git
- Other command line git operations:

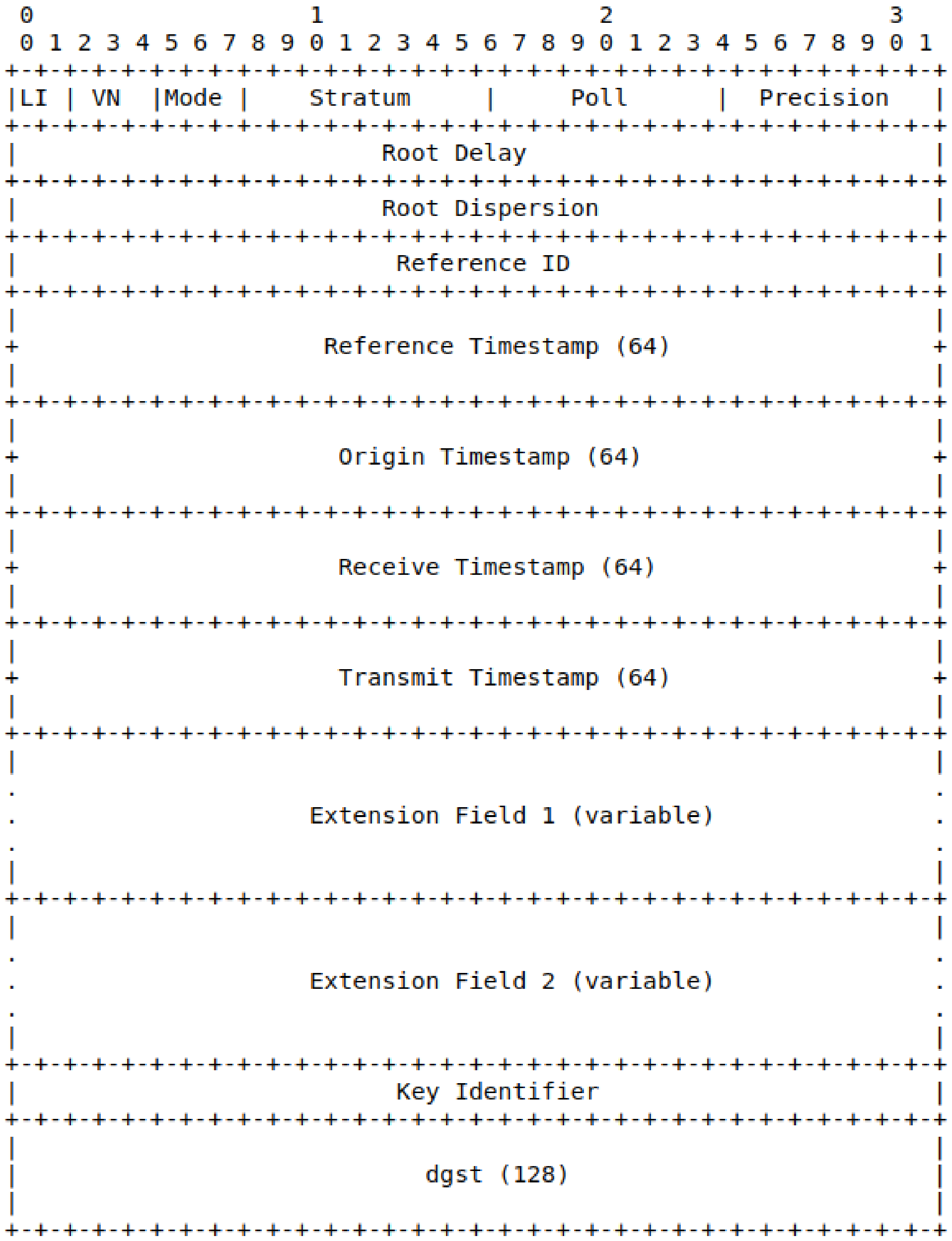
  ```
  • git checkout main            # checkout main br
  • git checkout -b ntp-NNN-fix  # create a fix branch and check it out
  • git add .                    # add your changes to a commit
  • git commit                   # commit your changes to the branch
  • git fetch --prune origin     # pull down updates by others
  • git rebase origin/main       # re-create your changes on top of them
  • git rebase -i origin/main    # rebase interactive (for squashing fixup commits together)
  • git push origin ntp-NNN-fix  # push your branch's commits (changes) for others to see
  ```
- Using browser: Create a pull request for others to review

