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Information Modeling with JADN Version 2.0

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- *JSON Abstract Data Notation Version 2.0*. Edited by David Kemp. Latest stage: https://docs.oasis-open.org/openc2/jadn/v2.0/jadn-v2.0.html.

Abstract:

An Information Model (IM) defines the essential content of data used in computing, independently of how it is represented for processing, communication or storage. JSON Abstract Data Notation (JADN) is an information modeling language based on Unified Modeling Language (UML) datatypes designed to both express the meaning of data items at a conceptual level and formally type and validate their essential content. Essentially it is a UML profile for defining messages and other data structures. JADN uses information theory to define logical equivalence, allowing translation of essential content across a wide range of representations without loss. This Committee Note provides background on the nature and value of IMs, contrasts JADN with other IM languages such as ASN.1, and explains how to construct IMs using JADN, represent them in various formats such as formal languages and entity-relationship diagrams, and integrate them with knowledge graphs and concrete data models.

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1 Introduction

This Committee Note (CN) describes the nature of information models and the application of the *JSON Abstract Data Notation* [JADN Specification] information modeling language in the creation and use of IMs.

JADN is a simple standard language for specifying strong typing of messages and other data structures using Unified Modeling Language (UML) DataTypes. It establishes information equivalence (i.e., consistency of meaning) across multiple serialization options to enhance interoperability between systems and among systems of systems and provides a range of type definition options that enable addressing a broad range of information modeling needs.

1.1 Background: Motivation for JADN

Information is *what* needs to be communicated between applications (i.e., meaning), and data is *how* that information is represented when communicating (i.e., presentation). Information *models* are a means to understand and document the essential information content relevant to a system, application, or protocol exchange without regard to how that information is represented in actual implementations. Having a clear view of the information required provides clarity regarding the goals that the eventual implementation must satisfy. This section provides the background for the creation of JADN as an information modeling language for a spectrum of applications.

JADN complements existing schema languages such as JSON Schema and XSD while providing distinctive features that focus on accurate definition of the information of interest:

- Unambiguous definition of the meaning of information separate from its representation for transmission or storage
- Ready translation of JADN models to widely-used formats such as JSON Schema and XML Schema that can then be used with common tooling for those formats
- Serialization rules for JSON, CBOR, and XML, easily extensible to other representations
- Conversion of representation between formats that preserves the underlying meaning
- Concise, readable format that accurately represents the information model and is readily translatable

An excerpt from the Digital Music Library example presented in full in Section 3.3.1 helps to illustrate. Each music track in the library is described by a collection of metadata (presented here in JADN Interface Definition Language [JIDL] format):

Figure 1-1 -- Music Track Metadata Example (JIDL)

```
Track-Info = Record                              // information about the individual audio tracks
   1 track_number     Integer                    // track sequence number
   2 title            String                     // track title
   3 length           Integer{1..*}              // length of track in seconds;
                                                 // anticipated user display is mm:ss; minimum length is 1 second
   4 audio_format     Audio-Format               // format of the digital audio (enumeration)
   5 featured_artist  Artist unique [0..*]       // optional notable guest performers
   6 track_art        Image optional             // each track can have optionally have individual artwork
   7 genre            Genre                      // musical genre of the track (enumeration)
```

The JIDL presentation is concise and easily understood. Each element is defined by its meaning (e.g., the track number is an *integer*, not a string containing only digits). The details of `Artist`, `Image`, and other types referenced in this metadata record are defined in other similar structures. The JADN from which the JIDL is generated can be readily translated into JSON schema (Figure 1-2) or XML schema (Figure 1-3) forms for use with existing tooling for those formats but the readability of the JIDL format simplifies development, examination, and refinement of the model. (The descriptive comments have been omitted from the JSON and XML schemas below for space reasons.)

Figure 1-2 -- Music Track Metadata JSON Schema

```
"Track-Info": {
  "title": "Track Info",
  "type": "object",
  "additionalProperties": false,
  "required": [
    "track_number",
    "title",
    "length",
    "audio_format",
    "genre"
  ],
  "maxProperties": 100,
```

```
          "properties": {
            "track_number": {
              "type": "integer",
            },
            "title": {
              "type": "string",
              "maxLength": 255
            },
            "length": {
              "type": "integer",
              "minimum": 1
            },
            "audio_format": {
              "$ref": "#/definitions/Audio-Format",
            },
            "featured_artist": {
              "type": "array",
              "uniqueItems": true,
              "minItems": 0,
              "items": {
                "$ref": "#/definitions/Artist",
              }
            },
            "track_art": {
              "$ref": "#/definitions/Image",
            },
            "genre": {
              "$ref": "#/definitions/Genre",
            }
          }
        },
```

Figure 1-3 -- Music Track Metadata XML Schema

```
        <xs:complexType name="Track-Info">
            <xs:sequence>
                <xs:element id="track_info_track_number" name="track_number" type="jadn:Integer"
minOccurs="1" />
                <xs:element id="track_info_title" name="title" type="jadn:String" />
                <xs:element id="track_info_length" name="length">
                    <xs:simpleType>
                        <xs:restriction base="jadn:Integer">
                            <xs:minInclusive value="1" />
                        </xs:restriction>
                    </xs:simpleType>
                </xs:element>
                <xs:element id="track_info_audio_format" name="audio_format" type="Audio-Format" />
                <xs:element id="track_info_featured_artist" name="featured_artist" type="Artist"
minOccurs="0" maxOccurs="unbounded" />
                <xs:element id="track_info_track_art" name="track_art" type="Image" minOccurs="0" />
                <xs:element id="track_info_genre" name="genre" type="Genre" />
            </xs:sequence>
        </xs:complexType>
```

The following sections examine the meaning of information and the value of information models in more detail.

1.1.1 Information Models and Data Models

"On the Difference between Information Models and Data Models", Internet Engineering Task Force (IETF) [RFC 3444], says:

> - The main purpose of an IM is to model managed objects at a conceptual level, independent of any specific implementations or protocols used to transport the data. The degree of specificity (or detail) of the abstractions defined in the IM depends on the modeling needs of its designers. (Section 2)
> - The terms "conceptual models" and "abstract models", which are often used in the literature, relate to IMs. IMs can be implemented in different ways and mapped on different protocols.
> - IMs can be defined in an informal way, using natural languages such as English. Alternatively, IMs can be defined using a formal language or a semi-formal structured language. One of the

> possibilities to formally specify IMs is to use class diagrams of the Unified Modeling Language (UML).
>
> - In general, it seems advisable to use object-oriented techniques to describe an IM. In particular, the notions of abstraction and encapsulation, as well as the possibility that object definitions include methods, are considered to be important. (Section 3)
>
> - Compared to IMs, [Data Models] define managed objects at a lower level of abstraction. They include implementation- and protocol-specific details, e.g., rules that explain how to map managed objects onto lower-level protocol constructs. (Section 4)

Although RFC 3444 references protocols and object methods, the Unified Modeling Language [UML] places data models and object-oriented programming models in separate categories:

- Simple Classifiers (Section 10), including DataTypes (10.2), and
- Structured Classifiers (Section 11), including Classes (11.4)

JADN is aligned with UML's layered separation of concerns: the main purpose of an IM is to model *data*, not managed objects, at both conceptually- and formally-defined levels. This allows IMs to model any kind of data, from simple structures such as value ranges or coordinates, to protocol messages, APIs, and method signatures, to complete documents, without the complexity of also modeling programming languages and techniques. An IM is a declarative specification that defines desired outcomes (data item validity and equivalence) without describing control flow. Protocol models can use IMs to define and validate messages exchanged over the wire.

Because abstraction establishes a correspondence between logical values and concrete representations, information modeling can be used for **synthesis** starting with conceptual and logical design while leaving representation details for later, or for **analysis** starting with existing data to find patterns and meaning:

- An IM defines the essential content of data artifacts used in computing independently of how they are represented for processing, communication, or storage.
- An IM defines "information equivalence" of data artifacts, meaning that all representations of a logical value are equivalent and data values can be converted from any representation to any other without loss of information.

Focusing on meaning encourages interoperability between applications by capturing agreement about what the information conveys and how it can be used, deferring decisions on storage and transmission details until a clear understanding of purpose has been reached.

1.1.2 The Information Modeling Gap

In the "Report from the Internet of Things (IoT) Semantic Interoperability (IOTSI) Workshop 2016" [RFC 8477], the IETF attributed challenges in achieving interoperability to a lack of information modeling:

> One common problem is the lack of an encoding-independent standardization of the information, the so-called information model. Another problem is the strong relationship between data formats and the underlying communication architecture. (Section 1)

Section 2 of the IOTSI Workshop Report recapitulates RFC 3444 terminology:

> - **Information Model** -- An information model defines an environment at the highest level of abstraction and expresses the desired functionality. Information models can be defined informally (e.g., in prose) or more formally (e.g., Unified Modeling Language (UML), Entity-Relationship Diagrams, etc.). Implementation details are hidden.

> - **Data Model** -- A data model defines concrete data representations *at a lower level of abstraction, including implementation- and protocol-specific details*. Some examples are SNMP Management Information Base (MIB) modules, World Wide Web Consortium (W3C) Thing Description (TD) Things, YANG modules, Lightweight Machine-to-Machine (LwM2M) Schemas, Open Connectivity Foundation (OCF) Schemas, and so on.

A JADN IM uses UML datatypes to define *data*, not *an environment*, and expresses *desired effects* (meaning of datatype instances), not *desired functionality* (temporal behavior of methods and protocols). Datatypes can define object state, function signatures, and protocol messages, but imperative specification of methods and protocols is out of scope.

DThaler's [*IoT Bridge Taxonomy*] addresses the challenges created when "many organizations develop and implement different schemas for the same kind of things", and concludes:

> To ... increase semantic interoperability, it is desirable that different data models for the same type of thing (e.g., light bulbs) are as similar as possible for basic functionality. In an ideal world, data models used by different protocols and organizations would express exactly the same information in ways that

> are algorithmically translatable by a dynamic schema bridge with no domain-specific knowledge. Sharing data models more widely, and having agreements in principle of at least using the same abstract information model, would be very beneficial.

The notion of "express[ing] exactly the same information in ways that are algorithmically translatable" is a fundamental purpose of information modeling, reflected in JADN's focus on *information equivalence*.

1.1.3 Defining Information

Formally, information is the unexpected data, or entropy, contained in a document, file, or message. When information is serialized for transmission in a canonical format, the additional data used for purposes such as text conversion, delimiting, and framing contains no information because it is known *a priori* by the sender(s) and receiver(s). If the serialization is non-canonical, any additional entropy introduced during serialization (e.g., whitespace, leading zeroes, field reordering, case-insensitive capitalization) is discarded on deserialization.

JADN is based on Information Theory [Info-Theory], which provides a concrete way of quantifying information that is explicitly independent of both semantic meaning and data representation. It may sound paradoxical, but information modeling is based on separating application-specific abstract schemas from application-independent encoding rules. A data format specifies encoding rules used for each core information type, providing an unambiguous bridge between semantics and data. This supports implementation flexibility while maintaining interoperable information exchange across implementations.

A basic problem with discussing information models is that the terms "information" and "data" are used widely but defined imprecisely. The use of these terms across technical literature has considerable variation and overlap. As described in *What is Shannon information?* [Lombardi], a precise definition of "information" is a relatively recent development:

> Nevertheless, it is traditionally agreed that the seminal work for the mathematical view of information is the paper where Claude Shannon (1948) introduces a precise formalism designed to solve certain specific technological problems in communication engineering. ... Nowadays, Shannon's theory is a basic ingredient of the communication engineers training.

Shannon's original article was later published as a book and gave rise to the field of Information Theory [Shannon].

A DataType is a UML classifier, an instance of a DataType is a value. For IMs, DataTypes have two kinds of instances: (logical) values from the type's value space (values represented by program variables), and lexical values from the type's lexical space (serialized data).

The [Resource Description Framework (RDF)] defines the concept of *lexical-to-value mapping*, which provides a precise vocabulary for describing the relationship between "data" and information:

> - A *datatype* consists of a *lexical space*, a *value space*, and a *lexical-to-value mapping*.
> - The *lexical-to-value* mapping of a datatype is a set of pairs whose first element belongs to the *lexical space* and second element belongs to the *value space* of the datatype.

A small example may help clarify the concept of information. The information content of a logical value can be no greater than the smallest lexical value for which lossless round-trip conversion is possible. A variable that can take on 2^N different values conveys at most N bits of information. For example, an IPv4 address (as defined in [RFC 791]) can specify exactly 2^32 different addresses and therefore is, by definition, a 32-bit value*. But different data may be used to represent that information:

- IPv4 dotted-quad contained in a JSON string: "192.168.141.240" (17 bytes / 136 bits).
- IPv4 dotted-quad contained in a CBOR string: 0x6F3139322E3136382E3134312E323430 (16 bytes / 128 bits)
- Hex value contained in a JSON string: "C0A88DF0" (10 bytes / 80 bits)
- CBOR byte string: 0x44c0a88df0 (5 bytes / 40 bits).
- IPv4 packet (unadorned RFC 791-style serialization): 0xc0a88df0 (4 bytes / 32 bits).

* *Note: all references to information assume independent uniformly-distributed values. Non-uniform or correlated data contains less than one byte of information per data byte, but source coding is beyond the scope of this description.*

The 13 extra bytes used to format a 4-byte IP address as a dotted quad are useful for display purposes, but provide no information to the receiving application. Field names and enumerated strings selected from a dozen possibilities convey less than four *bits* of information, while the strings themselves may be half a dozen to hundreds of *bytes* of data. By distinguishing information from data, information modeling is key to effectively using both binary data formats such as Protobuf and CBOR and text formats such as XML and JSON.

Expanding the example to include a full RFC 791 IP header illustrates some of the equivalent terms used to describe logical and lexical values:

- An Information Model abstract datatype defines the "essential content" of an IPv4 Header
- An IP packet being processed within a device or application is:
    - Information theory: information, entropy, or essential content
    - RDF: logical value in a value space
    - IM: logical value (instance of the IP Header abstract datatype, internal representation)
    - DM: an internal representation specific to a concrete data format
- An IP packet transmitted over the wire or stored in a packet capture file is:
    - Information theory: a sequence of channel symbols (bytes or characters)
    - RDF: lexical value in the lexical space defined by a data format
    - IM: lexical value (instance of the IP Header abstract datatype, external representation)
    - DM: physical value (instance of an IP Header concrete datatype)

As with individual IP addresses, the information in an IPv4 header is no greater than the 24 byte RFC 791 lexical value regardless of data format. Section 3.3.2 provides a more detailed illustration of an IM for an IPv4 packet header.

1.1.4 Information Modeling Goals and Principles

Lexical values are concrete visualizable representations of information, but information itself is an abstract concept that focuses on meaning. As described in [YTLee]'s 2008 paper on information modeling:

> The conceptual view is a single, integrated definition of the data within an enterprise that is unbiased toward any single application of data and independent of how the data is physically stored or accessed. It provides a consistent definition of the meanings and interrelationship of the data in order to share, integrate, and manage the data.
>
> The advantage of using an information model is that it can provide sharable, stable, and organized structure of information requirements for the domain context.

Note that while this description uses the term "data", the more important terms are "unbiased", "independent", "consistent", and "meanings and interrelationship".

Lee describes a "quality" IM as being:

- complete,
- sharable,
- stable,
- extensible,
- well-structured,
- precise, and
- unambiguous.

JADN's approach to precision and ambiguity is summarized in these key principles:

- An information model classifies serialized data with zero false positives and zero false negatives. That is, an information model is the authoritative definition of essential content, and all serialized data is unambiguously one of: a) consistent with the model, b) inconsistent with the model, or c) insignificant.

- An application compares logical values in accordance with the UML properties defined by their abstract datatype.

- Lexical values are equivalent if they are instances of the same abstract datatype and have the same logical value. If a logical value can be losslessly converted among multiple lexical values then its information content is no greater than the smallest of those values.

Additional quality metrics (completeness, sharability, structure, extensibility, etc.) are discussed in Section 3.

1.1.5 Information Modeling Languages

[YTLee] describes an IM language as follows:

> "An information modeling language is a formal syntax that allows users to capture data semantics and constraints."

and defines their importance:

> "Formal information modeling languages that describe information requirements unambiguously is an enabling technology that facilitates the development of a large scale, networked, computer environment that behaves consistently and correctly."

Report from IoT Semantic Interoperability Workshop 2016 [RFC 8477] describes a lack of consistency across Standards Development Organizations (SDOs) in defining application layer data, attributing it to the lack of an encoding-independent standardization of the information represented by that data. The JADN information modeling language is intended to address that gap.

JADN is a syntax-independent schema language, based on Unified Modeling Language (UML) datatypes. JADN is designed to work with common Internet data formats (JSON, XML, CBOR), providing a schema to support them. JADN is also graph-oriented to align with the web and database design practices, with options to identify primary and foreign keys, including web URLs.

JADN's native format is structured JSON, and a broad variety of tools exist for creating and manipulating information in JSON format.

- A JADN schema is structured data that can be generated and transformed programmatically
- Types in JADN schemas are defined using a simple, regular structure (every type definition has the same five fields)

Abstract Syntax Notation One [ASN.1] is another example of an abstract schema language. ASN.1 is a formal notation used for describing data transmitted by telecommunications protocols, regardless of language implementation and physical representation of these data, whatever the application, whether complex or very simple. The notation provides a certain number of predefined basic types, and makes it possible to define constructed types. Subtyping constraints can be also applied on any ASN.1 type in order to restrict its set of values. Data described in ASN.1 is serialized and deserialized based on set of encoding rules, which are defined for a broad variety of formats including the Basic Encoding Rules (BER) and similar, which are closely associated with ASN.1, as well as less closely tied standards such as XML and JSON.

Other languages have been used for information modeling, although that is not their primary purpose. Some examples are Unified Modeling Language [UML], and Integration DEFinition for information modeling [IDEF1X].

The current version of RDF has two major limitations related to its potential use for information modeling: its lexical space is limited to "a set of strings" and cannot support binary variables or data formats, and its datatypes are limited to primitive "values such as strings, numbers and dates". A future version of RDF could in principle be extended to support full information modeling datatypes, but there is no roadmap indicating plans to do so.

1.2 Terminology

This CN uses the definitions contained in the [JADN Specification], section 1.1.1. The following additional terms are defined for this document:

- **Classifier:** The core organizational concept of UML is the classifier, used to classify different kinds of values according to their features. UML is a complex specification defining many kinds of simple and structured classifiers, but the only kind used by JADN is the simple Datatype. Given a data value, a datatype classifier determines whether the value is an instance of a type, indicating both whether the data is valid, and if so, its logical type(s). Two data values are equivalent if they are instances of the same datatype and their logical values are equal. (See [UML Specification] section 10.2.3 for additional details.)

- **Directed Acyclic Graph:** A directed acyclic graph (DAG) is a directed graph with no directed cycles. That is, it consists of vertices and edges (also called arcs), with each edge directed from one vertex to another, such that following those directions will never form a closed loop. A directed graph is a DAG if and only if it can be topologically ordered, by arranging the vertices as a linear ordering that is consistent with all edge directions (Wikipedia, https://en.wikipedia.org/wiki/Directed_acyclic_graph)

- **Entity Relationship Model:** An entity–relationship model (or ER model) describes interrelated things of interest in a specific domain of knowledge. A basic ER model is composed of entity types (which classify the things of interest) and specifies relationships that can exist between entities (instances of those entity types). (Wikipedia, https://en.wikipedia.org/wiki/Entity%E2%80%93relationship_model)

- **Lexical Mapping:** A prescribed relation which maps from the *lexical space* of the datatype into its *value space*. [XSD], adapted

- **Lexical Space:** The set of valid literal representations of a value from the *value space* for a datatype. [XSD], adapted

- **Ontology:** (information science) A representation, formal naming, and definition of the categories, properties, and relations between the concepts, data, and entities that substantiate one, many, or all domains of discourse. More simply, an ontology is a way of showing the properties of a subject area and how they are related, by defining a set of concepts and categories that represent the subject. (Wikipedia, https://en.wikipedia.org/wiki/Ontology_(computer_science))

- **Schema:** *(markup languages)* A formal description of data, data types, and data file structures, such as XML schemas for XML files.
  (Wiktionary, https://en.wiktionary.org/wiki/schema#Noun, definition #3)

- **Value Space:** The set of values for a given datatype. The value spaces and the values therein are abstractions. Each value in the value space of a datatype is denoted by one or more literals in its *lexical space*. Value spaces have certain properties (e.g., cardinality, some definition of equality, ordering) by which individual values within the value space can be compared to one another.
  [XSD], adapted

2 Creation and Use of Information Models

This section discusses the nature and benefits of IMs, the role of serialization, the application of information models, and desirable tool capabilities for information modeling.

2.1 Information Modeling

Modeling in the conceptual > logical > physical sense is a top-down process starting with goals and ending with a physical data model. But in practice "data modeling" is often a bottom-up exercise that begins with a collection of desired data instances and ends with a concrete schema. That bottom-up process could be called data-centric design, in contrast with information-centric design which begins with a set of types that reflect purpose rather than syntax. An information-centric design approach that creates conceptual and logical models can readily be connected with a data-centric design, allowing bottom-up and top-down approaches to meet in the middle. This connects information-centric synthesis and data-centric analysis, as described in Section 1.1.1. However, there are significant process and outcome differences between these approaches, as shown in Table 2-1.