APACHE Daffodil™

Git Workflow

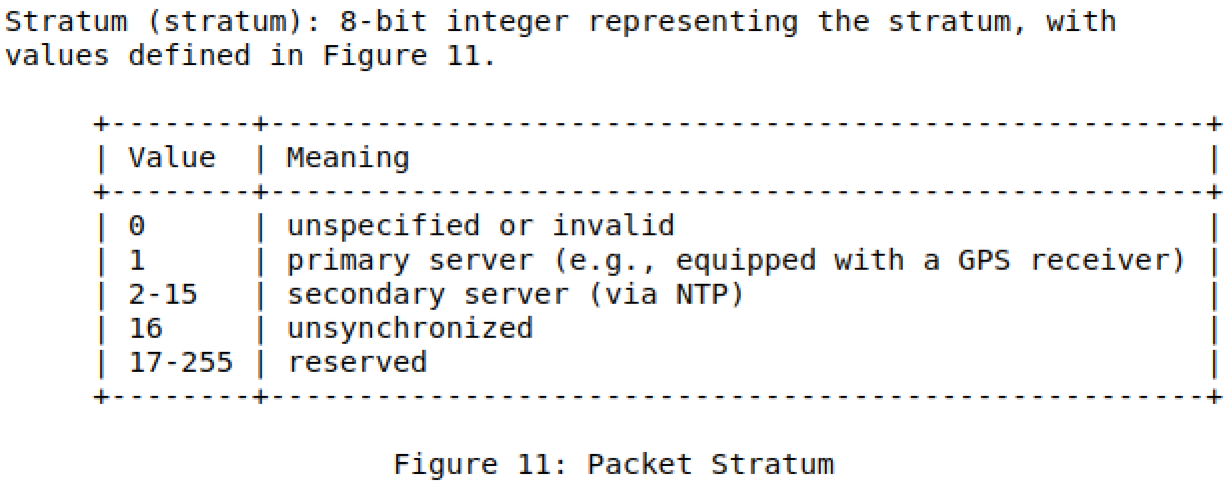
1. Do all your work locally, push to your fork repo
2. Name branches based on bug/issue numbers
3. Create PR (Pull Request) to merge to main in central repository
4. Request review
5. If changes are requested, fix, push again (to your fork)
   - Your changes will be added to the PR for re-review.
6. When your changes pass review…
   - squash changes into a single commit
   - rebase on top of any subsequent changes from others
   - retest to make sure it still works
   - push (with force) to your fork
     - git push --force origin myBranchName
   - merge (may require owner of main repo to do this)
7. Fetch from primary repo
8. Rebase your main onto the new main

NTP Packet Format



```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|LI | VN  |Mode |    Stratum     |     Poll      |  Precision   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                         Root Delay                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                         Root Dispersion                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Reference ID                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                     Reference Timestamp (64)                  +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                      Origin Timestamp (64)                    +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                      Receive Timestamp (64)                   +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                      Transmit Timestamp (64)                  +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
.                                                               .
.                    Extension Field 1 (variable)               .
.                                                               .
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
.                                                               .
.                    Extension Field 2 (variable)               .
.                                                               .
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Key Identifier                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|                            dgst (128)                         |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Enums



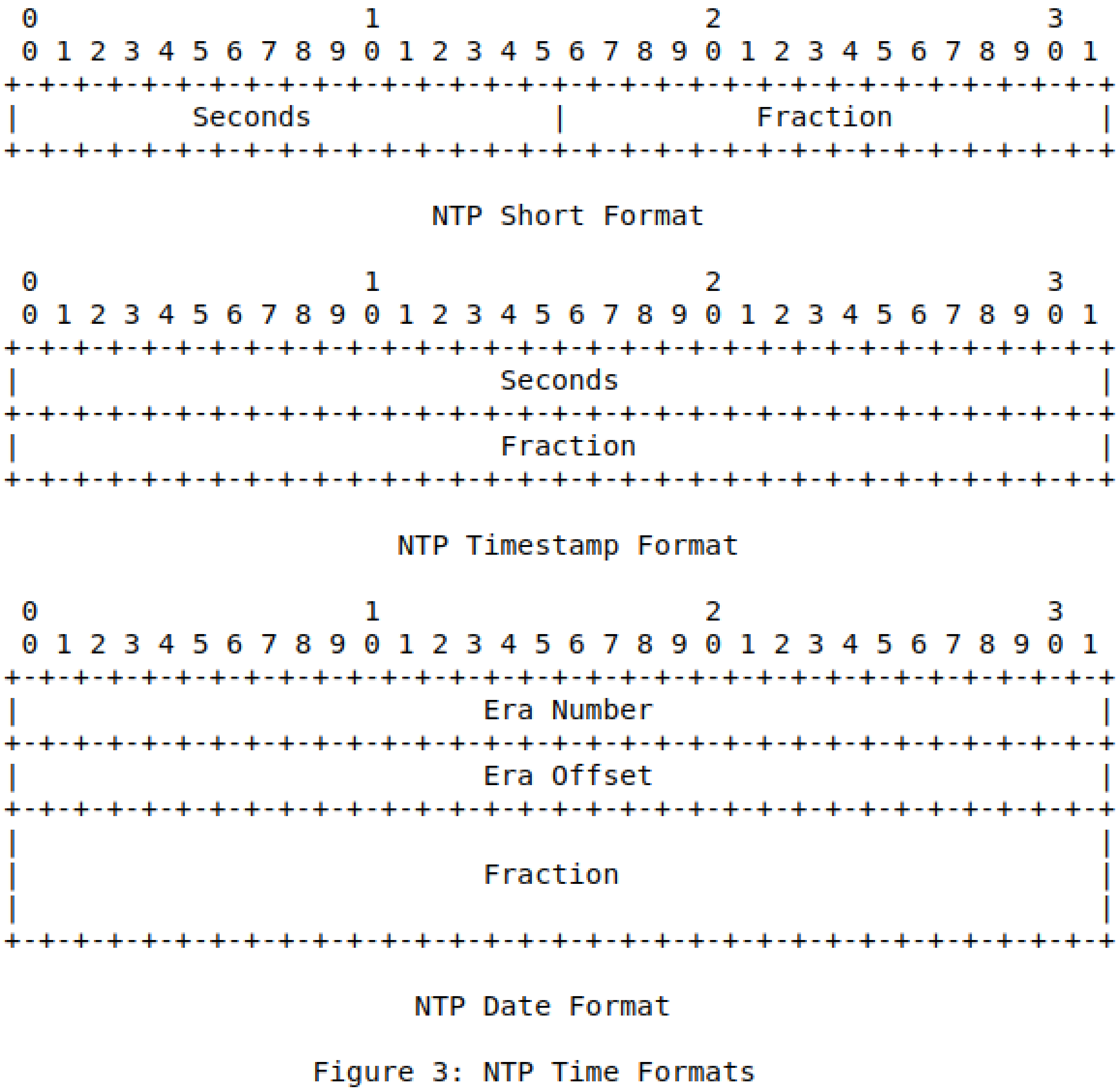
Stratum (stratum): 8-bit integer representing the stratum, with values defined in Figure 11.

Value	Meaning
0	unspecified or invalid
1	primary server (e.g., equipped with a GPS receiver)
2-15	secondary server (via NTP)
16	unsynchronized
17-255	reserved

Figure 11: Packet Stratum

- NTP has many Enums
- Technique uses Daffodil Extensions to DFDL v1.0
- Copy it from mil-std-2045 schema
  - github DFDLSchemas mil-std-2045

NTP Date/Times



```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          Seconds              |           Fraction            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

                         NTP Short Format

 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            Seconds                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            Fraction                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

                       NTP Timestamp Format

 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                           Era Number                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                           Era Offset                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|                           Fraction                            |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