Table 2-1 -- Modeling Approach Comparison

Data-centric	Information-centric
A data definition language defines a specific data storage and exchange format.	An information modeling language expresses application needs in terms of desired effects.
Serialization-specific details are built into applications.	Serialization is a communication function like compression and encryption, provided to applications.
JSON Schema defines integer as a value constraint on the JSON number type.	Distinct Integer and Number types reflect mathematical properties regardless of data representation.
CDDL types: "While arrays and maps are only two representation formats, they are used to specify four loosely-distinguishable styles of composition".	The five compound types are defined unambiguously in terms of composition characteristics. Each type can be represented in multiple data formats.
No table composition style exists.	Tables are a fundamental way of organizing information. The Record type holds tabular information that can be represented as either arrays or maps in multiple data formats.
Instance equality is defined at the data level.	Instance equality is defined in ways meaningful to applications. For example "Optional" and "Nullable" are different at the data level but applications make no logical distinction between "not present" and "present with null value". Record data values in array and map formats are different at the data level but their information instances can be compared for equality.
Data-centric design is often Anglocentric, embedding English-language identifiers in protocol data.	Information-centric design encourages definition of natural-language-agnostic protocols while supporting localized text identifiers within applications.

Information-centric design promotes consensus when faced with conflicting developer preferences. Because information is the "substance" of a message, separating substance (information) from style (data format) may make it easier to agree on an information model first, deferring debate on data formats. Reverse-engineering an information model from existing data models allows commonalities and incompatibilities to be identified, facilitating convergence across multiple specifications with similar goals.

2.2 Applying an Information Model

A primary application of an IM is in the translation of data into and out of in-memory representation and serialized formats for storage and transmission. The IM defines the types, organization, and validation requirements for the information manipulated by an application or protocol. Within an application the IM is instantiated through the data structures and types supported by the chosen programming language. The IM also guides the creation of routines to parse and validate data being input from storage or through communications, and to serialize data being output to storage or transmission.

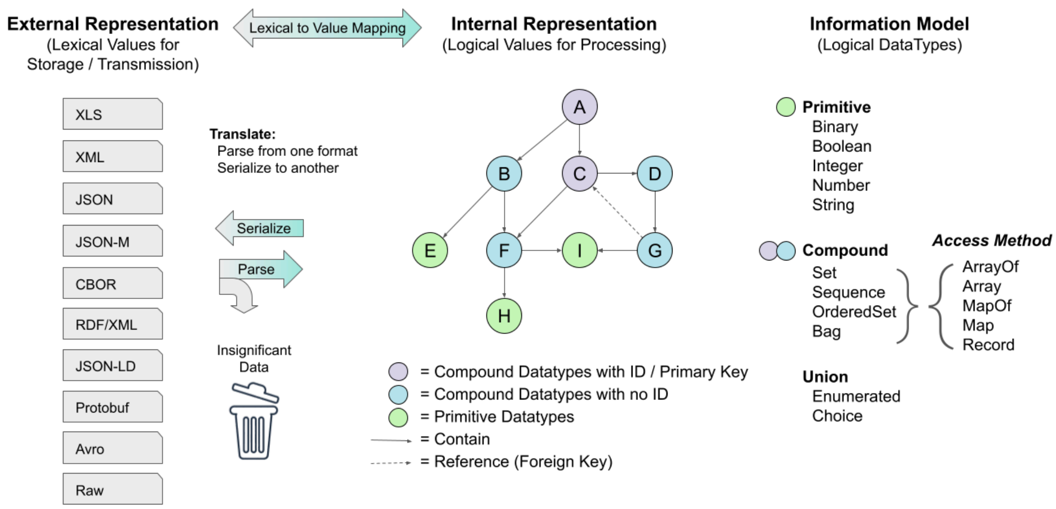
Two general approaches can be used to implement IM-based protocol specifications:

1. Translate the IM to a data-format-specific schema language such as [XSD], [JSON Schema], [Protobuf], or [CDDL], then use format-specific serialization and validation libraries to process data in the selected format. Applications use data objects specific to each serialization format.

2. Use the IM directly as a format-independent schema language, using IM serialization and validation libraries to process data without a separate schema generation step. Applications use the same IM instances regardless of serialization format, making it easy to bridge from one format to another.

Implementations based on serialization-specific code interoperate with those using an IM serialization library, allowing developers to use either approach. Deriving the processing capabilities from the IM ensures consistency as the data is manipulated. Figure 2-1 illustrates the concept of applying an IM to manage the associated data.

Figure 2-1 -- Parsing and Serializing With An IM



The internal representation, illustrated in Figure 2-1 as a graph, is the focal point for the validation of information against the model and is guided by rules associated with applying the IM:

- the internal representation conforms to the IM
- each node in the internal representation has an abstract core type from the IM
- each core type has associated serialization rules for each external representation format

Serialization and deserialization, as discussed in the next section, are essential operations for the transmission, reception, storage, and retrieval of information. It is the responsibility of the application to connect its internal information representation to externally usable formats but the validation of the information is performed using the internal representation.

As an example, consider an information element defined as a boolean type, which is the simplest core type. The essential nature of a boolean is that it is limited to only two values, usually identified as "true" and "false". However, the *data* representing a Boolean value is determined by serialization rules, and could be any of "false" and "true", 0 and 1, "n" and "y", etc. In a programming language, many variable types and values may evaluate as "true":

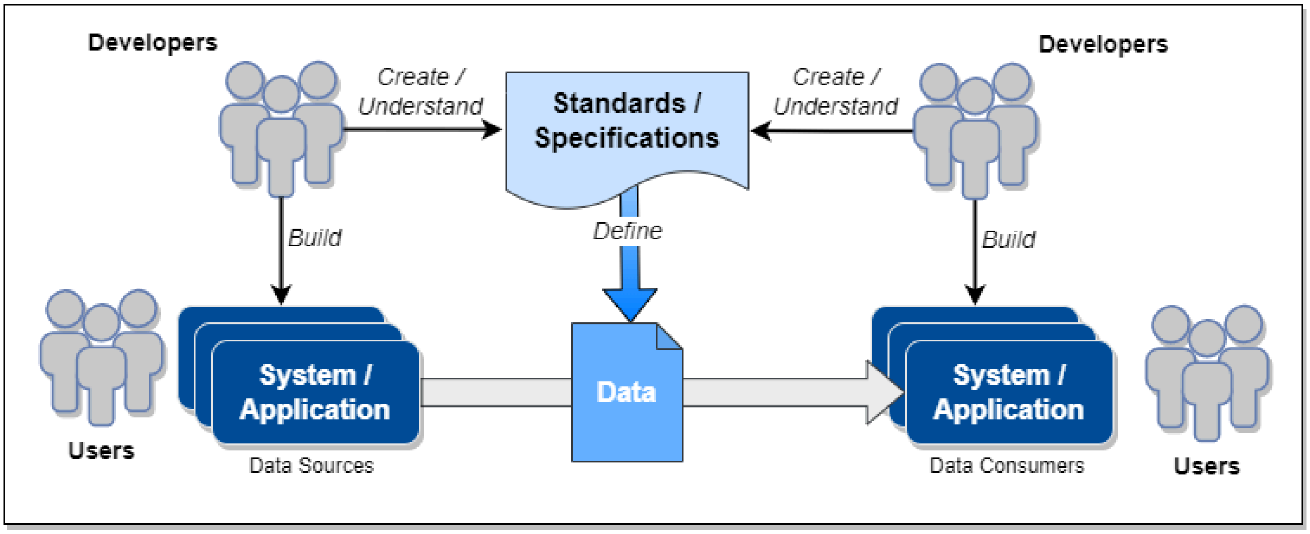
- Non-zero integers
- Non-empty strings
- Non-empty arrays

An abstract representation of an IM does not capture data types and values for a Boolean node, e.g. integer 0 or 37 or string "yes". It has only the characteristics of the node type: false or true. A JSON representation can use a Boolean type with values 'false' and 'true', but for efficient serialization might also use the JSON number type with values 0 and 1.

2.3 Serialization

Information exists in the minds of users (producers and consumers), in the state of applications running on systems, and in the data exchanged among applications. Serialization converts application information into byte sequences (a.k.a. protocol data units, messages, payloads, information exchange packages) that can be validated, communicated, and stored. De-serialization parses payloads back into application state. This can also be stated as serialization is the transformation from value space to lexical space, and de-serialization is the inverse transformation. Serialization is not a goal in and of itself, it is the mechanism by which applications exchange information in order to make it available to users. The user cares about the information the serialized data represents, not the format by which it is moved from system to system. An Automated Teller Machine customer cares about their bank balance, and an airline customer cares that their tickets are for the proper flights. How the information system handles the bits to make that happen is of no concern to the customer.

Figure 2-2 -- Serialization / Deserialization



Serialization and deserialization are intimately connected to the chosen format: the same data can be serialized in JSON, CBOR, and XML, and while the serialized data will look very different, the received information that is recovered by deserialization should match the transmitted information.

JADN defines three kinds of information that have alternate representations:

1. Primitive types such as dates and IP addresses: text representation or numeric value (formats)
2. Enumerations: string value or numeric id (Enumerated vocabularies and field identifiers)
3. Table rows: column name or position (Records)

These alternatives can be grouped into distinct serialization styles (Table 2-2).

Table 2-2 -- Serialization Styles

Style	Verbose	Compact	Concise
Serialization Method	*repeated name-value pairs*	*element / property names-values*	*machine-to-machine optimized*
Primitives	Text Representation	Text Representation	Integer / Binary / Base64
Enumerations	String	String	Integer
Table Rows	Column Name	Column Position	Column Position

A data format is a serialization style applied to a data language: "Compact JSON", "Concise JSON", "Compact XML", "Verbose CBOR", etc. The name "Verbose" here is intended to be descriptive rather than pejorative. An information model allows designers to compare Verbose and Compact styles for usability, and allows data to be validated and successfully round tripped between a readable JSON style and an actually concise CBOR style.

The [JADN Specification] defines 12 core types, each of which are described in Section 3.1.2 of this CN. The JADN Specification, Section 6, also defines serialization rules for multiple representation formats:

- Verbose JSON
- Compact JSON
- Concise JSON
- CBOR
- XML

Supporting a new data format ("external representation") requires defining serialization rules to translate each core type to that data format. The JADN Specification describes what is needed to connect JADN and IMs defined in JADN to other serialization formats:

- Specify an unambiguous serialized representation for each JADN type
- Specify how each option applicable to a type affects serialized values
- Specify any validation requirements defined for that format.

Regardless of format, serialization should be:

1. **Lossless**, so that information is not modified in transit and all applications have the identical information
2. **Transparent**, so that information is unaffected by whether or how it has been serialized; users should not know or care.

Shannon's information theory defines the relationship between information and serialization (coding). Mathematicians characterize conditions applied to a mechanism as *necessary* and/or *sufficient*: a serialization that omits necessary data loses information, one that uses more data than sufficient conveys no extra information, and potentially wastes storage or communications bandwidth. However, particular requirements (e.g., human readability) may indicate that a serialization that uses more data than sufficient is appropriate for particular situations.

2.4 Information Modeling Tools

The value of an IM language multiplies when automated tooling is available to support creation, maintenance, and use of models created in that language. The need for tools is discussed in [RFC 8477], citing particularly the need for code generation and debugging tools. A tool set to support an IM language should provide:

- Model creation capabilities
- Model validation capabilities
- Translation among alternative representations of the IM (e.g., textual, graphical)
- Generation of language-specific schemas from an IM
- Model translation to language- or protocol-specific serialization / deserialization capabilities

3 Creating Information Models with JADN

This section provides a description of the JADN language and its use in information modeling. JADN is a formal description technique that combines type constraints from the Unified Modeling Language (UML) with data abstraction based on information theory and structural organization using results from graph theory. The JADN information modeling language was developed against specific objectives:

1. Core types represent application-relevant "information", not "data"
2. Single specification unambiguously defines multiple data formats
3. Specification uses named type definitions equivalent to property tables
4. Specification is data that can be serialized
5. Specification has a fixed structure designed for extensibility

A JADN information model is a set of type definitions, where each definition is either a primitive, compound, or union type. Each field in a compound type may be associated with another model-defined type, and the set of associations between types forms a directed graph. Each association is either a container or a reference, and the direction of each edge is toward the contained or referenced type.

The container edges of an information model must be acyclic in order to ensure that:

1. every model has one or more roots,
2. every path from a root to any leaf has finite length, and equivalently
3. every instance has finite nesting depth.

There is no restriction on reference edges, so any container cycles among collection type in a model can be broken by converting one or more containers to references.

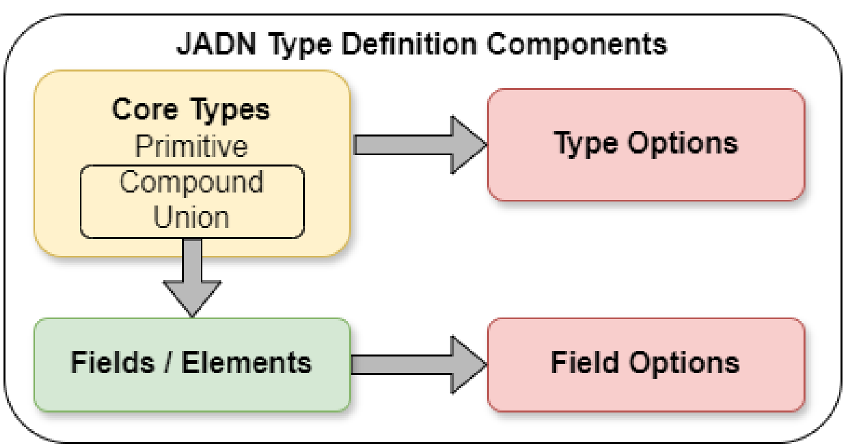
From UML JADN takes the concept of modeling information/data using Simple Classifiers (see [UML], 10.2 Datatypes) as opposed to the common practice of using Structured Classifiers (UML, 11.4 Classes), which do not define data in a unique way that can be validated and signed. The JADN use of the UML primitive types defined in UML, Table 21.1, can be found in Appendix D.1.

3.1 JADN Overview

> NOTE: The [JADN Specification] is the authoritative normative definition of the JADN language. Any discrepancies between that specification and this committee note should be resolved based on the specification.

Figure 3-1 provides a high-level view of the components of JADN type definitions that will be described in this section. JADN provides *primitive*, *compound* (both structured and unstructured), and *union* core data types that can be refined using type and field options (field options only apply to compound and union types).

Figure 3-1 -- JADN Type Definition Components



A JADN schema in its native form is a collection of one or more JSON documents, each containing a single JSON object consisting of an optional map labeled "meta" and an array labeled "types". Each document is called a "package".

- The "meta" map contains metadata about the schema contained in the document, including the types exported from this schema and namespace information to connect it with other JADN schema documents. The "meta" map is optional but if included it must define a namespace for the model.

- The "types" section of the schema document is an array of arrays, with each of the inner arrays defining one type in the schema. Each type in the schema document will use one of JADN's core types and may be either simple or compound. Each type array has five fields, two of which are themselves arrays: one for type options and one for the fields or elements that make up a compound type.
- The fields / elements array is always empty in the definition of a primitive type. For structured compound types and union types, each field or element within the fields / elements array is also an array, with three items in an element array and five items in a field array.

These structures are illustrated and explained in more detail in Section 3.1.3.1, Native JSON Representation. JADN can be represented in multiple formats, both textual and graphical, and automated tooling can transform a JADN model between the different representations without loss of information. The Native JADN representation as JSON data is authoritative, but each representation has advantages. The other representations are described in sections 3.1.3.2, 3.1.3.3, and 3.1.3.4. The examples that follow in subsequent sections are typically illustrated using both normative JADN (i.e., JSON data) for precision and the JADN Interface Definition Language (JIDL) format for its easy readability.

The [JADN Specification], Section 4.2, defines twelve core types (Table 3-1).

Table 3-1 -- JADN Core Types

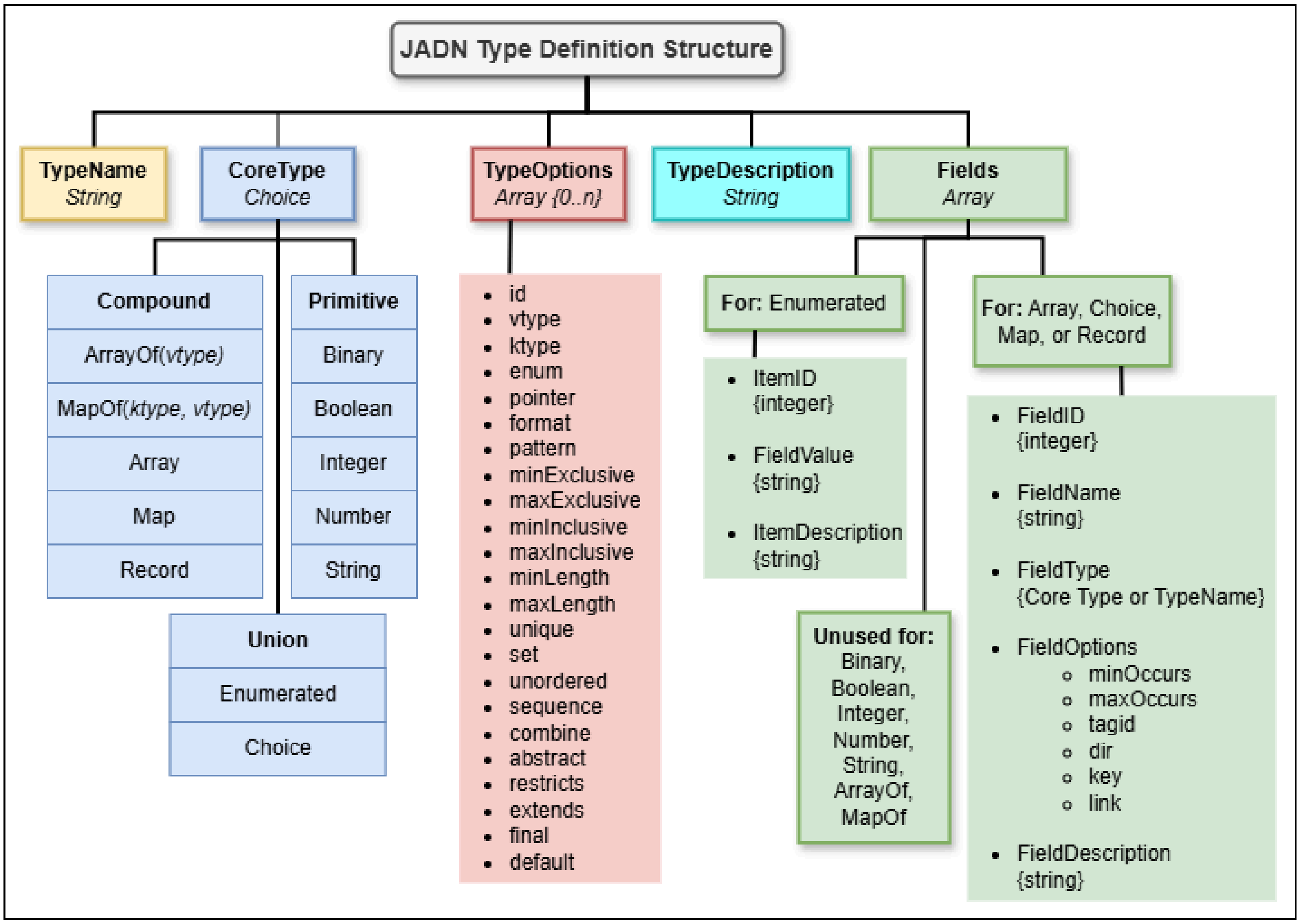
Primitive	Compound	Union
Boolean	Array	Enumerated
Integer	ArrayOf	Choice
Number	Map	
String	MapOf	
Binary	Record	

3.1.1 Type Definitions

Figure 3-2 illustrates the components of a JADN Type Definition, and identifies values for each of the five elements in the definition. As noted above, a Type Definition is an array; the elements must appear in the order listed here. The five elements are:

1. A **TypeName**, which is simply a string used to refer to that type.
2. The **CoreType** for the definition, which must be one the twelve core types shown in Figure 3-2.
3. Zero or more of the available JADN **TypeOptions** that refine the core types to fit particular needs.
4. An optional **TypeDescription** string that provides additional information about the type.
5. For structured compound types and union types, a set of **Item** or **Field** definitions for the items or fields that comprise the compound type.

Figure 3-2 -- JADN V2 Type Definition Structure



3.1.1.1 TypeNames and CoreTypes

The first two elements of a type definition are the **TypeName** and **CoreType**. A firm requirement of JADN is that a TypeName in a schema must not be a JADN predefined (i.e., core) type. There are also name formatting conventions intended to improve the consistency and readability of JADN schemas. These conventions are defined in the JADN Specification but can be overridden within a JADN schema package if desired (see the "Name Formats" item of Functional Metadata in Section 3.1.2 of the [JADN Specification]):

- **TypeNames** are written in PascalCase or Train-Case (using hyphens) with an initial upper case letter, and are limited to 64 upper case, lower case or numeric characters, or the "system" character (used for tool-generated type definitions).
- **FieldNames** are written in camelCase or snake_case (using underscores) with an initial lower case letter, and are limited to 64 upper case, lower case or numeric characters.
- **Name space identifiers** (nsids) are limited to 8 upper case, lower case or numeric characters and must begin with a letter.
- The **"system character"** (which defaults to `.`) is used by JADN processing tools when generating derived types while processing a JADN model; it is not normally used by JADN schema authors.

The CoreType must be one of the twelve JADN core types previously identified.