                        NTP Date Format

                  Figure 3: NTP Time Formats
```

dfdl:lengthKind 'implicit' vs. 'explicit'

- Complex type elements want dfdl:lengthKind 'implicit'
- Simple type elements want dfdl:lengthKind 'explicit'
- A whole schema file can only have one default

- Best Practice to avoid clutter/redundancy
  - Use lengthKind='implicit' as the default for all DFDL Schema Files
  - Create a types.dfdl.xsd schema file for all simple types
  - Create simple type base(s) for all simple types

- Base simpleType like this:

```
<simpleType name="UIntBase" dfdl:lengthKind='explicit'>
    <restriction base="xs:unsignedInt"/>
</simpleType>
```

- Every type that extends UIntBase will have explicit length:

```
<simpleType name="referenceID" dfdl:length="32">
  <restriction base="tns:UIntBase">
    <!-- if there are max/min facet constraints, they go here -->
  </restriction>
</simpleType>
```

Tasks

- Create a project: `sbt new apache/daffodil-schema.g8`
  - set namespaced option to yes
  - Main schema file will be pre-created.
- Create a types file - see next slide
- Create a simple type for all top level datatypes in an NTP packet.
  - At this point, all types can be simple unsigned integers with an appropriate length.
- Create a single type to be shared by all the timestamps.
- Create Enum types for the enumerated integers
- Using the previously created simple types, update the main schema to parse all Ntp Fields
- At the command line, try parsing some/all of the data files
- Update the Timestamp type to fully parse it
- Update the Root Delay and Root Dispersion types (these can be combined)
- Create and run test cases using the example data in TDML

Advanced Topics

Advanced Topics

- Multi-part DFDL Schemas
- Units Normalization
- Dealing with large format specification documents
  - DFDL Schema Generators
- Where to get DFDL schemas? Their status?

Multi-Part DFDL Schemas

- Some formats natural split into separate reusable DFDL schemas
- Ex: Common Idiom Header + Payload
  - Header format is shared by many different payload formats

- DFDL schemas are packaged as jars, and work just like Java jar files
- Automated dependency management assembles schema
  - From dependencies on other DFDL schemas
  - From dependencies on Daffodil plug-ins
    - user defined function libraries
    - layer transform libraries
    - charset encoder/decoder libraries
  - Classpath is searched (in order) for files of multi-file schemas
  - Enables overriding files - improves isolation and testability
- Dependencies are resolved transitively

Units Normalization

Longitude in Binary Data

- Before Parse: 24 bits not byte aligned, least-signif. bit first, little endian

```
00000001 10111010 01001111 10100000
      3   7   4    9   F    4   XXX
```

- After Parse

```
<longitude>3623412</longitude>
```

- Easy to access
- Not easy to interpret yet
  - Numeric value corresponds to -41.000000 degrees longitude
  - The raw number is 360/(2^24) degree units.

Longitude in Binary Data - Unit Normalized

```
<target_longitude>
    <raw>48884544</raw>
    <degrees>-97.7628737021349</degrees>
</target_longitude>
```

- DFDL schemas use dfdl:inputValueCalc property to compute normalized value and add to infoset.

DFDL as a Transformation Language?

- Use of InputValueCalc and OutputValueCalc allow for substantial general transformation

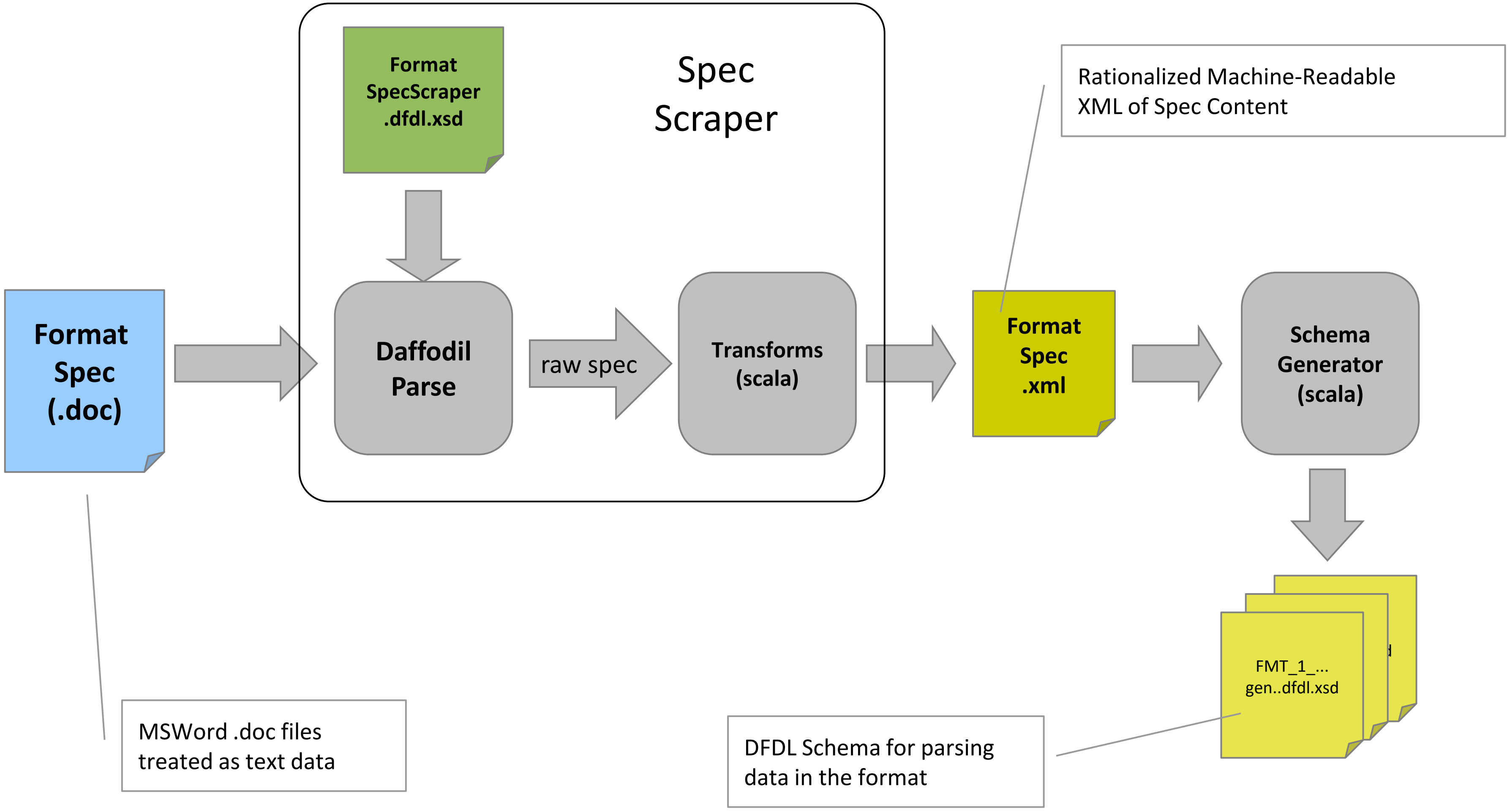
- Ex: pairs transform - converts 2 lists into a single list of pairs - effectively transposing a matrix
  - https://github.com/OpenDFDL/examples/tree/master/pairsTransform

- Ex: EthernetIP schema - has DFDL schema that parses 4 byte IP address, creates strings that look like "10.2.21.118" with the dots.
  - This is "heroic DFDL" i.e., not recommended as it is not very declarative any more.
  - No longer transforming data into XML, which after all should be
    - <ipAddr><b>10</b><b>2</b><b>21</b><b>118</b></ipAddr>
  - github DFDLSchemas EthernetIP

- Goes well beyond just data format needs.
- …. But it is an interesting, new, *schema-based* transformation technique.
- Very unlike XSLT or XQuery which are both instance based

DFDL Schema Generation

Coping with Large Format Spec Documents
Spec Scraping

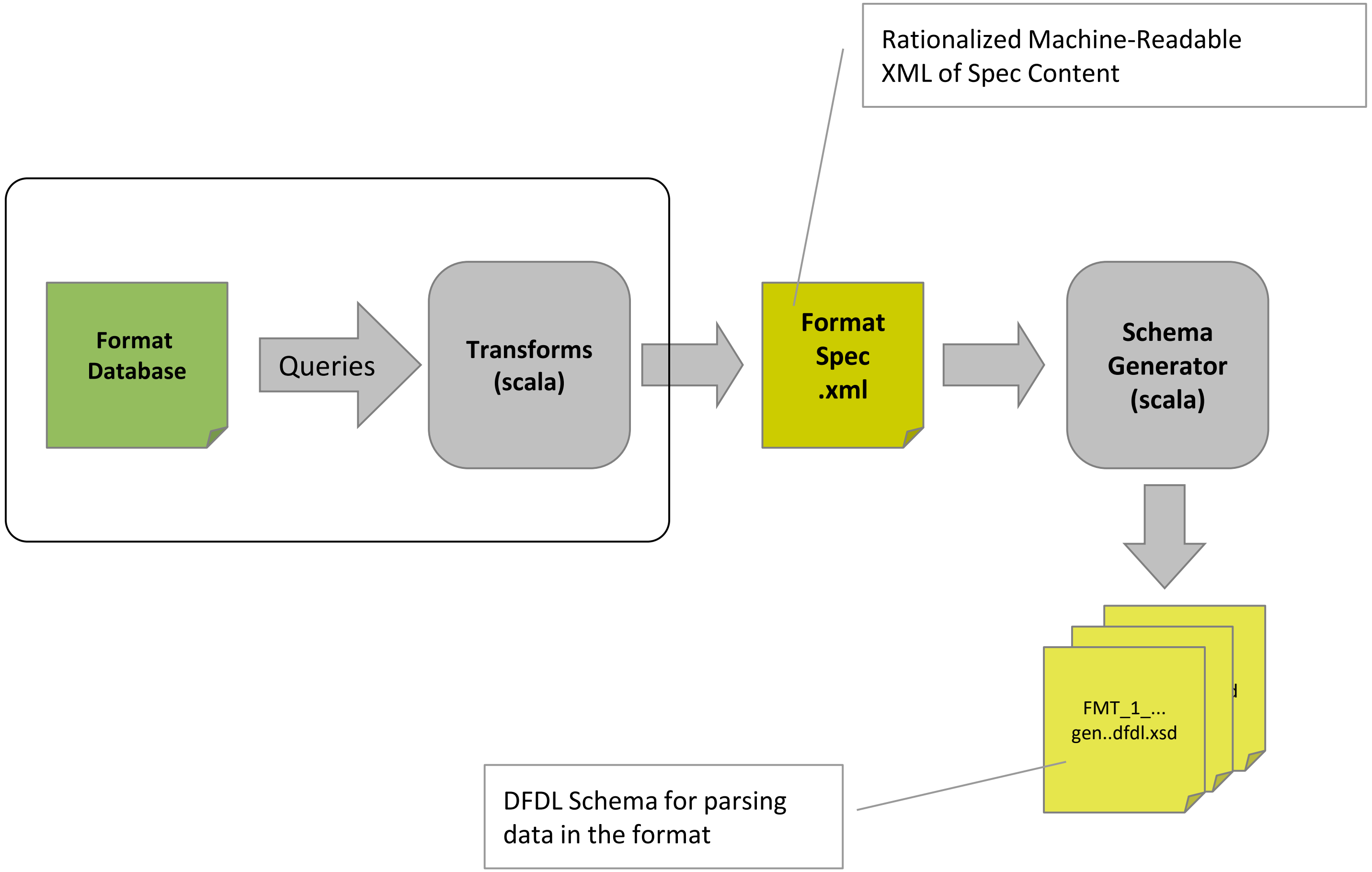


Rationalized Machine-Readable XML of Spec Content

MSWord .doc files treated as text data

DFDL Schema for parsing data in the format

Generate Large DFDL Schemas From Format-Spec Databases



Rationalized Machine-Readable XML of Spec Content

DFDL Schema for parsing data in the format

What are they? Where do we get them? Which ones exist?

DFDL Schemas