3.1.1.2 TypeOptions

The third element of a JADN type definition is an array of zero or more of the **TypeOptions** as described in Section 4.1.4 of the [JADN Specification]. JADN includes options for both *types* (discussed in this section) and *fields* (discussed in Section 3.1.1.4). As explained in the JADN Specification, options are presented in the normative JSON format as text strings containing the option ID character concatenated with the option value:

As an example the TypeOption "minLength = 1" is represented as:

```
+----+-----------+     Option ID = 0x7b (Left Curly Bracket) = "minLength"
| ID | Value     |     Value = 1
+----+-----------+     TypeOption string = "{1"
```

TypeOptions are classifiers that, along with the CoreType, determine whether data values are instances of the defined type. For example, the *pattern* TypeOption is used with the String CoreType to define valid instances of that string type using a regular expression conforming to [ECMAScript] grammar.

Table 3-2 lists the complete set of type options, including the option name, type, ID character, and description. Note that the ID characters are the normative form and are used in standard JADN representation (Section 3.1.3.1) when specifying type options. The text labels for the options (e.g., vtype, ktype, pattern) are non-normative and intended to be human friendly. Many of the Type and Field options labels have JSON Schema and XML Schema equivalents. An option whose type is Boolean is True if the option ID appears in a type definition. Options whose type is String, Integer, or Number indicate the type of information expected as the option's value.

Table 3-2 -- JADN Type Options

Option	Type	ID	Description
id	Boolean	`=`	Items and Fields are denoted by FieldID rather than FieldName
vtype	String	`*`	Value type for ArrayOf and MapOf
ktype	String	`+`	Key type for MapOf
enum	String	`#`	Shortcut: Enumerated type derived from a specified type
pointer	String	`>`	Shortcut: Enumerated type pointers derived from a specified type
format	String	`/`	Semantic validation keyword identifying data value boundaries
pattern	String	`%`	Regular expression used to validate a String type
minExclusive	Number	`w`	Minimum numeric/string value, excluding bound
maxExclusive	Number	`x`	Maximum numeric/string value, excluding bound
minInclusive	Number	`y`	Minimum numeric/string value, including bound
maxInclusive	Number	`z`	Maximum numeric/string value, including bound
minLength	Integer	`{`	Minimum byte or text string length, collection item count
maxLength	Integer	`}`	Maximum byte or text string length, collection item count
unique	Boolean	`q`	ArrayOf instance must not contain duplicate values
ordered	Boolean	`q`	MapOf, Map, Record instance is an ordered set
set	Boolean	`s`	ArrayOf instance is unordered and unique
unordered	Boolean	`b`	ArrayOf instance is unordered and not unique (bag)
combine	Boolean	`C`	Choice instance is a logical combination (anyOf, allOf, oneOf)
extends	Boolean	`e`	Inheritance: extension - superset of referenced type
restricts	Boolean	`r`	Inheritance: restriction - subset of referenced type
abstract	Boolean	`a`	Inheritance: abstract, non-instantiatable
final	Boolean	`f`	Inheritance: final - cannot have subtype

Option	Type	ID	Description
default	String	`u`	Default value
const	String	`v`	Constant value

Detailed explanations of each type option can be found with the descriptions of the types to which they apply throughout section 4 of the [JADN Specification]. In general, any type option can only be applied once in a type definition, using the format of concatenating the Option ID with the Option Value described above. The semantic validation `format` option is an exception to this, as explained in Section 4.2.5 of the specification: "format options have no value; the keyword is part of the key so a type may include multiple format options". An example is provided in the specification of applying both the `/date-time` format and the `/d3` format to an `Integer` type to specify a time resolution in milliseconds:

```
Timestamp = Integer /date-time          // 1727877600 sec:     2024-10-02T15:00:00Z
Timestamp-ms = Integer /date-time /d3   // 1727877600000 msec: 2024-10-02T15:00:00.000Z
```

Format options have two important characteristics:

- Each format option is applicable only to one or more specific JADN primitive types
- The implications of format options vary with the serialization format being used

As noted in section 6 of the JADN Specification, the definition of a new serialization format must "specify how each option applicable to a type affects serialized values". The various serialization formats defines in that section of the specification include tables documenting how format options apply to that format.

Table 3-3 summarizes the applicability of type options to JADN core types. The `ArrayOf` and `MapOf` types have required options, as indicated. Other type options can be applied to individual types where the option is relevant, as indicated by table cells with an "X".

Table 3-3 -- Type Option Applicability

	Boolean	Integer	Number	String	Binary	Array	ArrayOf	Map	MapOf	Record	Choice	Enumerated
id								X			X	X
vtype							Req		Req			
ktype									Req			
enum												X
pointer												X
format		X	X	X	X	X						
pattern				X								
minExclusive		X	X	X								
maxExclusive		X	X	X								
minInclusive		X	X	X								
maxInclusive		X	X	X								
minLength				X	X	X	X	X	X	X		
maxLength				X	X	X	X	X	X	X		
unique							X					
ordered								X	X	X		
unordered							X					
set							X					
combine											X	
abstract	X	X	X	X	X	X	X	X	X	X	X	X
restricts	X	X	X	X	X	X	X	X	X	X	X	X
extends	X	X	X	X	X	X	X	X	X	X	X	X
final	X	X	X	X	X	X	X	X	X	X	X	X
default	X	X	X	X	X							
const	X	X	X	X	X							

The `min/max` type options fall into two groups:

- `minLength/maxLength` apply to the *size* of a Binary or String type; an instance of either of those types must be of at least the specified `minLength` and not longer than the specified `maxLength`, but these options place no constraints on the value contained in that instance.
- `min/max/Inclusive/Exclusive` apply to the *value* that an instance that a numeric or String type can contain. These type options imply that there is an ordering of possible values for the type they are applied to, but place no constraints on the size of an instance of the type, only its possible values.

3.1.1.3 Item Or Field Definitions

The use of the **Fields** element to convey Item or Field Definitions is dependent on the **CoreType** selected, as illustrated in Figure 3-2. The rules pertaining to the **Fields** array are as follows:

- If the **CoreType** is a Primitive type, ArrayOf, or MapOf, no fields are permitted (i.e., the **Fields** array must be empty).
- If the **CoreType** is Enumerated, the fields for each item definition in the **Fields** array are described with three elements:
    1. **ItemID:** the integer identifier of the item
    2. **ItemValue:** the string value of the item
    3. **ItemDescription:** a non-normative comment
- If the **CoreType** is Array, Choice, Map, or Record, the fields for each item definition in the **Fields** array are described with five elements:
    1. **FieldID:** the integer identifier of the field
    2. **FieldName:** the name or label of the field
    3. **FieldType:** the type of the field, a predefined type or a TypeName with optional Namespace ID prefix **NSID:TypeName**
    4. **FieldOptions:** an array of zero or more **FieldOption** or **TypeOption** applicable to the field
    5. **FieldDescription:** a non-normative comment

Note that the JADN Specification constrains the ItemID and FieldID values to be Integers.

The selection of Map or Record for a type definition carries serialization implications, which are discussed in Section 3.1.4.2.

3.1.1.4 Field Options

Compound types containing Items or Fields support field options in addition to the type options described in Section 3.1.1.2. JADN defines six field options. As with the type options described in Section 3.1.1.2, the ID characters are normative and used in standard JADN representation (Section 3.1.3.1) when specifying field options. Table 3-4 lists the JADN **FieldOptions**.

Table 3-4 -- JADN Field Options

Option	Type	ID	Description	JADN Spec Section
minOccurs	Integer	`[`	Minimum cardinality, default = 1, 0 = optional	4.2.2.2
maxOccurs	Integer	`]`	Maximum cardinality, default = 1, <0 = inherited or none	4.2.2.2
tagId	Enumerated	`&`	Field containing an explicit tag for this Choice type	4.2.3.4
not	Boolean	`N`	Value is not an instance of the FieldType in an untagged union	4.2.3.4
key	Boolean	`K`	Field is a primary key for this type	4.2.2.3
link	Boolean	`L`	Field is a foreign key reference to a type instance	4.2.2.3

The type options described in Section 3.1.1.2 can also apply to fields, with the constraint that the type option must be applicable to the field's type, as described in the core type examples in Section 3.1.2. The application of a type option to a field triggers an "anonymous" type definition when the JADN model is processed, as described in Section 3.1.4.1.

3.1.2 Core Type Examples

This section provides illustrative examples of the JADN core types. For each type, the relevant [JADN Specification] section is identified, the definition from the JADN Specification is quoted, the relevant type options are listed, and an example is provided using the JADN and JIDL formats. The inheritance type options described in Section 3.1.4.5 are applicable to all JADN types and so are not included in the type option lists in this section.

3.1.2.1 Boolean

Definition (JADN Spec 4.2.1.1)	**TypeOptions**
A Boolean instance is one of the predefined values *true* and *false*.	*const, default*

The **Boolean** core type is used for representing bi-valued (i.e., true/false, yes/no, on/off) information. An information item fitting a Boolean type would be defined as follows:

```
["AccessGranted", "Boolean", [], "Result of access control decision", []]
```

The corresponding JIDL representation would be:

```
AccessGranted = Boolean   // Result of access control decision
```

3.1.2.2 Integer

Definition (JADN Spec 4.2.1.2)	**TypeOptions**
An Integer instance is a value in the ordered infinite set of integers (…, -2, -1, 0, 1, 2, …).	*const, default, format, minInclusive, maxInclusive, minExclusive, maxExclusive*

The **Integer** core type is used for representing numerical information with discrete integer values. An information item fitting an Integer type would be defined as follows:

```
["TrackNumber", "Integer", [], "Track number for current song", []]
```

The corresponding JIDL representation would be:

```
TrackNumber = Integer   // Track number for current song
```

The *minInclusive/maxInclusive* and *minExclusive/maxExclusive* TypeOptions are used to specify minimum and/or maximum values that may be assigned to an Integer type.

Table 3-5 lists the *format* options applicable to the Integer type:

Table 3-5 -- Integer Type Format Options

Keyword	**Type**	**Requirement**
i<*n*>	Integer	Signed n-bit integer, value must be between -2^(n-1) and 2^(n-1) - 1
u<*n*>	Integer	Unsigned integer or bit field of n bits, value must be between 0 and 2^n - 1.
d<*n*>	Integer	Decimal integer scale factor of 10^n: for n>0 value has n fractional digits.

These format options provide flexibility in defining Integer types in an IM:

- The "i<*n*>" format option provides flexible scaling of the size of an Integer type and its associated value range
- The "u<*n*>" format option provides for specifying unsigned (i.e., positive-only) Integers or creating bit fields
- The "d<*n*>" format option allows using performing fixed point math against Integer types without rounding errors or loss of precision.

The "d<*n*>" option supports arbitrary fixed point representation of values. For example, the Integer option `/d3` specifies an integer that is scaled by 10^3, providing three decimal digits after a "decimal point". So an integer formatted as `/time` with no scaling option would be valued as seconds before or after the POSIX epoch. The same integer with the `/d3` option would be valued to milliseconds, or with `/d6` would be valued to microseconds. If an integer temperature is documented to be degrees Celsius, its type could use the option `/d1` or `/d2` to give precision of tenths or hundredths of a degree.

3.1.2.3 Number

Definition (JADN Spec 4.2.1.3)	TypeOptions
A Number instance is a value in the ordered infinite set of real numbers.	*const, default, format, minInclusive, maxInclusive, minExclusive, maxExclusive*

The **Number** core type is used for representing numerical information with continuous values. An information item fitting a Number type would be defined as follows:

```
["Temperature", "Number", [], "Current temperature observation in degrees C", []]
```

The corresponding JIDL representation would be:

```
Temperature = Number   // Current temperature observation in degrees C
```

The *minInclusive/maxInclusive* and *minExclusive/maxExclusive* TypeOptions are used to specify a minimum and/or maximum value that may be assigned to a Number type. Table 3-6 lists the *format* options applicable to the Number type. These *format* options are only relevant when serializing using binary formats; see the [JADN Specification], Sections 4.2.5.1 and 6.4:

Table 3-6 -- Number Type Format Options

Keyword	Type	Requirement
f16	Number	**float16**: Serialize as IEEE 754 Half-Precision Float (#7.25)
f32	Number	**float32**: Serialize as IEEE 754 Single-Precision Float (#7.26)
f64	Number	**float64**: Serialize as IEEE 754 Double-Precision Float (#7.27)
f128	Number	**float64**: Serialize as IEEE 754 Quadruple-Precision Float (n/a)

The parenthetical (#7.2x) references in the above table identify the CBOR major type (7) and associated additional information (25/26/27) as defined in the Concise Data Definition Language (CDDL) Standard Prelude specified in Apppendix D of [RFC 8610].

3.1.2.4 String

Definition (JADN Spec 4.2.1.4)	TypeOptions
A String instance is a sequence of characters in a character set.	*const, default, pattern, format, minLength, maxLength, minInclusive, maxInclusive, minExclusive, maxExclusive*

The **String** core type is used for representing information best presented as text. An information item fitting a String type would be defined as follows:

```
["TrackTitle", "String", [], "Title of the song in the selected track", []]
```

The corresponding JIDL representation would be:

```
TrackTitle = String   // Title of the song in the selected track
```

Strings have a large variety of applicable type options that have the potential for overlapping meanings. As stated in the [JADN Specification]: "The pattern, length, and range options are not normally used together, but if more than one kind is present in a type definition an instance must satisfy all conditions." In particular:

- The `minLength / maxLength` options define the acceptable character count for an instance of a String type.

- The `minInclusive / maxInclusive / minExclusive / maxExclusive` options define ranges of acceptable content for an instance of a String type if the character set defines a collation order.

Any of those options could potentially overlap with a pattern specification.

The `pattern` option in JADN is used to provide a regular expression to be applied to a string type instance. When representing the `pattern` option in JIDL, it should be directly connected to the `String` type name. The JIDL pattern specification is surrounded with braces "{ }", containing `pattern="REGEX"` where `REGEX` is the regular expression that governs the format of the string. Here are the JADN and JIDL presentations of a String with an associated pattern:

```
["Barcode", "String", ["%^\d{12}$"], "A UPC-A barcode is 12 digits", []]

Barcode = String{pattern="^\d{12}$"}    // A UPC-A barcode is 12 digits
```

The preferred pattern grammar for JADN is defined in the 15th edition of the [ECMAScript] specification (June 2024). Note that the `pattern` type option is distinct from the `/regex` format type option: the former specifies a regular expression used to validate a string value whereas the latter specifies that the string value must *be* a regular expression.

Semantic validation keywords for Strings are defined in Sections 4.2.5.2 and 4.2.5.3 the JADN Specification. These keywords support constraining a String type to represent a variety of commonly used formats, such as dates and times, emails, hostnames, etc.

3.1.2.5 Binary

Definition (JADN Spec 4.2.1.5)	TypeOptions
A Binary instance is sequence of octets.	*const, default, format, minLength, maxlength*

The **Binary** core type is used for representing arbitrary binary data. An information item fitting a Binary type would be defined as follows:

```
        ["FileData", "Binary", [], "Binary contents of file", []]
```

The corresponding JIDL representation would be:

```
  FileData = Binary   // Binary contents of file
```

Binary values are not ordered so the range Type Options are not applicable. The *minLength* and *maxLength* TypeOptions are used to specify a minimum and/or maximum number of octets for a binary type. If *minLength* equals *maxLength* the size of the binary type is fixed. Table 3-7 lists the *format* options applicable to the Binary type:

Table 3-7 -- Binary Type Format Options

Keyword	Type	Requirement
eui	Binary	IEEE Extended Unique Identifier (MAC Address), EUI-48 or EUI-64 as specified in [EUI]
ipv4-addr	Binary	IPv4 address as specified in [RFC 791] Section 3.1
ipv6-addr	Binary	IPv6 address as specified in [RFC 8200] Section 3
x, X	Binary	Binary value represented as hexadecimal (pairs of characters [0-9a-fA-F])
b64	Binary	Binary value represented with base64 encoding as defined in [RFC 4648]

3.1.2.6 Enumerated

Definition (JADN Spec 4.2.3.1)	TypeOptions
A vocabulary of items where each item has an id and a tag (i.e., a string value).	*id, enum, pointer*

The Enumerated core type is used to represent information that has a finite set of applicable values. An information item fitting the Enumerated type would be defined as follows:

```
        ["L4-Protocol", "Enumerated", [], "Value of the protocol (IPv4) or next header (IPv6) field in an IP packet. Any IANA value, [RFC 5237]", [
            [1, "icmp", "Internet Control Message Protocol - [RFC 0792]"],
            [6, "tcp", "Transmission Control Protocol - [RFC 0793]"],
            [17, "udp", "User Datagram Protocol - [RFC 0768]"],
            [132, "sctp", "Stream Control Transmission Protocol - [RFC 4960]"]
        ]]
```

The corresponding JIDL representation would be:

```
L4-Protocol = Enumerated  // Value of the protocol (IPv4) or next header (IPv6)
                          // field in an IP packet. Any IANA value per RFC 5237
   1 icmp                 // Internet Control Message Protocol - [RFC 0792]
   6 tcp                  // Transmission Control Protocol - [RFC 0793]
  17 udp                  // User Datagram Protocol - [RFC 0768]
 132 sctp                 // Stream Control Transmission Protocol - [RFC 4960]
```

When validating an enumerated value the default is to match the value against the tag defined in the enumeration (e.g., `"icmp"` or "`tcp`" in the example above). If the `id` type option is applied, the value will instead be evaluated against the id of the enumeration's fields (e.g., `1` or `6`).

The `enum` type option is used to derive an enumeration using the fields defined in another structured compound type such as a Map (see Section 5.3 of the JADN v2 Specification for examples).

The `pointer` type option generates an enumeration using the fields defined in another structured compound type such as a Record (see Section 5.5 of the JADN v2 Specification for an example). Each item in the enumeration generated by expanding such a type definition corresponds to a leaf type in the original compound type referenced.

3.1.2.7 Choice (Tagged / Untagged)

Definition (JADN Spec 4.2.3.2 / 4.2.3.3)	TypeOptions
Without a *combine* TypeOption: a tagged union, a structure that defines a set of tag:type pairs. With a *combine* TypeOption: an untagged union, a structure that defines a set of types used collectively to classify a value.	*id, combine*

The **Choice** core type, without any `combine` option is used to represent information limited to selecting one type from a defined set of named or labeled types. An information item fitting such a Choice type would be defined as follows:

```
        ["IdentityType", "Choice", [], "Nature of the referenced identity", [
          [1, "person", "Person", [], "Identity refers to a person"],
          [2, "organization", "Organization", [], "Identity refers to an organization"],
          [3, "tool", "Tool", [], "Identity refers to an automated tool"]
        ]]
```

The corresponding JIDL representation would be:

```
IdentityType = Choice                  // Nature of the referenced identity
   1 person            Person          // Identity refers to a person
   2 organization      Organization    // Identity refers to an organization
   3 tool              Tool            // Identity refers to an automated tool
```

When validating a `choice` the tag in the value (e.g., `peron`, `organization`, `tool` in this example) is used to identify which option has been chosen.

The `combine` option provides additional flexibility in applying the **Choice** type by specifying a required combination of the field types in the Choice. Any one of three values can be applied to a Choice using the `combine` option:

- `A`: value must be an instance of `allOf` the types
- `O`: value must be an instance of `anyOf` the types, tried in field order until a match is found
- `X`: value must be an instance of `oneOf` the types and no others

When validating a `choice` with a `combine` option, the `combine` option guides the evaluation of the value against the types defined to determine a match. When either the `allOf` or `oneOf` values is used, the order of the fields in the Choice is irrelevant as the value of an instance must be compared to all of the possible types to determine its validity. In contrast, order is significant for the `anyOf` option value because the instance values are checked against the Choice fields in the order they are defined.

> EDITOR'S NOTE: need examples of applying the TypeOptions include the v2.0 enhancements.

3.1.2.8 Array

Definition (JADN Spec 4.2.2)	TypeOptions
An ordered list of labeled fields with positionally-defined semantics. Each field has a position, label, and type.	*format, minLength, maxLength*

The **Array** type is used to represent information where it is appropriate to group related information elements together, even if the elements of the array are heterogeneous. Each element in the array is defined as a field, using the field definitions described in Section 3.1.3 and refined using the field options described in Section 3.1.4. An information item fitting the Array core type would be defined as follows:

```
["License-Data", "Array", [], "Driver's license data based on Real ID requirements", [
    [1, "last_name", "String", [], "family name of license holder"],
    [2, "given_names", "String", [], "given (first and zero or more middle) names of license holder"],
    [3, "issuing_state", "String", ["%[A-Z]{2}"], "State of issuance (pattern matching pairs of capital
letters)"],
    [4, "license_number", "String", [], "License identification number per format used by issuing state"],
    [5, "vision_correction", "Boolean", [], "Is license holder required to use vision correction?"],
    [6, "dob", "Integer", ["/date"], "License holder's date of birth"],
    [7, "exp_date", "Integer", ["/date"], "License expiration date"],
    [8, "photo", "Binary", [], "Photo of license holder (JPEG format)"]
  ]]
```

and the corresponding JIDL representation:

```
License-Data = Array  // Driver's license data based on Real ID requirements
   1  String                     // last_name:: family name of license holder
   2  String                     // given_names:: given (first and zero or more middle) names of license holder
   3  String{pattern="[A-Z]{2}"}  // issuing_state:: State of issuance (pattern matching pairs of capital
letters)
   4  String                     // license_number:: License identification number per format used by issuing
state
   5  Boolean                    // vision_correction:: Is license holder required to use vision correction?
   6  Integer /date              // dob:: License holder's date of birth (/date)
   7  Integer /date              // exp_date:: License expiration date (/date)
   8  Binary                     // photo:: Photo of license holder (JPEG format)
```

Note that in the JIDL representation the Array field names are moved into the description field, as described in Section 3.1.3.2.