DFDL Schemas - Many Exist

Public (most on github)	MIL-STD-2045 PCAP NITF PNG JPEG NACHA VCard QuasiXML Geonames CSV	EDIFACT IBM4690-TLOG ISO8583 BMP GIF Praat TextGrid ARINC429-PoC IPFIX Syslog	iCalendar IMF SHP (shape file) KNXNet/IP(indust. control) Siemens S7 (indust. control) Asterix (Cat 034, 048) MagVar AFTN Flight Plan RASTER (RPF) ICD-GPS-240
FOUO / CUI	VMF VMF_S2S unit-normalizing (Rev A) USMTF ATO (MIL-STD-6040) LINK16 (NATO STANAG 5516) LINK16 (MIL-STD-6016F subset) A-GNOSC REMEDY ARMY DRRS USCG UCOP CEF-R1965 GMTIF (STANAG 4607)		SOTF JICD NACT JREAP-C DISV6 SIMPLE (STANAG 5602 Ed 3) P8 JANAP-128
Commercial License $$$	SWIFT-MT (IBM) HIPAA-5010 (IBM) HL7-2.7 (IBM)	USMTF ATO, ACO, etc. (Owl) LINK16 (MIL-STD-6016 E, F, G) (Owl) VMF (MIL-STD-6017 A, B, C, D) (Owl)	

DFDL Schemas - Many Exist

Public (most on github)	MIL-STD-2045 PCAP NITF PNG JPEG NACHA VCard QuasiXML Geonam CSV	08583 BMP GIF Praat TextGrid ARINC429-PoC FIX g	iCalendar IMF HP (shape file) let/IP(indust. control) S7 (indust. control) A t 034, 048) Mag AFTN lan RASTER ICD-GPS
FOUO / CUI	VMF VMF_S2 -normalizing (Rev A) USMTF / IL-STD-6040) LINK16 (STANAG 5516) LINK16 (M D-6016F subset) A-GNOSC ARMY DRRS USCG UCOP CEF-R1965 GMTIF (STANAG 46		SOTF JICD NACT JREAP-C DISV6 SIMP AG 5602 Ed 3) 8
Commercial License $$$	SWIFT-MT (IBM) HIPAA-5010 (IBM) HL7-2.7 (IBM)	 E, F, G) (Owl) VMF (MIL-STD-6017 A, B, C, D) (Owl)	

DFDL Schemas by Tech Readiness Level (TRL)

Ownership	TRL 7, 8, 9	TRL 4, 5, 6		TRL 1, 2, 3	
	(deployed / ready)	(in development)		(prototype, PoC)	