JADN provides several semantic validation keywords for the Array type which invoke predefined Array structures that fit specific information modeling needs. The following example shows the `/ipv4-net` keyword, which defines an array that conveys the address in CIDR form with a 32-bit binary field and an integer prefix.

```
           ["IPv4-Net", "Array", ["/ipv4-net"], "IPv4 address and prefix length", [
             [1, "ipv4_addr", "Binary", ["/ipv4-addr"], "32-bit IPv4 address as defined in [RFC 791]"],
             [2, "prefix_length", "Integer", ["[0"], "CIDR prefix-length. If omitted, refers to a single host
address."]
           ]]
```

The corresponding JIDL representation would be:

```
IPv4-Net = Array /ipv4-net   // IPv4 address and prefix length
   1  Binary /ipv4-addr      // ipv4_addr:: 32-bit IPv4 address as defined in RFC 791
   2  Integer optional       // prefix_length:: CIDR prefix-length. If omitted, refers to a single host address.
```

Table 3-8 lists the *format* options applicable to the Array type:

Table 3-8 -- Array Type Format Options

Keyword	Type	Requirement
ipv4-net	Array	Binary IPv4 address and Integer prefix length as specified in [RFC 4632] Section 3.1
ipv6-net	Array	Binary IPv6 address and Integer prefix length as specified in [RFC 4291] Section 2.3
tag-uuid	Array	Tag portion is a String, UUID portion is a 128-bit (16 byte) binary value

The `ipv4-net` and `ipv6-net` format options impose constraints appropriate for their respective address type:

- Specifies the Binary element of the Array to be 32 or 128 bits, respectively
- Constrains the Integer prefix value to a range of 0..32 or 0..128, respectively
- Specifies that text representations of the type will use CIDR notation

The `tag-uuid` format option imposes similar constraints:

- Specifies a two-field Array with one String and one Binary value
- The String value contains the tag, which is descriptive text and may contain hyphens
- The Binary value contains the 128-bit UUID value
- The JSON serialization will be `"tagString--<UUID as text>"`; e.g., `"my-tag-type--ccf8a573-bbf3-48b8-b0ba-b14ddd1fc27d"`

The `tag-uuid` format for identifiers is used in the [STIX] and [CACAO] specifications (see sections 2.9 and 10.10, respectively, of those specifications).

3.1.2.9 ArrayOf(vtype)

Definition (JADN Spec 4.2.2)	TypeOptions
A collection of items, each of which is of the type *vtype*.	*vtype, minLength, maxLength, unique, set, unordered*

The **ArrayOf** type is used to represent information where it is appropriate to group a set of uniform information elements together. The fields of the array are defined by the *vtype*, which can be primitive or compound. An information item fitting the ArrayOf core type would be defined as follows. This example uses an explicit ArrayOf type derived using the multiplicity extension on the "tracks" field of Album, as shown in Section 3.3.1):

```
[
  ["Tracks", "ArrayOf", ["*Track", "{1"], "Tracks is an array of one or more Track values", []],

  ["Track", "Record", [], "for each track there's a file with the audio and a metadata record", [
    [1, "location", "String", [], "path to the file audio location in local storage"],
    [2, "metadata", "TrackInfo", [], "description of the track"]
  ]]
]
```

And the corresponding JIDL would be:

```
Tracks = ArrayOf(Track){1..*}                      // Tracks is an array of one or more Track values

Track = Record                                     // for each track there's a file with the audio and a metadata
record
   1 location           String                     // path to the file audio location in local storage
   2 metadata           TrackInfo                  // description of the track
```

By default an ArrayOf is a sequence: an ordered collection of items with no requirement the items be unique. The `set`, `unique`, and `unordered` type options can be used to modify those properties.

> EDITOR'S NOTE: need examples of applying the TypeOptions

3.1.2.10 Map

Definition (JADN Spec 4.2.2)	TypeOptions
An unordered map from a set of specified keys to values with semantics bound to each key. Each key has an id and name or label, and is mapped to a value type.	*id, ordered, minLength, maxLength*

The **Map** type is used to represent information that can be represented as (key, value) pairs. Another term for this type of information structure is an "associative array":

> An *Associative Array* is "an abstract data type that stores a collection of (key, value) pairs, such that each possible key appears at most once in the collection." Alternative names include "map", "symbol table", and "dictionary". (https://en.wikipedia.org/wiki/Associative_array)

The Map core type always uses an integer identifier as the key, with each integer associated with a specific value. An information item fitting the Map type would be defined as follows:

```
["Hashes", "Map", ["{1"], "Cryptographic hash values", [
  [1, "md5", "Binary", ["/x", "{16", "}16", "[0"], "MD5 hash as defined in [RFC 1321]"],
  [2, "sha1", "Binary", ["/x", "{20", "}20", "[0"], "SHA1 hash as defined in [RFC 6234]"],
  [3, "sha256", "Binary", ["/x", "{32", "}32", "[0"], "SHA256 hash as defined in [RFC 6234]"]
]]
```

The corresponding JIDL representation would be:

```
Hashes = Map{1..*}    // Cryptographic hash values
   1 md5        Binary{16..16} /x optional   // MD5 hash as defined in RFC 1321
   2 sha1       Binary{20..20} /x optional   // SHA1 hash as defined in RFC 6234
   3 sha256     Binary{32..32} /x optional   // SHAs26 hash as defined in RFC 6234
```

In the example above, note the combination of the `{minLength..maxLength}` type options in the record's definition and the presence of the `optional` keyword on all fields of the record. This reflects a design pattern: the compound type's cardinality of `{1..*}` defines that there is a minimum number of required fields even though every individual field is optional. An empty `Hashes` map is invalid, but a map where any one or more of the three hash types exists is valid. This is an example of one application of *minLength*, *maxLength*, as described above in Section 3.1.4.4.

3.1.2.11 MapOf(ktype,vtype)

Definition (JADN Spec 4.2.2)	TypeOptions
An unordered map from a set of keys of the same type to values with the same semantics. Each key has key type *ktype*, and is mapped to value type *vtype*.	*ktype, vtype, minLength, maxLength, ordered*

The **MapOf** type is used to represent information that can be represented as (key, value) pairs, where the types for the keys and the values in the MapOf are of specific types and are defined using type options. MapOf is suitable when the collection of items can't be represented as an enumeration, such as the association of employee identification numbers, which have an arbitrary and non-contiguous distribution, to employees. An information item fitting the MapOf type would be defined as follows:

```
  [
    ["Employees","MapOf", ["+EID","*Employee"], "Maps employee identifier numbers to employee
information", []],

    ["EID", "Integer", ["{0","}1000"], "will need new system when exceed 1,000 employees", []],

    ["Employee", "Record","", "Employee Information",[
      [1, "name", "String", "", "Usually First M. Last"],
      [2, "start_date", "Date", "", "always record start date"],
      [3, "end_date", "Date", ["[0"], "if end_date is present = former employee"]
    ]],

    ["Date", "String", ["/date"], "", []]
  ]
```

The corresponding JIDL representation would be:

```
// Maps employee identifier numbers to employee information
Employees = MapOf(EID, Employee)

// Employee identifier numbers
EID = Integer{0..1000}        // will need new system when exceed 1,000 employees

// Employee information
Employee = Record
  1 name        String         // usually "First M. Last"
  2 start_date  Date           // always record start date
  3 end_date    Date optional  // if end_date is present = former employee

Date = String /date
```

3.1.2.12 Record

Definition (JADN Spec 4.2.2)	TypeOptions
An ordered map from a list of keys with positions to values with positionally-defined semantics. Each key has a position and name, and is mapped to a value type. Represents a row in a spreadsheet or database table.	*minLength, maxLength, ordered*

The **Record** type is used to represent information that has a consistent repeated structure, such as a database record. Elements of a record can be accessed by either position or value. The following example defines a JADN Record type for the common 5-tuple often used to describe a network connection.

```
["IPv4-Connection", "Record", ["{1"], "5-tuple that specifies a tcp/ip connection", [
  [1, "src_addr", "IPv4-Net", ["[0"], "IPv4 source address range"],
  [2, "src_port", "Port", ["[0"], "Source service per RFC 6335"],
  [3, "dst_addr", "IPv4-Net", ["[0"], "IPv4 destination address range"],
  [4, "dst_port", "Port", ["[0"], "Destination service per RFC 6335"],
  [5, "protocol", "L4-Protocol", ["[0"], "Layer 4 protocol (e.g., TCP)"]
]]
```

The corresponding JIDL representation would be:

```
IPv4-Connection = Record{1..*}                  // 5-tuple that specifies a tcp/ip connection
   1 src_addr         IPv4-Net optional         // IPv4 source address range
   2 src_port         Port optional             // Source service per RFC 6335
   3 dst_addr         IPv4-Net optional         // IPv4 destination address range
   4 dst_port         Port optional             // Destination service per RFC 6335
   5 protocol         L4-Protocol optional      // Layer 4 protocol (e.g., TCP)
```

As with the `Map` example in Section 3.1.2.10, the cardinality of `{1..*}` for the `Record` defines that there is a minimum number of required fields even though every individual field is optional. An empty IPv4-Connection record is invalid, but an IPv4-Connection record where any one or more of the five fields exists is valid.

3.1.3 JADN Representations

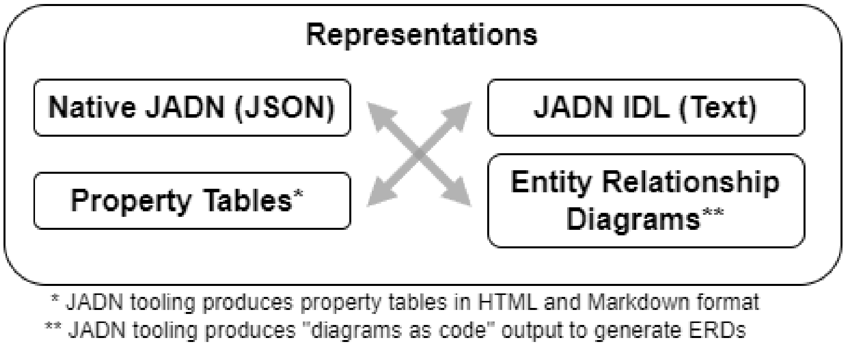
The native format of JADN is JSON, but JADN content can be represented in other ways that are often easier to edit or more useful for documentation. This section describes the JSON content used for each of the JADN basic types, and then illustrates the other representations using a simple example or reference.

The [JADN Specification] identifies three presentation formats in addition to the native JSON format:

- JADN Interface Definition Language (JIDL, Section 7.1)
- Property Tables (Section 7.2)
- Entity Relationship Diagrams (ERDs, Section 7.3)

Figure 3-3 identifies the various representations. Each of the four representations is described below.

Figure 3-3 -- JADN Representations



3.1.3.1 Native JSON Representation (Normative)

This section illustrates the JSON representations of the Base Types described in Section 3.1. Depictions are provided for the overall structure of a JADN schema and for each of three ways that the **Fields** array is used, depending on the core type used in a particular type definition.

Figure 3-4 illustrates the top-level structure of a native JADN schema document, as described in Section 3.1.

Figure 3-4 -- JADN Schema Top-Level Structure

```
{
  "meta": { schema document metadata },
  "types": [ array of type definition arrays ]
}
```

Figure 3-5 illustrates the JADN structure for defining any Primitive **CoreType**, or ArrayOf or MapOf type; for all of these the **Fields** array is empty:

Figure 3-5 -- JADN for Primitive, ArrayOf, MapOf Types

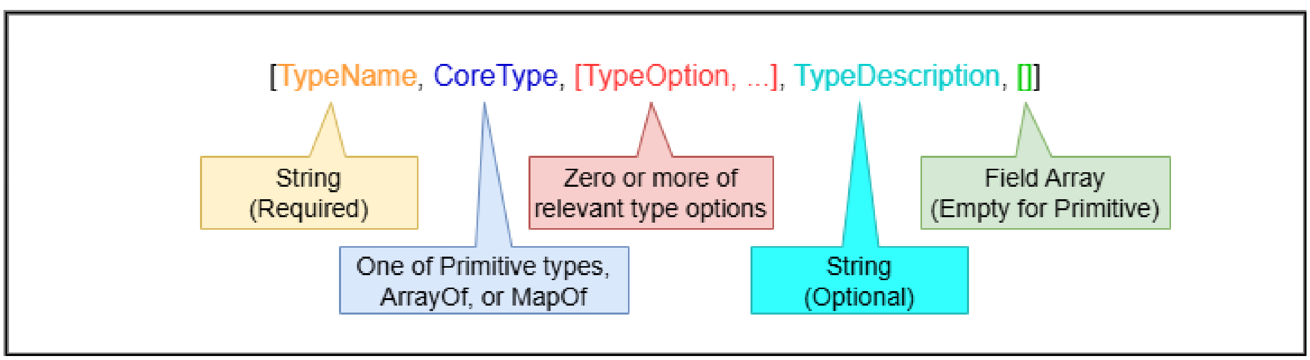


Figure 3-6 illustrates the JADN structure for defining an Enumerated **CoreType**; for enumerations each item definition in the **Fields** array has three elements:

Figure 3-6 -- JADN Fields for Enumerated Types

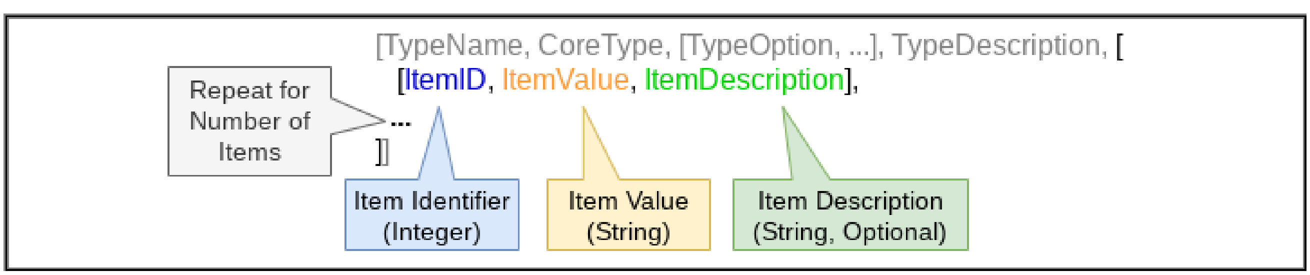
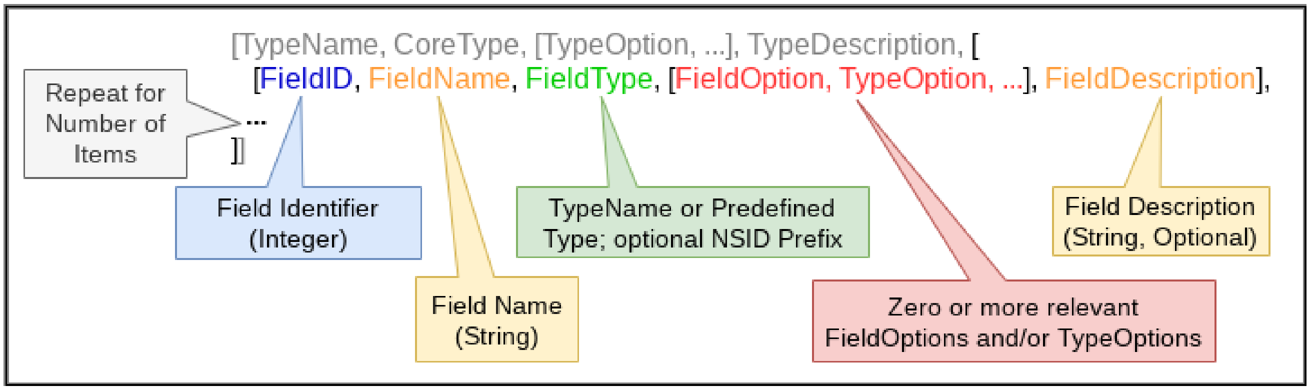


Figure 3-7 illustrates the JADN structure for defining a **CoreType** of Array, Choice, Map, or Record; for these types each field definition in the **Fields** array has five elements:

Figure 3-7 -- JADN Fields for Structured Compound Types



For each of the type definition formats illustrated in Figures 3-5, 3-6, and 3-7, only the initial elements are required to create a valid type or field definition, and unused elements default to an empty value of the relevant type. For a JADN schema in normative JSON format this means the optional fields at the end of a type or field definition can either be represented by empty elements (arrays or strings, as appropriate) or simply omitted. As an illustration, all of the following are legitimate representations of a primitive type definition where none of the optional fields are used:

```
["Counter", "Integer",[],"",[]]  <-- empty arrays and string for unused optional elements
["Counter", "Integer",[],""]     <-- field array omitted
["Counter", "Integer",[]]        <-- description string and field array omitted
["Counter", "Integer"]           <-- all optional fields omitted
```

The same principle applies to item and field definitions for union and compound types.

3.1.3.2 JADN Interface Definition Language (JIDL)

JIDL is a compact representation of JADN that is both easily readable, even for those with a minimal familiarity with JADN, and easy to edit. JIDL combines each type and its options into a single string formatted for readability, and lossless conversion between the normative JSON format and JIDL is straightforward. The basic structure of a simple type in JIDL is:

```
TypeName = <Primitive Core Type or IM-defined type> <type options> // <description>
```

Types with fields or items show those indented underneath the TypeName being defined, for example:

```
ARecordType = Record <type options> // an illustrative record type
  1 fieldName FieldType <field options>  // field description
  ...
```

The field or items definitions in the JIDL convey all of the same information as the normative JSON illustrated in Figures 3-5 and 3-6. The Information Modeling Examples in Section 3.3 include numerous examples of JIDL representation of a variety of JADN types.

When defining elements of type Array or Enum.ID in JIDL, no field names are used. These types are defined using a field ID and a TypeName. For documentation and debugging purposes a FieldName can be included in the JIDL comment field, immediately following the `//` and followed by a double colon delimiter (i.e., `::`). For more information see the [JADN Specification] discussion of fields in Compound types (Section 4.2.2) and JADN-IDL format (section 7.1). Here is a brief JIDL example of this format:

```
Publication-Data = Array         // who and when of publication
    1 String          // label:: name of record label
    2 String /date    // rel_date:: and when did they let this drop
```

3.1.3.3 Property Tables

Property tables commonly used in specifications to describe the format of, e.g., database records or protocol data units provide a structured representation that is easy to read but less efficient for editing. The JADN Specification describes the characteristics of property tables but does not define a normative format for them.

A typical property table for a JADN type with fields will have columns for:

- Identifier (ID), a number
- Name
- Type (with field options)
- Cardinality constraints
- Description

where the Type column will also convey field options other than cardinality constraints. The multiple representations example in Section 3.3.3 and the tables for the music library example in Appendix E.1.3 illustrate the use of property table presentation of JADN type definitions.

3.1.3.4 Entity Relationship Diagrams (ERDs)

Entity relationship diagrams (ERDs) are used to visually display the structure of an IM and can convey varying levels of detail. A normative JADN schema can be translated into a diagram-as-code representation such as [GraphViz] or [PlantUML] to generate ERDs, at any of three levels of detail:

- Conceptual: A top-level overview of the IM showing the organization of types
- Logical: A more detailed illustration of the IM including attributes of its types
- Informational: A complete illustration with all of the details of the constituent types

The music library example in Section 3.3.1 and the multiple representation examples in Section 3.3.3 both provide examples of ERDs generated from JADN models at various levels of detail.

3.1.3.5 Translation Among JADN Representations

Automated tooling makes it straightforward to translate among all four of these formats in a lossless manner, and each format has its advantages:

- JADN in native JSON format can be readily processed by common JSON tooling.
- JADN in table style presentation is often used in specifications (e.g., as property tables such as are commonly found in specifications).
- JADN presented in entity relationship diagrams aids with visualization of an information model.
- JADN in JIDL format, a simple text structure, is easy to edit, making it a good format for both the initial creation and the documentation of a JADN model. JIDL is also more compact than table style presentation.

The table style and ERD representations can be readily generated in an automated manner by translating the JADN schema to source code for rendering in various formats. For example, tables can be created using Markdown or HTML code, and ERDs can be created from code for rendering engines such as [Graphviz] or [PlantUML].

3.1.4 Type Definition Shortcuts and Nuances

This section describes JADN shortcuts and other usage details that add flexibility or simplify the development of IMs. [JADN Specification] section 5 defines a collection of shortcuts that "make type definitions more compact or support the Don't Repeat Yourself (DRY) software design principle. Shortcuts are syntactic sugar that can be replaced by core definitions without changing their meaning." These shortcuts can reduce the level of effort required by a JADN schema author and can make a schema more compact and understandable. Each shortcut description in the JADN Specification include a brief example.

The JADN Specification also defines a "system character" (by default the period, `.`) and in the Name Formats discussion (section 3.1.2) reserves the use of that character to automated tooling, saying "Schema authors should not create TypeNames containing the System character, but schema processing tools may do so".

3.1.4.1 "Anonymous" Type Definitions

As noted in Section 3.1.1.4, JADN Type Options can be applied to fields in compound types, but as explained in Section 5.1 of the JADN Specification, this is an shortcut that leads to the anonymous definition of a new type when processed by automated tooling. An example of this is the application of the `/email` format type option in this record specification:

```
Member = Record
  1 name         String
  2 email        String /email   // email is a type option for String types
```

Expanding replaces the type specification in field 2 of the record with a reference to the automatically generated type `Member.email`:

```
Member = Record
  1 name         String
  2 email        Member.email   // email is a type option for String types

Member.email = String /email    // email type option triggers tool-generated type definition.
```

The type definition for `Member.email` was generated by the tooling, as both noted in the comment and indicated by the presence of the `.` character in the type name. The same result could be achieved in Core JADN by defining a separate `Email` type:

```
Member = Record
  1 name         String
  2 email        Email

Email = String /email
```

The author(s) of an IM can determine whether the use of anonymous type definitions generated by JADN tooling improves the clarity of a model. For the example above, defining an email type that can be referenced throughout the model would likely be better than multiple, equivalent anonymous email types. In other cases the readability of the model can benefit from concisely written JADN (or JIDL) that relies on the tooling to generate the necessary types.

3.1.4.2 Selection and Use of JADN Compound Types

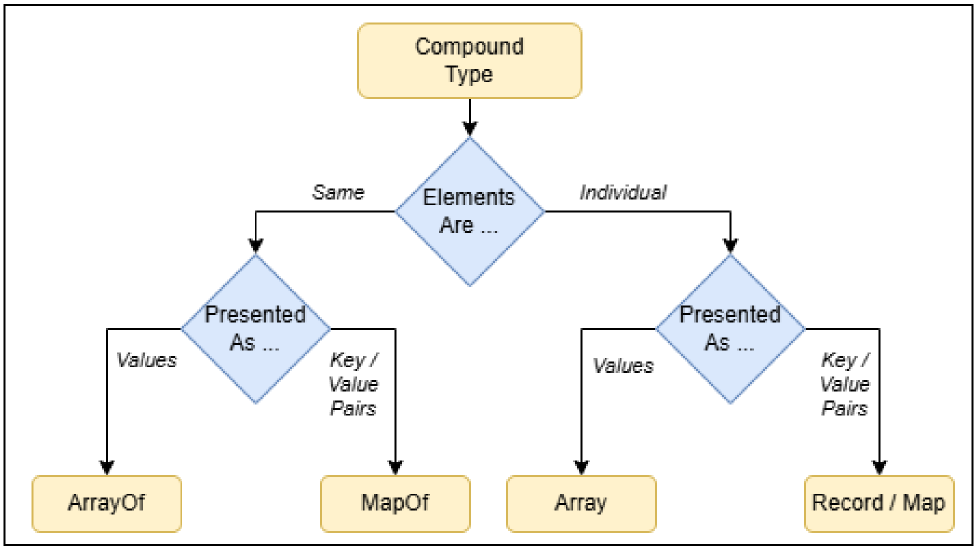
As described in Section 4.2.2 of the JADN Specification, each of the compound types defines a *collection* of related items such as the latitude and longitude of a geographic coordinate, or the set of properties of an object. In addition to its individual items, every collection has *multiplicity* attributes, including limits on the number of items, whether the items have a sequential ordering, and whether duplicate items are allowed.

The JADN compound types and their options are chosen for an IM based on the information characteristics to be modeled:

- Array and ArrayOf contain a group of values.
- Map, MapOf and Record contain a group of keys and corresponding values (a mapping)
- All items in ArrayOf and MapOf groups have the same value (and key) type
- Each item in Array, Map, and Record groups has an individual value (and key) type

and the decision tree for which compound type to use is shown in Figure 3-8:

Figure 3-8 -- Compound Type Decision Tree



For the last information type - collections of individually-defined key:value pairs - JADN provides two types: Map and Record. The difference is that Record keys have a sequential ordering while Map keys do not. Map instances are always serialized as key:value pairs, while Record instances may be serialized as either key:value pairs or table rows with values in column position, depending on data format.

For example if Location is a Record type:

```
Location = Record
  1 name       String
  2 state      String
  3 latitude   Number
  4 longitude  Number
```

its instances are serialized using *verbose* JSON data format as:

```
[
  {
    "name": "St. Louis",
    "state": "Missouri",
    "latitude": "38.627003",
    "longitude": "-90.199402"
  },
  {
    "name": "Seattle",
    "state": "Washington",
    "latitude": "47.60621",
    "longitude": "-122.33207"
  }
]
```

The same Record values are serialized using *compact* JSON data format (where the column positions are 1: name, 2: state, 3: latitude, 4: longitude) as:

```
[
  ["St. Louis", "Missouri", "38.627003", "-90.199402"],
  ["Seattle", "Washington", "47.60621", "-122.33207"]
]
```

If Location is a Map type, its instances are always serialized as key:value pairs regardless of data format, the same as a Record in verbose JSON.

3.1.4.3 JADN Handling of UML Multiplicity Options

Another significant UML concept is that JADN distinguishes among all four multiplicity types ([UML], Table 7.1), while logical models typically support only sets. Table 3-9 replicates the information from UML Table 7.1 and adds the equivalent JADN types. Note that the UML Specification cites the "traditional names" in its "Collection Type" column.

Table 3-9 -- Multiplicity Types

isOrdered	isUnique	Collection Type	JADN Type
false	*true*	Set	ArrayOf+set, MapOf
true	*true*	OrderedSet	ArrayOf+unique
false	*false*	Bag	ArrayOf+unordered
true	*false*	Sequence	ArrayOf

JADN accepts the UML philosophy that schemas are classifiers that take a unit of data and determine whether it is an instance of a datatype, and recognizes the idea of generalization ([UML], 9.9.7) through use of the Choice type.

Beyond these UML concepts, JADN recognizes that information models are directed graphs with a small predefined set of core datatypes and only two kinds of relationship: "collection" and "reference" (Section 4.2.2.3 of the JADN Specification).

3.1.4.4 Application of minLength / maxLength

The `minLength` and `maxLength` type options are distinctive in that they can apply to both primitive and compound types, with a different meaning in these two applications:

- When applied to a primitive type (Binary, Integer or String), the `minLength` and `maxLength` type options constrain the *values* that an instance of that type may hold. Specifically, when applied to:
  - An Integer type, the `minLength` and `maxLength` type options constrain the numeric values an instance of that type may hold.
  - A String type, the `minLength` and `maxLength` type options constrain the number of characters in the string.
  - A Binary type, the `minLength` and `maxLength` type options constrain the number of octets (bytes) in the binary value.

For example, the following specifies an Integer type that can be assigned values between `1` and `1000`, using both JADN (see Section 3.1.3.1) and JIDL notation (see Section 3.1.3.2):

```
["count","integer",["{1", "}1000"], "count of objects",[]]

// define a restricted count value
  count = integer {1..1000}  // count of objects
```

- When applied to a compound type (Array, ArrayOf, Map, MapOf, Record), the `minLength` and `maxLength` type options constrain the *number of elements* an instance of that type may have. For example, the following specifies a Record type that must have at least two fields populated, even though only one field is required (fields `field_2` and `field_3` are indicated as optional by the `["[0"]` *field* option [see Section 3.1.1.4]):

```
["RecordType", "Record", ["{2"], "requires field_1 and either or both field_2 and field_3", [
  [1, "field_1", "String", [], ""],
  [2, "field_2", "String", ["[0"], ""],
  [3, "field_3", "String", ["[0"], ""],
]]


RecordType = Record {2..*} // requires field_1 and either or both field_2 and field_3
  1 field_1   String
  2 field_2   String optional
  3 field_3   String optional
```

3.1.4.5 Inheritance

> NOTE 1: Inheritance capabilities are a new feature in JADN v2.0.

> NOTE 2: The JADN v2 inheritance-oriented `extends` type option is unrelated to deprecated `extend` type option in JADN v1.

JADN supports inheritance in information modeling, providing for referenced type / subtype relationships. There are four type options defined in Section 4.2.4 of the [JADN Specification] to manage the inheritance relationships among types:

- `abstract`: The `abstract` option indicates that a type definition is only a basis for defining subtypes and should never be instantiated in data.

- `extends`: The `extends` option indicates that the associated subtype definition is adding to the reference type on which it is based. An extending subtype can add new fields to or modify the cardinality of existing fields in the reference type but cannot redefine other aspects of existing, inherited fields.

- `restricts`: The `restricts` option indicates that the associated subtype definition is subtracting from the reference type on which it is based. A restricting subtype can remove optional fields defined in its reference type, however required fields cannot be removed.

- `final`: The `final` type option identifies a type that cannot have subtypes defined based on it.

The ability to use `extend` to modify a subtype field's cardinality is only permitted if every instance of the base type is also an instance of the extended type (i.e., it cannot make the cardinality or length more restrictive). For example, the `extend` type option cannot change a base type cardinality of `[3,10]` in a referenced type to a more restrictive cardinality of `[3,5]` in the subtype.

Type inheritance is static and can be applied both to primitive and compound types. However, as explained in the JADN Specification, there are other mechanisms applicable to primitive and some compound types to achieve equivalent results. The primary applications on inheritance identified in the specification are:

- adding, removing, or modifying the cardinality of fields in structured compound types
- adding items to Enumerated types

An example of applying the inheritance type options to an IM loosely based on geography markup language concepts can be found in Section 3.3.5.

3.1.5 Reference Relationships: Keys and Links

As explained in Section 3, JADN recognizes only two kinds of relationship: "collections" and "references". The relationships shown in previous examples are all of the "collection" variety. The "reference" relationship type applies when using a "collection" relationship would either:

1. create a cycle or loop in the graph of the information model, or
2. create data duplication.

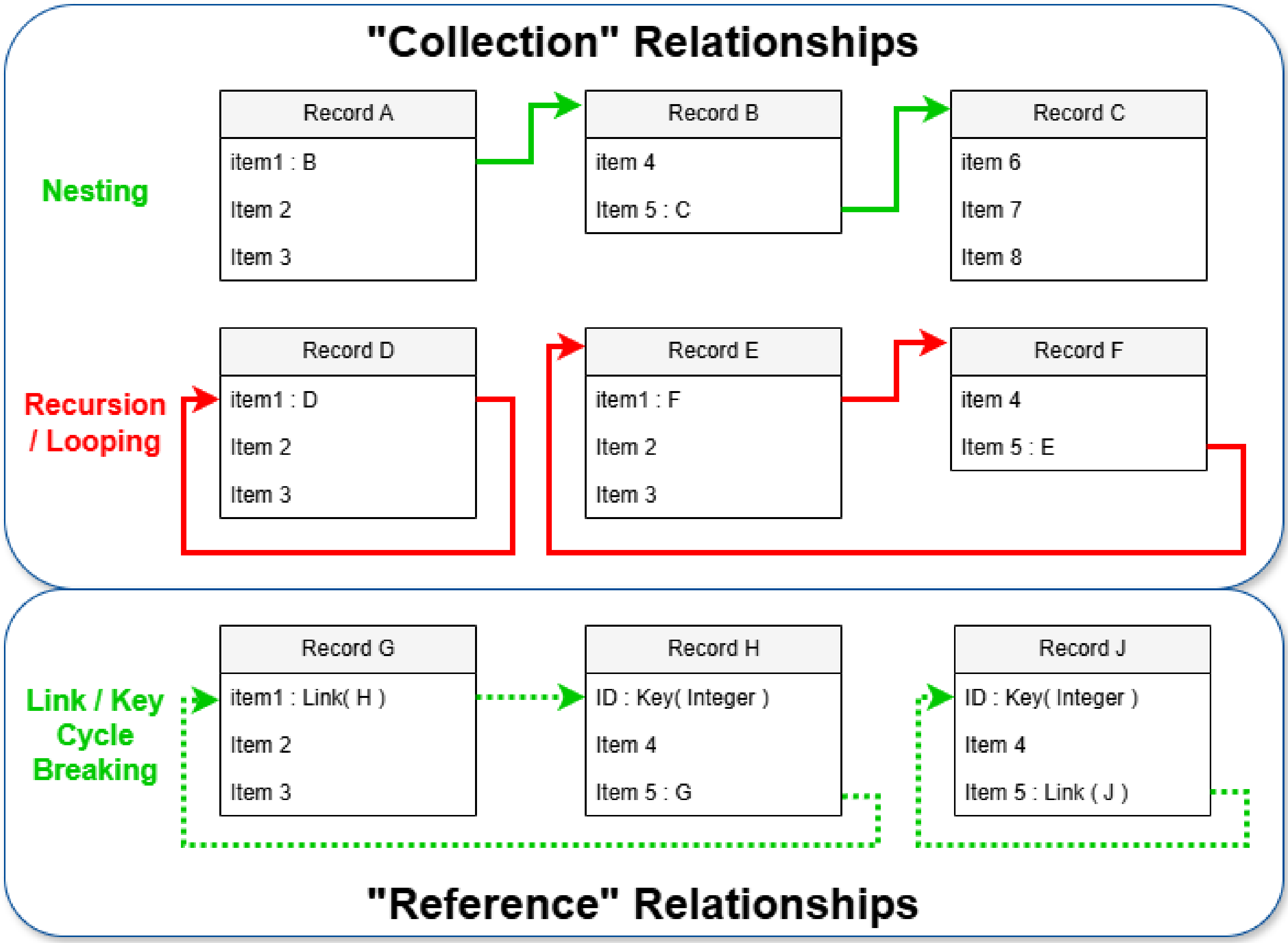
An example of cycle creation might occur, for example, in an IM for an SBOM format: because software components often incorporate other components a recursive situation arises when referring to the incorporated components:

```
Component - Record
  ...
  8  Components  ArrayOf(Component) {0..*}
  ...
```

When recursion is used in programming it is terminated by a base condition, but as a declarative specification an IM has no corresponding concept to terminate recursion. JADN uses "reference" relationships in situations where cycles occur in order to address this need. The method to define reference relationships is explained in Section 4.2.2.3, *Links*, of the [JADN Specification].

Figure 3-9 illustrates preferred (non-recursive) and problematic (recursive) "collection" relationships, and the use of the `key` and `link` keywords combined with an identifier field to establish "reference" relationships. The green lines show preferred relationships, the red lines the problematic ones that create cycles in the graph. The dotted green line in the lower left portion is a "reference" relationship enabled by the inclusion of a unique identifier in `Record H`, created by the use of the `key` field option to designate a primary key for objects described by `Record H`, and the corresponding use of the `link` field option in `Record G` when referring to such objects; the `link` field option both designates the field as a reference and generates the correct key type when extensions are removed by JADN tooling.

Figure 3-9 -- Collection and Reference Relationships



`Record J` in the lower right portion of the figure shows a self-referential `key / link` application. This is a generalization of the example from Section 4.2.2.3 of the JADN Specification, which allows for numerous relationships between objects of type `Person`:

```
Person = Record
    1 id        Key(Integer)
    2 name      String
    3 mother    Link(Person)
    4 father    Link(Person)
    5 siblings  Link(Person) [0..*]
    6 friends   Link(Person) [0..*]
```

The "references" relationship is also useful to reduce duplication when an information item may appear multiple times in a data structure. This use of the `key` / `link` structure is demonstrated in Section 3.3.3. In that example university classes are linked to students by a reference relationship to account for the likelihood that any individual student will most likely be registered for multiple classes. By *referencing* students records, only one record per student need appear in the data set regardless of how many classes they are registered for.

While is it common to use a primitive type such as `Integer` for a key, JADN permits the use of a compound type to support composite keys.

3.1.6 Schemas, Packages and Namespaces

Section 3 of the [JADN Specification] introduces the use of packages as the mechanism for organizing JADN schemas. This section provides additional information on the use of packages, along with the associated concept of namespaces.

3.1.6.1 Packages

At the simplest level, a package is a file containing a JADN schema in the form of JSON data, as described in Section 3.1.3.1. A JADN package document may contain a complete JADN schema or a portion of a schema. The file has two top-level components:

- optional metadata about the file, labeled as `meta`, and
- the schema content itself, labeled as `types`.

Definitions of all of the `Metadata` fields are provided in the JADN specification (sections 3.1.1 and 3.1.2).

The metadata portion is entirely optional, but if present must include the `package` field providing a URI for the package to enable the package to be referenced from other packages. A single schema may be divided into multiple packages (e.g., common types that are used extensively in a model might be collected into a library package), and a schema might also import one or more packages from a different schema (e.g., to use information objects defined in the official schema for a standard).

The `roots` portion of the package information is informational; JADN packages aren't intended to enforce a rigorous distinction between public and private types distinction. The `roots` list provides a means for schema authors to indicate the intended public types, and a basis for JADN schema tools to detect discrepancies.

3.1.6.2 Namespaces

> NOTE: this discussion of namespace management includes features to be added in JADN v2.0. The implementation of these features is backward-compatible with the handling of namespaces in JADN v1.0.

Namespaces identified in a schema package's metadata are the mechanism for managing the relationships among multiple schema packages. JADN namespace management provides for:

- Breaking a schema into multiple packages that can be combined without defining a namespace
- Including types defined in other schema packages under a specified namespace, including importing multiple packages under a single namespace

The JIDL representation of JADN namespace definition is:

```
Metadata = Map                     // Information about this package
     ...
   8 namespaces   Namespaces optional // Referenced packages
     ...

Namespaces = Choice(anyOf)            // anyOf v2.0 or v1.0, in priority order
   1  NsArr                           // ns_arr:: [prefix, namespace] syntax - v2.0
   2  NsObj                           // ns_obj:: {prefix: namespace} syntax - v1.0

NsArr = ArrayOf(PrefixNs){1..*}       // Type references to other packages - v2.0

PrefixNs = Array                      // Prefix corresponding to a namespace IRI
   1  NSID                            // prefix::
   2  Namespace                       // namespace::

NsObj = MapOf(NSID, Namespace){1..*}  // Type references to other packages - v1.0

Namespace = String /uri               // Unique name of a package
```

The `Namespaces = Choice(AnyOf)` type allows the flexible association of Namespace Identifiers (`NSID`) with the `Namespace` other packages declare for themselves. A Namespace Identifier (NSID) is, by default, a 1-8 character string beginning with a letter and containing only letters and numbers (the default formatting can be overridden by inserting an alternative definition into a JADN schema's `Metadata` map's `Config` section). The JADN v2.0 `NsAr / PrefixNS` structure enables multiple schema packages to be mapped to one NSID to group all of the types defined in that collection of packages into a single namespace. For any array element where the `NSID` field is blank, the types in the referenced package are made available in the current package without need for any NSID.

Within the schema package's `Types` definitions JADN uses the common convention of using the NSID followed by a colon to link an item to the namespace where it is defined (e.g., `NSID:TypeName`). So assuming the existence of `Package A`, and `Package B`, where `Package B` imports `Package A` with the NSID `packa`, then types defined in `Package A` can be used within `Package B` by identifying them as `packa:Some-Package-A-Type`.

An example of grouping multiple packages into the namespace of the importing package can be drawn from an IM of the NIST Open Security Controls Assessment Language [OSCAL], where the packages for the common `metadata` and `backmatter` structures, along with the various OSCAL document types, are imported without any NSID to create a single schema.

```
namespaces: [["", "https://example.gov/ns/oscal/0.0.1/metadata/"],
              ["", "https://example.gov/ns/oscal/0.0.1/backmatter/"],
              ["", "https://example.gov/ns/oscal/0.0.1/catalog/"],
              ["", "https://example.gov/ns/oscal/0.0.1/profile/"],
              ["", "https://example.gov/ns/oscal/0.0.1/component/"],
              ["", "https://example.gov/ns/oscal/0.0.1/ssp/"],
              ["", "https://example.gov/ns/oscal/0.0.1/assessment_plan/"],
              ["", "https://example.gov/ns/oscal/0.0.1/assessment_results/"],
              ["", "https://example.gov/ns/oscal/0.0.1/component/poam/"]]
```

> EDITOR'S NOTE: is it worthwhile to present both the v1.0 and v1.1 approaches to the following example?

As a concrete example of applying distinct namespaces for multiple packages, here is the `meta` portion of a JADN Schema for an OpenC2 consumer that implements two actuator profiles: stateless packet filtering (SLPF) and posture attribute collection, along with the OpenC2 Language Specification:

```
"meta": {
      "package": "http://acme.com/schemas/device-base/pacf/v3",
      "title": "OpenC2 base device schema for the PACE collection service and packet filter",
      "roots": ["OpenC2-Command", "OpenC2-Response"],
      "namespaces": {
       "ls": "http://docs.oasis-open.org/openc2/ns/types/v2.0",
       "slpf": "http://docs.oasis-open.org/openc2/ns/ap-slpf/v2.0",
       "pac": "http://docs.oasis-open.org/openc2/ns/ap-pac/v2.0"
      }
}
```

Within this schema `ls:`, `slpf:`, and `pac:` will be used when referencing types from the three external schemas .

3.2 Information Modeling Process

The JADN language is generally applicable to information modeling, and independent of the process used for developing a model. Future versions of this Committee Note will provide process notes based on experience developing and documenting information models using JADN. Brief summations are provided here of the approaches described in available literature; the reader is encouraged to reviewed the referenced papers for a more thorough discussion of each process described.

3.2.1 Y. Tina Lee Modeling Process

In her paper *Information Modeling: From Design to Implementation* [YTLee], the author discusses the importance of information models and describes a process. While the paper focuses on information modeling for manufacturing, the process described is generally applicable. The process described in this paper has the following steps:

1. Define the scope of the model, identifying the domain of discourse and the processes to be supported by the IM.
2. Conduct a requirements analysis to define information requirements.
3. Develop the model, transforming information requirements into a conceptual model. This may employ a top-down, bottom-up, or mixed / inside-out approach.
4. Group concepts to identify units of functionality
5. Structure information requirements into entities, objects, or classes
6. Capture the model in the chosen modeling language

3.2.2 Frederiks / van der Weide Modeling Process

In their paper *Information modeling: The process and the required competencies of its participants* [Frederiks], the authors discuss the process of information modeling, its quality and the required competencies of its participants.