Public	MIL-STD-2045 ISO8583 Syslog/Solarwinds	Quasi-XML Shape (shp) NACHA VCard	EDIFACT IBM4690-TLOG PCAP	JPEG NITF PNG BMP GIF Praat TextGrid ARINC429	IPFIX GeoNames KNXNet/IP (indust. control) Siemens S7 (indust. control) MagVar HL7-v2.7
USG Unlimited Rights	VMF Subset Link16 (NATO) NACT	Link16 Subset, iCalendar IMF, OILSTOCK USMTF (subset)		GMTIF A-GNOSC Remedy Army DRRS USCG-UCOP CEF-R1965	SOTF JICD VMF SPOCK Link16 SPOCK
Commercial (Vendor)	Link16 (MDA), JREAP-C USMTF-Generic JANAP-128	Boeing P8A VMF Link16			

Conclusion

Review: Goals of this Training

- Learn how to self-teach about DFDL
  - What are the sources of information?
  - How to find things in the DFDL Spec
  - How structure a DFDL Schema project
    - setting it up for testing
    - composing schemas together
  - Where to get help

- Manipulate and learn DFDL schemas

- Learn enough DFDL properties to create an interesting and real DFDL Schema
  - We will build one, for NTP, on Day 3.

In Conclusion…

- Please provide feedback

That's all folks.

Extra or draft slides may follow this slide.

END

Reject Elements

- Reject element means…
  - Part of the data didn't parse
  - We were able to determine how big it is
  - Create element as hexBinary
  - Ex: `<unknown>090809afb9028ff</unknown>`
- Should these be allowed?
  - Maybe yes: if there are a small number of reject records
    - A reasonable thing some file formats may allow
  - Clearly no: if there are no non-BLOB records. It's all BLOBs.
- Sometimes it is a matter of degree!

Reject Elements

- You want a reject element to be
  - well-formed
  - always invalid

- XSD Trick