In the Frederiks approach, the process has two roles (which may be filled by groups):

- A **Domain Expert**: someone with superior detailed knowledge of the Universe of Discourse (UoD) but often minor powers of abstraction from that same UoD
- A **System Analyst**: someone with superior powers of abstraction, but limited knowledge of the UoD.

and the process has four phases:

1. *Elicitation*: used to drive creation of a requirements document, an informal specification in natural language.

2. *Modeling*: the creation of a conceptual model based on the requirements document.

3. *Verification*: confirmation that the formal specification correctly applies the formal syntax rules of the chosen modeling technique.

4. *Validation*: confirmation with the domain expert that the formal model properly represents the requirements document.

The process is executed in an iterative sequence of modeling, verification and validation. At least one iteration of the modeling loop is required.

3.3 Information Modeling Examples

As discussed in Section 1.1.5, JADN is a general purpose tool for information modeling, and can be applied to a broad range of IM needs. Some possible subjects for IMs are:

- Complex organizations, such as a business (people, departments, roles, locations, organizational structure) or university (people, departments, classes, buildings, rooms, schedules)
- Shopping Website (customers, accounts, catalogs, carts, payment processing, shipping)
- Vehicle Rental Management (customers, accounts, vehicles, rentals, check-out, check-in, billing)
- Boutique Manufacturer (catalog, customization options, supply chain, orders, builds, shipping)
- Website Message Board (users, accounts, forums, threads, messages)
- Information structures such as a software bill of materials (SBOM)
- Standard Development Organization (SDO) management system (member organizations, member persons, voting rights, topic-focused groups and rosters, discussion forums and messages, calendars, meeting attendance, draft and approved documents, ballots)
- Music Database (artists, albums, songs, tracks, metadata, guest artists)

This CN provides several examples to illustrate approaches to information modeling and the application of JADN. The example IMs are:

- A digital music library: an example of top-down analysis to develop an IM
- The IP version 4 packet header: an example of developing an IM from a well-defined data structure
- A university with classes and people (teachers and students): an example to illustrate the relationship among the available JADN representations described in Section 3.1.3
- A calendar event model: an example of developing a JADN model from an existing JSON schema
- An example applying JADN inheritance features, loosely inspired by the [CityGML] and [CityJSON] geographic modeling languages

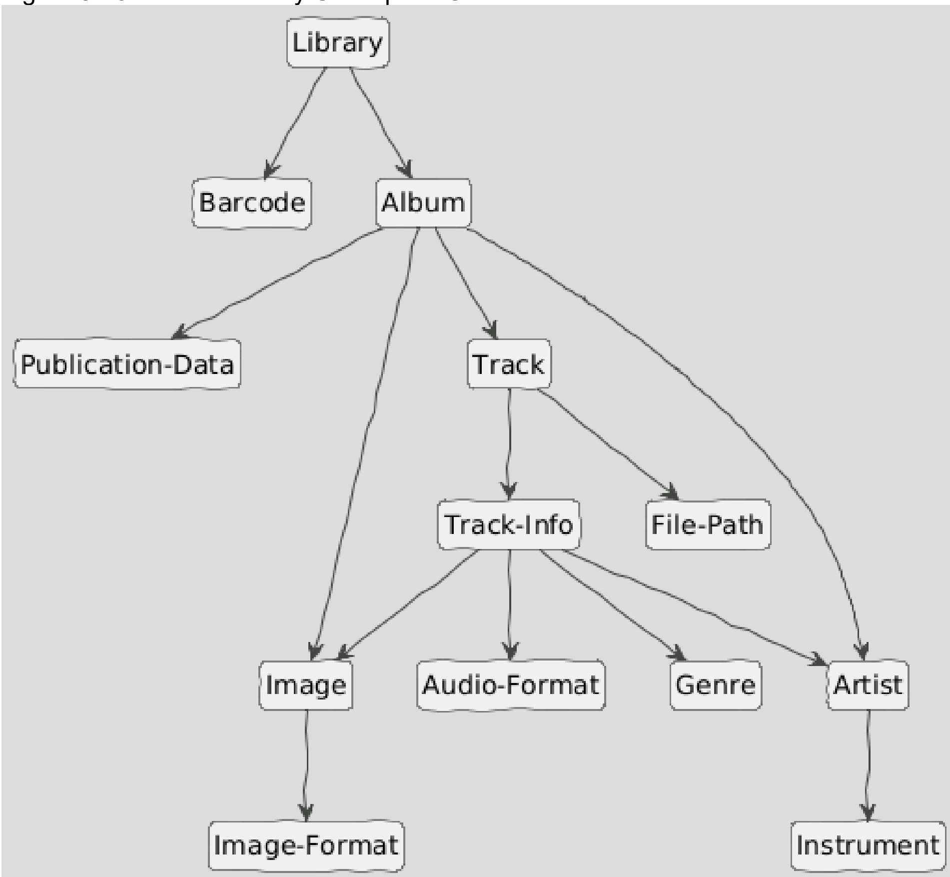
These examples use a mixture of the various JADN representation formats described in Section 3.1.3. The university example in Section 3.3.3 specifically incorporates all of the representations describing a single information model.

3.3.1 Digital Music Library

This example shows a simple IM for a digital music library and can be considered a "Hello World" example of applying the concepts described in this committee note. The components of the library are presented here in JIDL form along with brief descriptions. The final ERD for the library appears at the end of this section. The complete, consolidated JADN, JIDL, and property tables can be found in Appendix E.1.

The model assumes that each track is stored as a file with its audio in one of several recognized formats. The library organizes tracks into albums, which are associated with a barcode identifier. The model is loosely based on the ID3 metadata used with MP3 audio files. Figure 3-10 provides a conceptual overview of the music library's structure.

Figure 3-10 -- Music Library Conceptual Overview



The JADN package for the music library IM provides basic metadata:

```
       title: "Music Library"
     package: "http://fake-audio.org/music-lib"
     version: "1.1"
 description: "This information model defines a library of audio tracks,
              organized by album, with associated metadata regarding
              each track. It is modeled on the types of library data
              maintained by common websites and music file tag editors."
     license: "CC0-1.0"
     roots: ["Library"]
```

At the top level, the library is map of barcodes to albums. The barcode serves as a convenient unique identifier for each album. A UPC-A barcode is a 12-digit number, and a `pattern` Type Option is used to constrain the `String` type that models it accordingly.

```
Library = MapOf(Barcode, Album){1..*} // Top level of the library is a map of CDs by barcode

Barcode = String{pattern="^\d{12}$"}  // A UPC-A barcode is 12 digits
```

Each album is represented by a record containing the album's artist, title, publication data, cover art, total track count, and an array of individual audio tracks. Multiple digital image formats are supported for the cover art. Note that this example also contains an example of an anonymous type definition (i.e., the `release_date` field in the `Publication-Data` record) as described in Section 3.1.4.1.

```
Album = Record                          // model for the album
   1 album_artist     Artist            // primary artist associated with this album
   2 album_title      String            // publisher's title for this album
   3 pub_data         Publication-Data // metadata about the album's publication
   4 tracks           Track [1..*]      // individual track descriptions and content
   5 total_tracks     Integer{1..*}     // total track count
   6 cover_art        Image optional    // cover art image for this album

Publication-Data = Record               // who and when of publication
```

```
   1 publisher        String           // record label that released this album
   2 release_date     String /date     // and when did they let this drop

Image = Record                         // pretty picture for the album or track
   1 image_format     Image-Format     // what type of image file?
   2 image_content    Binary           // the image data in the identified format

Image-Format = Enumerated              // can only be one, but can extend list
   1 PNG
   2 JPG
   3 GIF
```

Artists have a name and one or more associated instruments that they perform on. The same information applies whether the artist is the primary performer (i.e., `album_artist` in the `Album` record) or a guest performer (i.e., `featured_artist` in a `Track-Info` record)

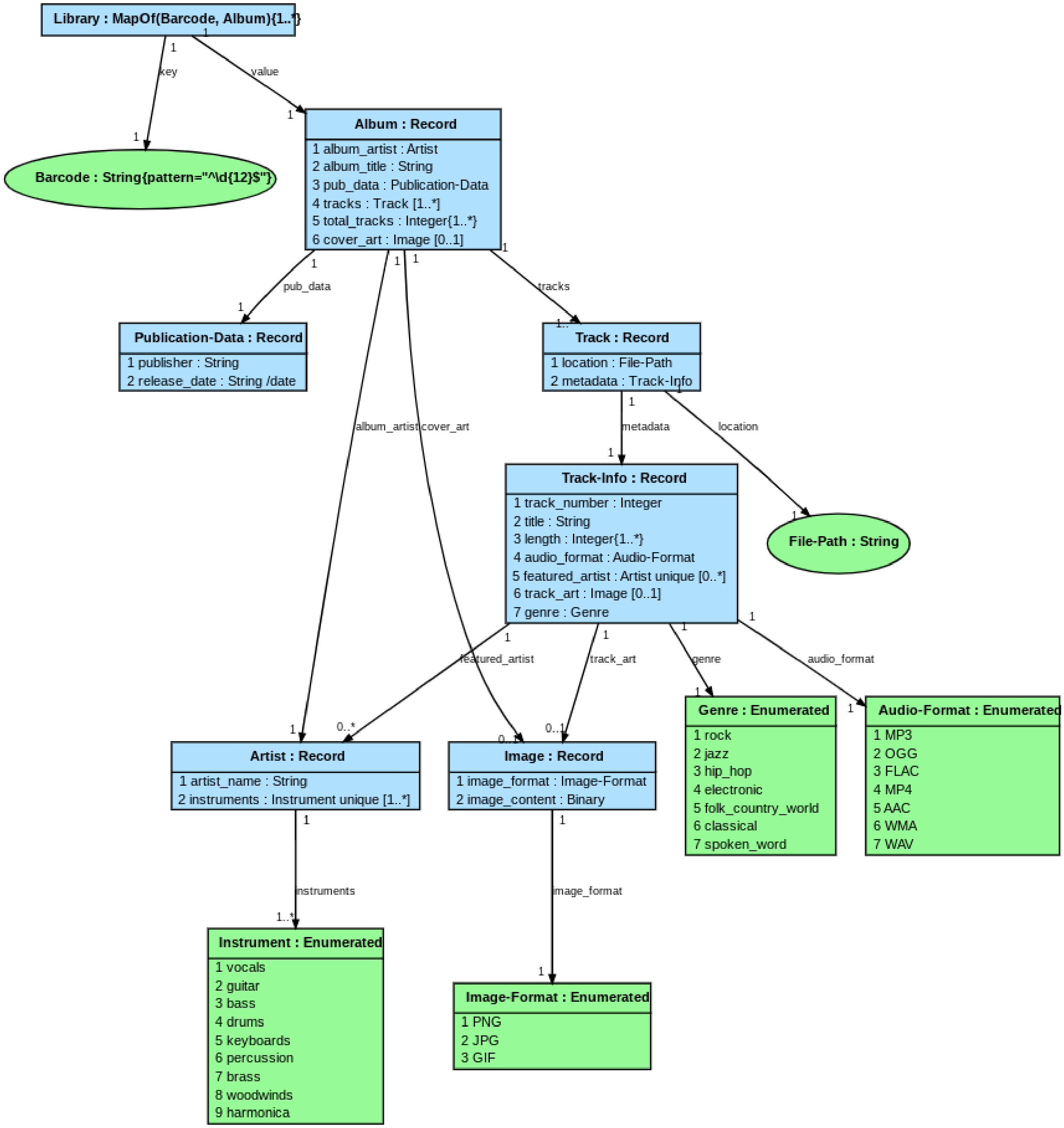
```
Artist = Record                                // interesting information about a performer
   1 artist_name      String                   // who is this person
   2 instruments      Instrument unique [1..*] // and what do they play

Instrument = Enumerated                        // collection of instruments (non-exhaustive)
   1 vocals
   2 guitar
   3 bass
   4 drums
   5 keyboards
   6 percussion
   7 brass
   8 woodwinds
   9 harmonica
```

Each track is stored in a file, and has a track number within the album along with a title, length, genre, potentially "featured" artists, the audio data, and optionally individual track art. Multiple digital audio formats are supported for the audio content.

```
Track = Record                             // for each track there's a file with the audio and a metadata record
   1 location         File-Path            // path to the audio file location in local storage
   2 metadata         Track-Info           // description of the track

Track-Info = Record                        // information about the individual audio tracks
   1 track_number     Integer              // track sequence number
   2 title            String               // track title
   3 length           Integer{1..*}        // length of track in seconds; anticipated user display is mm:ss;
                                           // minimum length is 1 second
   4 audio_format     Audio-Format         // format of the digital audio
   5 featured_artist  Artist unique [0..*] // notable guest performers
   6 track_art        Image optional       // each track can have optionally have individual artwork
   7 genre            Genre

Audio-Format = Enumerated                  // can only be one, but can extend list
   1 MP3
   2 OGG
   3 FLAC
   4 MP4
   5 AAC
   6 WMA
   7 WAV

Genre = Enumerated                         // Enumeration of common genres
   1 rock
   2 jazz
   3 hip_hop
   4 electronic
   5 folk_country_world
   6 classical
   7 spoken_word

File-Path = String                         // local storage location of file with directory path
                                           // from root, filename, and extension
```

The entity relationship diagram in Figure 3-11 illustrates how the model components connect.

Figure 3-11 -- Music Library Example ERD



3.3.2 Internet Protocol Version 4 Packet Header

This example illustrates developing an abstract IM from an existing well-defined data structure. The IPv4 packet header definition originates from [RFC 791], with some details of the header modified by subsequent RFCs. While there may be limited utility in leveraging JADN's information equivalence focus to generate IPv4 packet header encodings other than binary, the model is useful to document the fields of the header and describe their conceptual purpose. This model was developed based on the content of three Wikipedia pages related to the IPv4 packet header:

- The Header section of the IPv4 article
- The Classification and Marking section of the Differentiated Services article
- The Operation of ECN with IP section of the Explicit Congestion Notification article

The model comprises a JADN Array type containing all of the fields of the IPv4 packet header (except the `options` field), supported by two Enumerated types to explicate the meanings of particular fields. Figure 3-12 shows the packet header array in JIDL form. In this representation the field "names" are embedded in the JIDL comment field between the `//` and `::` delimiters, as described in Section 3.1.3.2.

Figure 3-12 -- IPv4 Header (JIDL)

```
IPv4-Packet-Header = Array    // fields in an IPv4 packet header, per RFC 791 and subsequent contributions
   1  Integer /u4             // version:: version; always = 4 for an IPv4 packet header (4 bits)
   2  Integer /u4             // ihl:: Internet Header Length (4 bits)
   3  Diff-Svcs-Code-Point    // dscp:: Differentiated Services Code Point (enumeration, 6 bits)
   4  ECN                     // ecn:: Explicit Congestion Notification (enumeration, 2 bits)
   5  Integer{20..65535} /u16 // total_length:: entire packet size in bytes, including header and data
                              // (min: 20 bytes (header without data) / max: 65,535 bytes)
   6  Integer /u16            // ident:: identification field; primarily used for uniquely identifying
                              // the group of fragments of a single IP datagram
   7  Boolean                 // reserved_flag:: Reserved flag field; should be set to 0 (1-bit)
   8  Boolean                 // dont_frag:: Don't Fragment flag (1 bit)
   9  Boolean                 // more_frags:: More Fragments (1 bit): cleared for unfragmented packets
                              // and last fragment of a fragmented packet
  10  Integer{0..8191} /u13   // frag_offset:: specifies the offset of a particular fragment relative to
                              // the beginning of the original unfragmented IP datagram (13 bits)
  11  Integer /u8             // time_to_live:: datagram's lifetime specified in seconds, but time intervals less
than
                              // 1 second are rounded up to 1. In practice, the field is used as a hop count
  12  Integer /u8             // protocol:: transport layer protocol, per IANA registry
  13  Integer /u16            // header_checksum:: used for error checking of the packet header
  14  Binary /ipv4-addr       // source_addr:: source address for the packet sender; may be modified by NAT
  15  Binary /ipv4-addr       // dest_addr:: address for the intended recipient of the packet; may be modified by
NAT
```

This portion of the model highlights the application of a number of JADN capabilities:

- The use of the Array type for an information structure with rigid positioning
- The use of the /u<*n*> Integer type format option to define fields of arbitrary bit length
- The combination of a Binary type and the `/ipv4-addr` TypeOption to specify IPv4 network addresses
- The use of the Boolean type to clarify the meaning of flag field bits

Three fields of the IPv4 packet header are functionally enumerations:

- Differentiated Service Code Point (DSCP)
- Explicit Congestion Notification (ECN)
- Protocol

The values for the `Protocol` field are managed by the Internet Assigned Numbers Authority (IANA); this model does not include an explicit enumeration of the IANA-assigned values. The model makes the meaning and use of the DSCP and ECN fields clearer by defining associated enumerations, as illustrated in Figure 3-13.

Figure 3-13 -- IPv4 Packet Header Enumerations

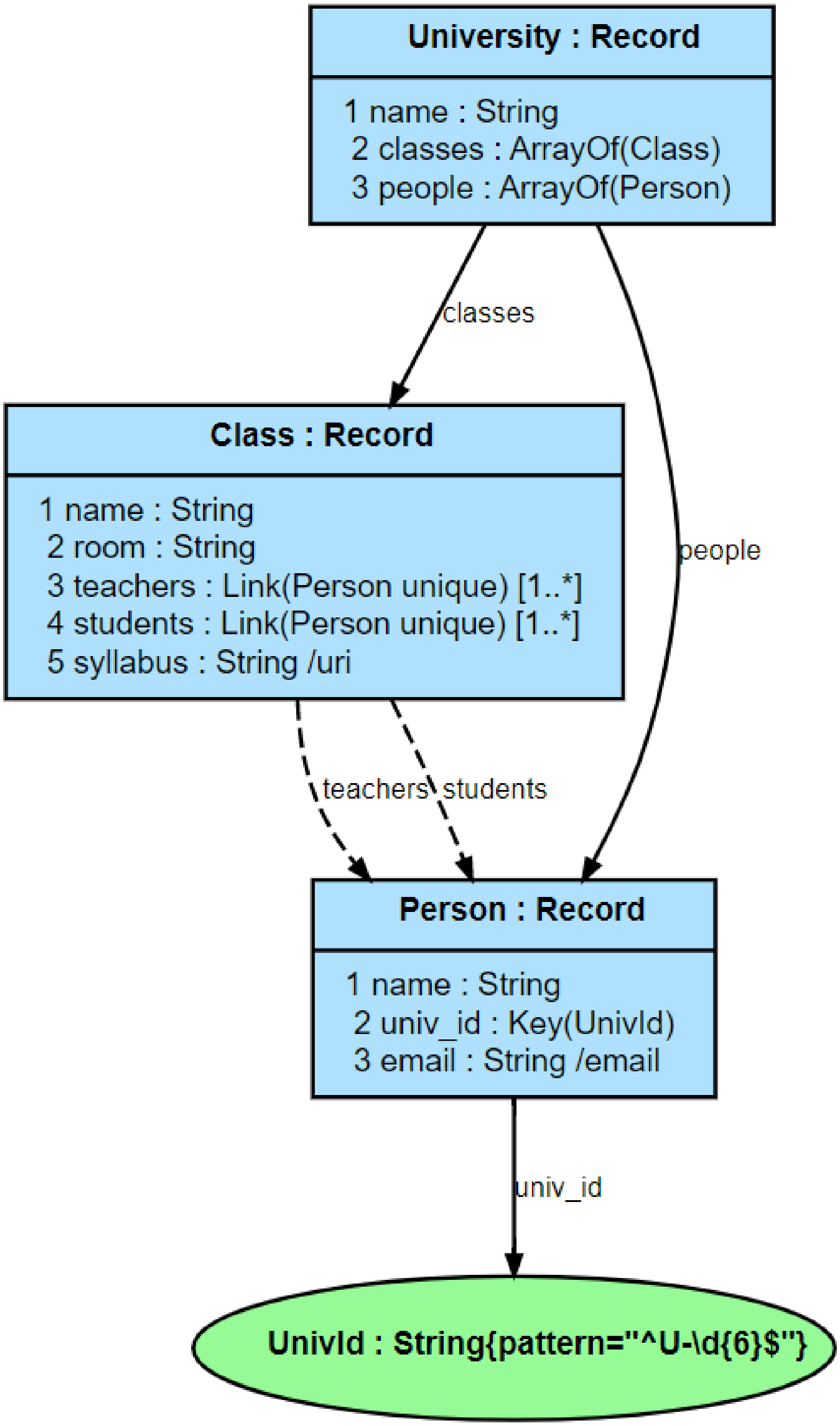
```
Diff-Svcs-Code-Point = Enumerated       // Differentiated Services Code Point, 6 bits
   0 df          // Default Forwarding (best effort)
  10 af-c1-dpL   // Assured Forwarding (RFCs 2597 / 3260) - class 1 / drop probability low
  12 af-c1-dpM   // Assured Forwarding (RFCs 2597 / 3260) - class 1 / drop probability medium
  14 af-c1-dpH   // Assured Forwarding (RFCs 2597 / 3260) - class 1 / drop probability high
  18 af-c2-dpL   // Assured Forwarding (RFCs 2597 / 3260) - class 2 / drop probability low
  20 af-c2-dpM   // Assured Forwarding (RFCs 2597 / 3260) - class 2 / drop probability medium
  22 af-c2-dpH   // Assured Forwarding (RFCs 2597 / 3260) - class 2 / drop probability high
  26 af-c3-dpL   // Assured Forwarding (RFCs 2597 / 3260) - class 3 / drop probability low
  28 af-c3-dpM   // Assured Forwarding (RFCs 2597 / 3260) - class 3 / drop probability medium
  33 af-c3-dpH   // Assured Forwarding (RFCs 2597 / 3260) - class 3 / drop probability high
  34 af-c4-dpL   // Assured Forwarding (RFCs 2597 / 3260) - class 4 / drop probability low
  36 af-c4-dpM   // Assured Forwarding (RFCs 2597 / 3260) - class 4 / drop probability medium
  43 af-c4-dpH   // Assured Forwarding (RFCs 2597 / 3260) - class 4 / drop probability high
  44 va          // Voice Admit (RFC 5865)
  46 ef          // Expedited Routing (RFC 3246)

ECN = Enumerated // Explicit Congestion Notification (RF 3168)
   0 not_ect     // Not ECN-Capable Transport, Not-ECT
   1 ect_1       // ECN Capable Transport(1), ECT(1)
   2 ect_0       // ECN Capable Transport(0), ECT(0)
   3 ce          // Congestion Experienced, CE
```

In order to align with the various RFCs documenting the use of DCSP, the DSCP enumeration defines its field values in terms of the IETF's recommended values as documented in the Wikipedia article, rather than a simple monotonic sequence of field values that would be the usual approach in a more design-oriented modeling activity.