```
<element name="unknown">
  <simpleType>
    <restriction base="xs:hexBinary"
       <maxLength value="0"/> <!-- always invalid -->
    </restriction>
  </simpleType>
</element>
```

Reject Elements

- Best to leave it up to the application
- Control from outside the DFDL Schema via externally set DFDL variable.
- Sometimes unavoidable - errors deep in the nest of data for a large file
  - that applications might be able to tolerate/skip.

Filtering Structured Text

- Data in this *CSV variant* format
- But Guard is XML-only…. ?

```
/foo/bar/data.csv

FIELD1, FIELD2, FIELD3
1, 2, [11,22,33]
4, sym_data, [66, 77]
/a/b/c, 9, 9873AF897FED080989873AF897FED080989873AF897FED0809898
```

Wrong! - Just a bypass

```
<? xml version="1.0" ?>
<textOK><![CDATA[
/foo/bar/data.csv

FIELD1, FIELD2, FIELD3
1, 2, [11,22,33]
4, sym_data, [66, 77]
/a/b/c, 9, 873AF897FED080989873AF897FED080989873AF897FED0809898
]]></textOK>
```

- This is technically valid XML for a trivial schema

```
<xs:element name="textOK" type="xs:string"/>
```

- Not in the spirit of XML for data verification, inspection, and sanitization.

Right - Parse Verifies Well-Formed

```
<d:csv1 xmlns:d="urn:com.tresys.dfdl/csv1">
  <version>1.0</version>
  <fileName>/foo/bar/data.csv</fileName>
  <columns>
    <column>FIELD1</COLUMN>
    <column>FIELD2</COLUMN>
    <column>FIELD3</COLUMN>
  </columns>
  <rows>
    <row>
      <c><i>1</i></c><c><i>2</i></c>
      <vector><v>11</v><v>22</v><v>33</v></vector>
    </row>
    <row>
      <c><i>4</i></c><c><s>sym_data</s></c>
      <vector><v>66</v><v>77</v></vector>
    </row>
    <row>
      <c><p>/a/b/c</p></c>
      <c><i>9</i></c>
      <hex>9873AF897FED080989873AF897FED080989873AF897FED0809898</hex>
    </row>
  </rows>
</d:csv1>
```

Is this CSV variant Well-Formed ?

DFDL Parse/Unparse can insure many things:

- Number of fields in each row matches the number of column headers.
- Only last column can be variable-length vector or hex blob.
- Fields can be tab or comma separated.
- Fields can have a maximum field length - excluding the vectors/blobs. (which could have a different max length)
- Fields syntax can either match the syntax of integers, identifiers, file names, dates/times, etc., for some list of acceptable field syntaxes.
- Hex blobs are hex-digits only. Enforce maximum length.
- Files obey a specified character-set encoding.
- Maximum number of rows/lines.
- Some characters are disallowed (control characters, for example).

Why is DFDL Needed? - ASN.1 ECN

- What about ASN.1 Encoding Control Notation?
- Already an ISO Standard (since 2008)
- Conceptually similar
  - Logical schema language + notations for physical representation
- Very different in the details.
- Developers [Love | Hate] [ASN.1 | XML]
- Differences that matter:
  - ASN.1 ECN
    - No open-source implementation (as of 2018-08-29)
    - Extension of a binary data standard ASN.1 BER/PER/DER
    - Goal to describe legacy protocol messages
  - DFDL
    - Open-source Daffodil implementation
    - Extension of a textual data standard XML
    - Goal to be union of data integration tool capabilities for format description

Things DFDL (v1.0 + BLOB) Does

- DFDL is for Images and Video
- Originally not in scope
- Large user demand to use DFDL on the metadata content of image file formats
  - Cybersecurity applications
- Adding BLOB (Binary Large Object) feature to DFDL language to enable DFDL to describe image files