3.3.3 Multiple Representations Example

The [JADN Specification], section 7.3, uses a simple example of an IM for a university to illustrate the use of ERDs for IMs. This section uses that ERD as a starting point for an example to illustrate the various JADN representations described in Section 3.1.3. The example begins with the ERD for the model:

Figure 3-14 -- Simple University Example ERD



The package (see Section 3.1.6.1) containing the JADN corresponding to the above ERD is shown here:

Figure 3-15 -- Simple University Example JADN (JSON format)

```
{
 "info": {
  "package": "http://example.com/uni",
  "roots": ["University"]
 },

 "types": [
  ["University", "Record", [], "A place of learning", [
    [1, "name", "String", [], "University Name"],
    [2, "classes", "ArrayOf", ["*Class"], "Available classes"],
    [3, "people", "ArrayOf", ["*Person"], "Students and faculty"]
  ]],

  ["Class", "Record", [], "Pertinent info about classes", [
    [1, "name", "String", [], "Name of class"],
    [2, "room", "String", [], "Where it happens"],
    [3, "teachers", "Person", ["L", "]0", "q"], "Teacher(s) for this class"],
    [4, "students", "Person", ["L", "]0", "q"], "Students attending this class"],
    [5, "syllabus", "String", ["/uri"], "Link to class syllabus on the web"]
  ]],

  ["Person", "Record", [], "", [
    [1, "name", "String", [], "Student / faculty member name"],
    [2, "univ_id", "UnivId", ["K"], "Unique ID for student / faculty member"],
    [3, "email", "String", ["/email"], "Student / faculty member email"]
  ]],

  ["UnivId", "String", ["%^U-\\d{6}$"], "University ID (U-nnnnnn)", []]
 ]
}
```

Converting the JSON to JIDL yields a representation that is both more readable and easier to edit:

Figure 3-16 -- Simple University Example JADN (JIDL format)

```
     package: "http://example.com/uni"
     roots: ["University"]

University = Record                            // A place of learning
   1 name             String                   // University Name
   2 classes          ArrayOf(Class)           // Available classes
   3 people           ArrayOf(Person)          // Students and faculty

Class = Record                                 // Pertinent info about classes
   1 name             String                   // Name of class
   2 room             String                   // Where it happens
   3 teachers         Link(Person unique) [1..*]  // Teacher(s) for this class
   4 students         Link(Person unique) [1..*]  // Students attending this class
   5 syllabus         String /uri              // Link to class syllabus on the web

Person = Record
   1 name             String                   // Student / faculty member name
   2 univ_id          Key(UnivId)              // Unique ID for student / faculty member
   3 email            String /email            // Student / faculty member email

UnivId = String{pattern="^U-\d{6}$"}           // University ID (U-nnnnnn)
```

Property tables are a common representation of data structures in specifications. JADN is easily converted to property tables, which are quite readable but somewhat more challenging to edit than JIDL (the package information has been omitted from the set of property tables illustrated here). Each property table is preceded by the comment on the type definition that created that table (e.g., the University Record type has the comment "A place of learning"). Those comments are set in italics in this example for clarity.

Figure 3-17 -- Simple University Example JADN (table format)

A place of learning

Type: University (Record)

ID	Name	Type	#	Description
1	**name**	String	1	University Name
2	**classes**	ArrayOf(Class)	1	Available classes
3	**people**	ArrayOf(Person)	1	Students and faculty

Pertinent info about classes

Type: Class (Record)

ID	Name	Type	#	Description
1	**name**	String	1	Name of class
2	**room**	String	1	Where it happens
3	**teachers**	Link(Person unique)	1..*	Teacher(s) for this class
4	**students**	Link(Person unique)	1..*	Students attending this class
5	**syllabus**	String /uri	1	Link to class syllabus on the web

Type: Person (Record)

ID	Name	Type	#	Description
1	**name**	String	1	Student / faculty member name
2	**univ_id**	Key(UnivI+d)	1	Unique ID for student / faculty member
3	**email**	String /email	1	Student / faculty member email

Type Name	Type Definition	Description
UnivId	String{pattern="^U-\d{6}$"}	University ID (U-nnnnnn)

Finally, the code to generate the ERD presented at the beginning of the example is easily generated from the JADN model. In this specific example code for the widely-used GraphViz tool is provided. JADN tooling can created "diagram as text" code for GraphVIZ and PlantUML with varying levels of detail (i.e., Conceptual, Logical, Informational). For example, contrast the simple conceptual view of the music library in Figure 3-10 with the detailed informational ERD at the start of this section (Figure 3-14).

Figure 3-18 -- Simple University Example ERD Source Code (GraphViz)

```
# package: http://example.com/uni
# roots: ['University']

digraph G {
  graph [fontname=Arial, fontsize=12];
  node [fontname=Arial, fontsize=8, shape=record, style=filled, fillcolor=lightskyblue1];
  edge [fontname=Arial, fontsize=7, arrowsize=0.5, labelangle=45.0, labeldistance=0.9];
  bgcolor="transparent";

n0 [label=<{<b>University : Record</b>|
  1 name : String<br align="left"/>
  2 classes : ArrayOf(Class)<br align="left"/>
  3 people : ArrayOf(Person)<br align="left"/>
}>]

n1 [label=<{<b>Class : Record</b>|
  1 name : String<br align="left"/>
  2 room : String<br align="left"/>
  3 teachers : Link(Person unique) [1..*]<br align="left"/>
```

```
  4 students : Link(Person unique) [1..*]<br align="left"/>
  5 syllabus : String /uri<br align="left"/>
}>]

n2 [label=<{<b>Person : Record</b>|
  1 name : String<br align="left"/>
  2 univ_id : Key(UnivId)<br align="left"/>
  3 email : String /email<br align="left"/>
}>]

n3 [label=<<b>UnivId : String{pattern="^U-\d{6}$"}</b>>, shape=ellipse, style=filled, fillcolor=palegreen]

  n0 -> n1 [label=classes]
  n0 -> n2 [label=people]
  n1 -> n2 [label=teachers, style="dashed"]
  n1 -> n2 [label=students, style="dashed"]
  n2 -> n3 [label=univ_id]
}
```

3.3.4 Converting JSON Schema to JADN

This example begins with an existing JSON schema that is developed into a JADN IM. The starting point is the Calendar schema on the examples page of the json-schema.org website. The first step was to validate the JSON schema using the JSON Schema Linter. The changes from the starting example were:

1. Change `"dtStart"` in the `"required"` field to `"startDate"`
2. Remove the reference to the geographic location schema

These changes enabled the JSON schema to pass validation. An automated JADN tool was used to convert the JSON scheme to JADN, leading to an initial JADN schema (JIDL representation):

```
     package: "https://example.com/calendar.schema.json"
     roots: ["$Root"]
      config: {"$FieldName": "^[$a-z][-_$A-Za-z0-9]{0,63}$", "$MaxString": 1000}

$Root = Record                          // A representation of an event
   1 startDate        String            // Event starting time
   2 endDate          String optional   // Event ending time
   3 summary          String
   4 location         String optional
   5 url              String optional
   6 duration         String optional   // Event duration
   7 recurrenceDate   String optional   // Recurrence date
   8 recurrenceRule   String optional   // Recurrence rule
   9 category         String optional
  10 description      String optional
```

This initial JADN schema reflects the original JSON schema with regard to field type and optionality but also presents multiple opportunities for fine tuning:

1. The `startDate`, `endDate`, `url`, and `recurrenceDate` fields can have validation keywords applied to limit their content to appropriate values (this is also possible in JSON schema but was not a feature of original example)
2. The `duration` field can be changed to an `Integer` representing duration in a time unit (e.g., minutes) to simplify automated processing
3. Guidance can be provided for the format of the recurrenceRule field
4. The automatically generated `"$Root"` name for record in the schema can be changed to something more meaningful (e.g., `Event`)
5. Comments can be added to fields that lack them to further clarify their intent

The starting JSON schema appears to have been modeled on the iCalendar standard [RFC 5545] which also can be used as a source for refinements:

1. The `summary` field can have a character limit applied to align with its intended use as "a short summary or subject for the calendar component"
2. Similarly, the `description` field could be given a larger character limit to align with its intended use as "a more complete description of the calendar component than that provided by the "SUMMARY" property"
3. The `recurrenceDate` and `recurrenceRule` fields can be connected to their iCalendar counterpart properties to clarify their use
4. Field comments can be updated to reflect the intents for the corresponding iCalendar properties

Applying these changes leads to a refined model for the event schema:

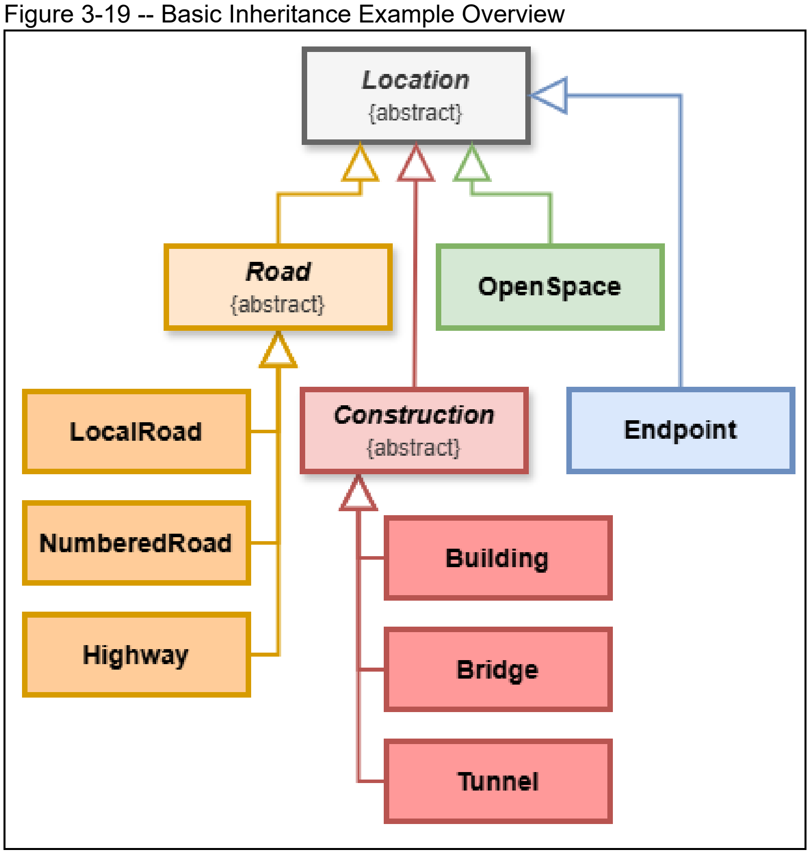
```
     package: "https://example.com/calendar.schema.json"
     roots: ["Event"]
      config: {"$FieldName": "^[$a-z][-_$A-Za-z0-9]{0,63}$", "$MaxString": 1000}

Event = Record                                   // A representation of an event
   1 startDate        String /date-time          // Event starting time
   2 endDate          String /date-time optional // Event ending time
   3 summary          String{1..120}             // a short summary or subject of the event (<= 120 characters)
   4 location         String optional            // the intended venue for the event
   5 url              String /uri optional       // a Uniform Resource Locator (URL) associated with the event
   6 duration         Integer optional           // Event duration in minutes (should display as DD : HH : MM)
   7 recurrenceDate   String /date-time optional // the list of DATE-TIME values for recurring events (populate
                                                    per iCalendar RDATE property, RFC 5545, Section 3.8.5.2)
   8 recurrenceRule   String optional            // Recurrence rule (populate per iCalendar
                                                    RRULE property, RFC 5545, Section 3.8.5.3)
   9 category         String optional            // defines the category (ies) for the event
  10 description      String optional            // a more complete description of the event than that provided
by the summary
```

Compared to the complexity of the iCalendar standard this IM for a calendar event is greatly simplified but could serve as the starting point for a more complete IM for describing calendar information for exchange among systems.

3.3.5 Inheritance Example

JADN v2.0 introduces inheritance features to support constructing DataType inheritance hierarchies. This example uses concepts inspired by the [CityGML] and [CityJSON] geographic modeling languages to provide an introduction to the use of inheritance in JADN. An overview of the key types defined in this example and their inheritance relationships is shown in Figure 3-19. This description focuses on the inheritance-related aspects of the model; the JIDL for the complete model is provided in Appendix E.2.

Figure 3-19 -- Basic Inheritance Example Overview



The example defines abstract (i.e., non-instantiable) types for `Location`, `Road`, and `Construction` as a basis for more specific types in the model. The `Location` type simply identifies the geographic center of a feature (i.e., its latitude and longitude) and optionally the political unit within which the feature resides:

```
Coordinate = Array            // A single geographic point (latitude / longitude)
   1  Number=[-90.0, 90.0]     // latitude::
   2  Number=[-180.0, 180.0]   // longitude::

PolUnit = String              // the name of the political area where the feature exists
                              // (city / county / state level, as appropriate)

Location = Record abstract
   1 geoCenter        Coordinate       // geographic center of the feature of interest at the location
   2 politicalUnit    PolUnit optional  // the name of the political area where the location exists
```

Note that this simplified model is 2-dimensional; the definition of `Coordinate` does not include an elevation component.

Endpoints use the `restricts` inheritance option to make the political unit field required in order to be able to specify where, politically, the endpoints of a road, tunnel, or bridge segment reside.

```
Endpoint = Record restricts(Location) // politicalUnit is required for an endpoint
   2 politicalUnit    PolUnit         // the name of the political area where the endpoint exists
```

This supports situations where, for example, a bridge or tunnel spans a river that runs between different states. Note that both `Location` and `Endpoint` are Record types, and in the definition of `Endpoint` the restricted field has the same identifier as in the referenced `Location` type. Both of these are important aspects when applying the inheritance type options.

The model uses the `extends` inheritance type option in multiple places. The first is `OpenSpace`, which extends the `Location` Record type with a field to define the boundary of an open space using the `Coordinates` type.

```
Coordinates = ArrayOf(Coordinate)     // A list of geographic points

OpenSpace = Record extends(Location)  // a defined area of open space
   3 boundary Coordinates     // an array of lat/long points defining the line segments
                              // around the boundary of an OpenSpace, equivalent to the
                              // gml:LinearRing type; the first and last Coordinates in
                              // the array MUST match
```

Because the `OpenSpace` type is adding a field to the referenced `Location` type a new identifier (`3`) is required for the new field (in contrast with the `Endpoint` restriction re-using the field identifier for `politicalUnit`).

The `Location` type is more extensively extended by the `Road`, `Bridge`, `Tunnel`, and `Building` types. The latter three types are grouped under the abstract `Construction` type which groups the subtypes. As with the extension for `OpenSpace`, all of the extensions for these new subtypes assign unique field IDs for the added fields. The same is true for the subtypes of `Road` (see the full JIDL in Appendix E.2 for details).

```
Road = Record extends(Location) abstract                // essential information about any road
   3 endpoints        Endpoints       // center of start/end points of a road, in lat/long + political unit
   4 waypoints        Coordinates     // list of center points (lat/long) of a road that defines its route;
                                      // curvature is approximated as straight line segments between waypoints
                                      // enabling arbitrary precision about the route
   5 width            Number{1.0..*}  // Width of the road in meters. MUST be >0
   6 name             String          // official (or commonly used) name of the road
   7 maintainedBy     Maintainer      // what level of government is responsible for maintenance

Construction = Record extends(Location) abstract  // Abstract type to connect location to constructed types, no
unique fields

Bridge = Record extends(Construction)
   3 endpoints        Endpoints       // center of start and end points of a bridge, in lat/long plus political
unit
   4 waypoints        Coordinates     // list of center points (lat/long) of a bridge that defines its route;
                                      // curvature is approximated as straight line segments between waypoints,
                                      // enabling arbitrary precision about the route
   5 width            Number          // width of the bridge in meters, must be >0
   6 maxHeight        Number          // maximum height of the bridge in meters
   7 name             String          // official (or commonly used) name of the bridge
   8 purpose          BridgePurpose   // purpose of this bridge

Tunnel = Record extends(Construction)
   3 endpoints        Endpoints       // center of start and end points of a tunnel, in lat/long plus political
```

```
unit
   4 waypoints        Coordinates     // list of center points (lat/long) of a tunnel that defines its route;
                                      // curvature is approximated as straight line segments between waypoints,
                                      // enabling arbitrary precision about the route
   5 width            Number          // width of the tunnel in meters, must be >0
   6 height           Number          // height of a tunnel from road surface to ceiling, in meters
   7 depth            Number          // lowest elevation of a tunnel's road surface, in meters
   8 name             String          // official (or commonly used) name of the tunnel
   9 purpose          TunnelPurpose   // purpose of this tunnel

Building = Record extends(Construction)
   3 address          Address
   4 perimeter        Coordinates     // an array of lat/long points defining the line segments around the
                                      // perimeter of a building, equivalent to the gml:LinearRing type;
                                      // the first and last Coordinates in the array MUST match
   5 maxHeight        Number          // maximum height of the building in meters
   6 function         BuildingFunction
```

Appendix A. Informative References

This appendix contains the informative references that are used in this document.

While any hyperlinks included in this appendix were valid at the time of publication, OASIS cannot guarantee their long-term validity.

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Appendix B. Acknowledgments

B.1 Special Thanks

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- Kevin Cressman, Praxis Engineering
- Matthew Roberts, Bestgate Engineering

B.2 Participants

The following individuals have participated in the creation of this document and are gratefully acknowledged:

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Appendix C. Revision History

C.1 Revision History Table

Revision	Date	Editor	Changes Made
imjadn-v1.0-cn01-wd01.md	2023-01-18	David Kemp	Initial working draft / CND01
imjadn-v1.0-cn01-wd02.md	2023-04-19	David Kemp	Second WD / CN01 candidate
imjadn-v1.0-cn01-wd02.md	2024-09-25	David Lemire	Music library example updates (PR #53)
imjadn-v1.0-cn01-wd02.md	2024-09-25	David Kemp	Reorganize introduction (PR #55)
imjadn-v1.0-cn01-wd02.md	2024-09-25	David Lemire	Normalize JADN Spec reference style (PR #56)
imjadn-v1.0-cn01-wd02.md	2024-10-04	David Kemp	Move information definition to introduction (PR #57)
imjadn-v1.0-cn01-wd02.md	2024-10-09	David Lemire	Overall updates to types descriptions in 3.1.x (PR #58)
imjadn-v1.0-cn01-wd02.md	2024-10-09	David Lemire	Generalize description of SDO management system IM (PR #60)
imjadn-v1.0-cn01-wd02.md	2024-10-23	David Lemire	Update namespaces discussion (4.1.2) with JADN v1.1 capabilities (PR #61)
imjadn-v1.0-cn01-wd02.md	2024-10-23	David Lemire	Initial revisions to Section 3.1 to improve readability (PR #63)
imjadn-v1.0-cn01-wd02.md	2024-10-28	David Lemire	Relocate multiple representations example (from 3.1.5.3 to 3.3.2) (PR #65)
imjadn-v1.0-cn01-wd02.md	2024-10-28	David Lemire	Revise structure of Section 3.1 for improved clarity and sequencing (PR #66)
imjadn-v1.0-cn01-wd02.md	2024-10-29	David Lemire	Refine Figure 4-1 (references relationships) (PR #70)
imjadn-v1.0-cn01-wd02.md	2024-11-06	David Lemire	Transfer Section 2 material from CS (PR #71) and integrate with existing content (PR #74)
imjadn-v1.0-cn01-wd02.md	2024-11-06	David Lemire	Add IPv4 packet header models as example of building from known structure (PR #71)
imjadn-v1.0-cn01-wd02.md	2024-11-07	David Lemire	Add definitions for lexical and value space and make associated adjustments (PR #76)
imjadn-v1.0-cn01-wd02.md	2024-11-07	David Lemire	Migrate Section 4 content into section 3.1 (PR #77)
imjadn-v1.0-cn01-wd02.md	2024-11-07	David Lemire	Administrative clean-up (PR #78)
imjadn-v1.0-cn01-wd02.md	2024-11-14	David Lemire	Update diagrams (PR #81) and text (PR #82) to align w/JADN Spec changes

Revision	Date	Editor	Changes Made
imjadn-v1.0-cn03.md	2024-11-26	David Lemire	Add example development JADN IM from JSON schema starting point (PR #xx), rename document for next CN version
imjadn-v1.0-cn03.md	2024-12-11	David Lemire	Add "Why JADN?" material in Section 1.1 (PR #88)
imjadn-v1.0-cn03.md	2024-12-23	David Lemire	Consolidate duplicative 2.1 content into 1.1.3 (PR #89)
imjadn-v1.0-cn03.md	2025-01-08	David Lemire	Document v2 changes in Appendix C, corrections to revision table (PR #90)
imjadn-v1.0-cn03.md	2025-01-08	David Lemire	Update Type & Field Options in section 3.x (PR #91)
imjadn-v1.0-cn03.md	2025-01-08	David Lemire	Incorporate "elevator speech" into abstract and section 1.0 (PR #93)
imjadn-v1.0-cn03.md	2025-02-12	David Lemire	New content addressing inheritance features added in JADV v2 (PRs #92 & #97)
imjadn-v1.0-cn03.md	2025-02-18	David Lemire	Update discussion of String type options for JADV v2 (PR #98)
imjadn-v2.0-cn01.md	2025-03-05	David Lemire	Update JADN Spec references, reorder primitive types to match (PR #102)
imjadn-v2.0-cn01.md	2025-03-26	David Lemire	Updates throughout CN for alignment with JADN v2 specification and improved presentation (PR #106)
imjadn-v2.0-cn01.md	2025-04-09	David Lemire	Explain omitting optional elements in type and field definitions (PR #108)
imjadn-v2.0-cn01.md	2025-04-09	David Lemire	Explain use of multiple format options in type definitions (PR #109)
imjadn-v2.0-cn01.md	2025-04-09	David Lemire	General updates throughout to improve JADN v2 specification alignment (PR #110)
imjadn-v2.0-cn01.md	2025-04-09	David Lemire	Administrative and editorial updates for document package preparation (PR #111)

C.2 JADN Version 2 Changes

This section details differences between versions 1 and 2 of JADN.

C.2.1 Breaking Change

In JADN v2.0 the "unlimited" value for the `maxOccurs` (formerly `maxc`) sentinel is changed from 0 to -1. *This minor but incompatible change required a new major version.* Two options are defined for an unspecified `maxOccurs` value:

- `maxOccurs` = -1 denotes an upper size limit defined by the JADN default value or package-specified upper value
- `maxOccurs` = -2 denotes an unbounded upper size limit

C.2.2 General Changes

The following general changes were made:

- The `namespaces` prefix list was changed from mappings to pairings to provide greater flexibility in managing namespaces and packages.
- The package `Information` element was renamed to `Metadata` to avoid conflation with information modeling.
- The package `exports` element was renamed to `roots` to better describe its purpose and effect.

- Type Options have been revised and expanded to support defining both size and content (value) range limits for primitive types

C.2.3 Type and Field Option Changes

The following changes were made to JADN type options:

- New options:
  - `minExclusive`, `maxExclusive`, `minInclusive`, `maxInclusive`: used to specify allowable value ranges for instances of types
  - `const`: specifies a pre-set value used as a classifier, equivalent to setting both `minInclusive` and `maxInclusive` to that value.
  - `minLength, maxLength`: used to specify the allowable size range for a binary or string type and to specify the number of items in a collection type
  - `combine`: provides greater flexibility for `Choice` types with `oneOf, anyOf, allOf, not` sub-options
  - `abstract`, `extends`, `restricts`, `final`: options related to defining and controlling types using inheritance
- Replaced options:
  - `minc`, `maxc`: these options have been renamed to `minOccurs, maxOccurs`
  - `minv`, `maxv`: these options have been separated into `minInclusive`, `maxInclusive` to specify value ranges and `minLength`, `maxLength` to specify size and item count ranges
  - `minf`, `maxf`: these floating-point specific options have been replaced by `minInclusive`, `maxInclusive`
- Removed options:
  - `extend`, `dir`

C.2.4 Inheritance

Four new type options were introduced to support inheritance in information models:

- `abstract`: a type definition with this option is only usable as a base type that other types can extend or restrict. Abstract types are never instantiated in serialized data.
- `restricts`: this option is used when defining a type that is a subset of the type that it references; it enables removing optional fields from the referenced type (required fields cannot be removed).
- `extends`: this option is used when defining a type that is a superset of the type that it references; it enables adding new non-conflicting fields to a subtype but cannot redefine existing fields from the referenced type.
- `final`: this option is used to designate a type that cannot be referenced to create a subtype.

The `extends` and `restricts` options are complementary: if B `extends` A then every instance of A MUST be an instance of B. If B `restricts` A then every instance of B MUST be an instance of A.

C.2.5 Format and Validation Options Changes

The following changes were made to format and validation options:

- `/d#` was added as an option for the time-oriented format options (i.e., `date-time`, `date`, `time`, `duration`) to allow for sub-second precision for the time aspect.
- `i<n>` replaces the `i8`, `i16`, `i32` format options to provide greater flexibility in specifying signed integer types; the permissible values are between -2^(n-1) and 2^(n-1)-1.
- `d<n>` applies a decimal integer scale factor of 10^n: value has n digits after decimal point, n > 0.

Appendix D. Frequently Asked Questions (FAQ)

This appendix responds to a variety of Frequently Asked Questions regarding JADN.

D.1 JADN vs. UML Primitive Data Types

The Universal Modeling Language UML says in section 21: "*The PrimitiveTypes package is an independent package that defines a set of reusable PrimitiveTypes that are commonly used in the definition of metamodels.*" and takes the position that the set of natural numbers includes the value zero.

JADN uses the same UML primitive types with two exceptions:

- JADN defines a Binary (byte sequence) primitive type, UML does not.
- UML defines an UnlimitedNatural primitive type, JADN does not.

UML natural numbers (integers greater than or equal to zero) are a subset of integers, so there is no need for a separate UnlimitedNatural primitive type. A JADN multivalued element may have an unlimited number of values if its type definition does not have a multiplicity upper bound. JADN assigns the Integer *sentinel value* -1, which is distinguished from all UML natural numbers, to indicate an unspecified upper bound in a multiplicity range. By convention text representations of a multiplicity range use the character "*" to indicate an unspecified upper bound.

- A **sentinel value** is a predefined data value used to indicate the end of a sequence or the absence of valid data.

Table D-1 lists the UML and JADN Primitive types.

Table D-1 -- UML and JADN Primitive Type Equivalence

UML	JADN
---	Binary
Boolean	Boolean
Integer	Integer
Real	Number
String	String
UnlimitedNatural	Integer {0..*}

D.2 Declarative Specifications

Editor's Note: Ignore numbering; Primitives will be moved into document body. Declarative may as well, or FAQ appendix may be renamed to something like "Notes"

The introduction states: "An IM is a declarative specification that defines desired outcomes (data item validity and equivalence) without describing control flow." But what does "declarative" mean in practice?

The DataOps Guide is a tutorial on the difference between declarative and imperative approaches, as well as the difference between those approaches when applied to software programming vs. database management. It uses simple relational database tables for illustration, but declarative schemas are also used with more flexible NoSQL databases such as Elasticsearch and MongoDB, graph databases including Neo4j, and non-database artifacts such as protocol messages and documents.

The *Guide* points out that:

> A declarative approach is an abstraction based on our interaction with the system. When you look under the hood, all systems depend on a set of imperative instructions. Instead of the system depending on you to supply those instructions, they are predefined.

An information model combines the abstraction of declarative specifications with the abstraction of separating logical datatypes from concrete representations. Its desired outcomes are:

- a classification decision: given a data value, is it an instance of an abstract datatype?

- an equality comparison decision: given two instances of the same datatype, do they have the same logical value?

Its predefined instructions implement the behavior of its built-in datatypes, which can be extended with application-specific imperative validation and translation functions.

D.3 Applications

Examples of other possible JADN applications include defining:

- Complex information structures, such as Software Bills of Materials (SBOMs) [NTIA-SBOM]; examples would be the SPDX and CycloneDX SBOM formats
- Formal definition of structured information exchanges, such as are described by NIEM

D.4 Why JADN and not RDF?

This section discusses the relationship between JADN and RDF, and why RDF does not serve the purpose of an Information Model

Comment

The following comment was submitted in response to the OASIS JADN public review:

> *Have you considered the following specifications from W3C:* ***RDF, RDFS, JSON-LD, SHACL****? RDF, RDFS (and potentially OWL and BFO) should take care of your information modelling needs, JSON-LD provides a JSON serializations, SHACL provides extensive validation capabilities. I would be interested to see the analysis why these technologies were eliminated after your consideration.*

Response

> NOTE: Need to update the following as the JADN v2 Spec does not contain the quoted wording.

The short answer (RDF models *knowledge* while JADN models *information*) is provided in the [JADN Specification] introduction:

> *UML class models and diagrams are commonly referred to as "Data Models", but they model knowledge of real-world entities using classes. In contrast, information models model data itself using datatypes.*

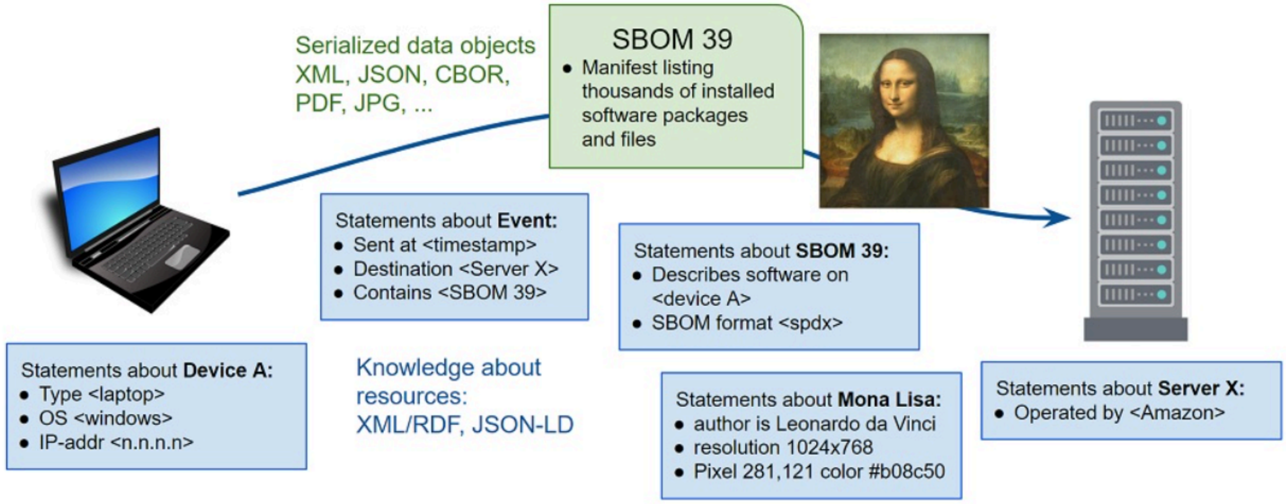
An RDF graph is a knowledge model / ontology consisting of (subject, predicate, object) triples, where each member of the triple can be an International Resource Identifier (IRI), blank node, or literal. An RDF triple encodes a statement—a simple logical expression, or claim about the world. A JADN graph, in contrast, consists of DataType definitions that define the information content of data instances.

In order to understand why RDF is not suitable as an information modeling language, one must understand two things about information:

1. **Information** distinguishes *significant* data from *insignificant* data. (In Shannon's original context signal and noise are in the analog domain, but entropy is meaningful even in purely digital communication.)

2. Information defines *loss*. Lossless transformations across data formats preserve information; after a round trip significant data is unchanged and insignificant data can be ignored. A lossy round trip is lossy not because it alters data, but because it alters significant data.

Information models define the information capacity of data instances; two data formats are *equivalent* if conversion between them is lossless.



Resources can be physical or digital entities. Both can be subjects of knowledge model statements, but only digital resources can be modeled as information instances and serialized for transmission and storage. The RDF primer contains the following example statements about resources:

- <Bob> <is a> <person>.
- <Bob> <is a friend of> <Alice>.
- <Bob> <is born on> <the 4th of July 1990>.
- <Bob> <is interested in> <the Mona Lisa>.

From context we can infer that <the Mona Lisa>, like <Bob> and <Alice>, is intended to be a physical resource.

Extreme Example

The physical painting can never be serialized losslessly, because even a multi-band 3D camera that captures near-infrared images of pencil sketches beneath the paint and elevation contours of the brush strokes still does not capture, for example, the chemical and physical properties of the canvas, pencils, washes, pigments, binders, or other materials used in the painting. But though physical entities can never be modeled completely as data, camera images of them can be. A 1920x1080 image contains 2 million pixels that could be serialized in the lossless PNG format, or as 2 million XML/RDF statements of the form <mona lisa pixel 192,13> <has color> <#32b82f>. The raw image data can be serialized as RDF and deserialized back to raw without loss, but is it useful to do so? RDF is useful for statements like the painting was created by da Vinci in 1503-1506, is housed in the Louvre, depicts a smiling woman, and has cedar trees in the background. But if an application needs the image, PNG serialization is an appropriate tool for the job, RDF is not.

Practical Example

JADN defines specific digital resources that can be stored, communicated, and referenced by an RDF graph. If Bob is a physical <person> and <person> is a Class, an information model specifies selected details about Person entities in terms of their format-independent information content:

```
People = ArrayOf(Person)

Person = Record
1 name       String
2 id         Key(PersonId)
3 dob        Integer /date-adhoc
4 weight     Weight optional
5 hair_color Color optional
6 eye_color  Color optional

Color = Enumerated
1 red
2 green
3 blue
4 brown
5 black
6 white

Weight = Integer        // unit = grams
```

```
PersonId = String{pattern="..."}
```

This defines a set of properties of the Person datatype and the collection characteristics of those properties: "Record" means that the collection is both ordered and unique, which in turn means that the properties could be serialized in JSON as either maps or arrays. Formats (in this case the hypothetical /date-adhoc) indicate that the "date of birth" property is the integer number of seconds since the epoch and can be serialized using the folksy string format from the RDF example. Defining times and durations as integers in the information model allows date strings of various text representations to be compared and ordered. The Color vocabulary could contain the 140 web-safe color names, or a defined set of fashion colors such as "medium golden blonde". Enumerations allow Color strings to be both validated for semantic meaningfulness and serialized as 8- or 16-bit values.

Measuring Information

If a data instance can be losslessly converted among serializations A, B, and C, then by definition the instance conveys no more information than the smallest of its serializations.

JSON verbose serialization of <People>:

```
[{
  "weight": 79546,
  "dob": "the 4th of July 1990",
  "id": "K193-3498-234",
  "name": "Bob"
}, {
  "name": "Alice",
  "dob": "the 27th of June 1982",
  "id": "B239-5921-348"
}]
```

JSON compact serialization of <People>:

```
[
  ["Bob", "K193-3498-234", "the 4th of July 1990", 79546],
  ["Alice", "B239-5921-348", "the 27th of June 1982"]
]
```

JSON concise serialization of <People>:

```
[
  ["Bob", "K193-3498-234", 647049600, 79546],
  ["Alice", "B239-5921-348", 393984000]
]
```

CBOR serialization of <People> (converted from concise JSON):

```
56 Bytes:
82                          # array(2)
84                          # array(4)
63                          # text(3)
426F62                      # "Bob"
6D                          # text(13)
4B3139332D333439382D323334 # "K193-3498-234"
1A 26913180                 # unsigned(647049600)
1A 000136BA                 # unsigned(79546)
83                          # array(3)
65                          # text(5)
416C696365                  # "Alice"
6D                          # text(13)
423233392D353932312D333438 # "B239-5921-348"
1A 177BB800                 # unsigned(393984000)
```

This illustrates that regardless of serialization, the properties of Bob and Alice convey less than 56 bytes of information, or on average 28 bytes per person. An RDF/XML serialization could be lossless but would not supply any additional information. Information instances can be stored in a database, transmitted as XML, JSON, CBOR, or other formats, referenced by RDF graphs and included in other structured data. As with the PNG example, this suggests that information can be serialized in any suitable format, with RDF statements generated from it dynamically if needed to satisfy queries. Although this Person example does not include Bob's friends or interests, relationships can be defined within the information model or specified independently with RDF. Section 3.3.3 provides a slightly larger information model example with three types and four container and reference relationships among them.

D.5 Why JADN and not OWL?

Capture from Google Doc at https://docs.google.com/document/d/1gY8ZaQJmJTpx8468Conchc2XVzTKE8x0WFSQT1qtB8o/edit#heading=h.ru8h2khtb5aw

The [OWL Primer] describes OWL as follows:

> The W3C OWL 2 Web Ontology Language (OWL) is a Semantic Web language designed to represent rich and complex knowledge about things, groups of things, and relations between things. OWL is a computational logic-based language such that knowledge expressed in OWL can be reasoned with by computer programs either to verify the consistency of that knowledge or to make implicit knowledge explicit.

Ontologies represent "knowledge about things", whereas IMs represent digital "things" themselves. As discussed in the body of this CN, an IM defines the essential content of entities used in computing independently of how those entities are serialized for communication or storage.

OWL has "object properties" and "data properties". Object properties are relationships between two entities and data properties are relations between an entity and a simple type. There is a rough correspondence between OWL terminology and concepts from Entity-Relationship modeling, Object Oriented Programming, and Information Modeling.

An information model models data, and the only entities in an information model are datatypes, where datatypes are either simple (a single value like string or integer) or structured (a collection of values like list or map). Translating an ontology's objects or classes into an information model's datatypes is often straightforward, but when there are alternative ways of representing the same objects as datatypes, an information model captures design decisions that are left unspecified in the ontology.

Some primary distinctions between knowledge and information models are *directionality*, *multiplicity*, *referenceability*, and *individuality*.

Directionality:

Although it may appear otherwise, an ontology is an undirected graph. Classes are connected by associations, and class associations are symmetric. If "car" and "part" are classes and a car is a composition of parts, then parts are components of car. If rose is a specialization of flower, then flower is a generalization of rose. If A is a parent of B, then B is a child of A. Arrows in an ontology diagram indicate which association term applies in the indicated direction, but the direction and term can be reversed together without changing the semantics of the graph. In contrast, an information model is a directed graph where direction determines syntax, and it has only two association types: contain and reference.

As an example, if a City datatype with name, elevation, and location properties contains a Coordinate datatype with latitude and longitude properties, one could say that Coordinate is "contained by" City without changing the model. The association direction is always container to contained, or referencing to referenced. A City instance with this graph direction is serialized as:

```
{ 'name': 'Hamilton',
  'elevation': 20,
  'location': { 'latitude': 32.2912, 'longitude': -64.7864 } }
```

Reversing the direction changes the model. If Coordinate were the container it would have place, latitude, and longitude properties, while City would have just name and elevation:

```
{ 'place': { 'name': 'Hamilton', 'elevation': 20 },
  'latitude': 32.2912,
  'longitude': -64.7864 }
```

Multiplicity:

OWL defines multiplicity as an attribute of associations. Collections (associations with a maximum cardinality greater than one) also have collection attributes ordered and unique, about which OWL says:

- By default, all associations are sets; that is, the objects in them are unordered and repetitions are disallowed.
- The {ordered, non-unique} attribute is placed next to the association ends that are ordered and in which repetitions are allowed. Such associations have the semantics of lists.

In an information model, collection attributes are intrinsic to the datatype itself and don't depend on associations with other datatypes. Just as a string type always has a string value, a list type always is an ordered, non-unique collection of values. In an information model both "object properties" and "data properties" are datatypes, and a collection datatype has fixed collection attributes regardless of where it is used.

For whatever reason, {ordered, non-unique} almost never appears in ontologies. In contrast, lists are a fundamental variable type in computing and a fundamental data type in data interchange. List elements have an ordinal position and can be referenced by position. Collections that are {ordered, unique} have elements that can be referenced by either position or name, used when modeling data that can be structured as tables.

The datatype names commonly applied to collection attributes are:

collection attributes	datatype
ordered, non-unique	sequence / list
unordered, unique	set, map
ordered, unique	ordered set, record
unordered, non-unique	bag

An information model specifies collection attributes that are not explicit in an ontology in order to ensure equivalence across syntaxes.

Continuing the City example, Coordinate was assumed to be the default map type. But an information model would generally make it a list type, resulting in more compact serialized instances. All properties of type Coordinate would be serialized as lists without having to individually designate every association as {ordered, nonunique}:

```
{ 'name': 'Hamilton',
  'elevation': 20,
  'location': [32.2912, -64.7864] }
```

Defining both City and Coordinate as record types (values are {ordered, unique}) allows them to be serialized either with property names or as table rows with "name", "elevation", and "location" columns:

```
[ 'Hamilton', 20, [32.2912, -64.7864] ]
```

The record datatype specifies data that can be losslessly converted between map and table serializations (an object-relational mapping - ORM), unlike an ontology's default unordered properties which are two-column sets of key:value pairs.

Referenceability:

Ontologies treat all objects as referenceable graph nodes, which requires every object to be assigned a primary key / unique identifier. Information models represent data structures using both referenceable and non-referenceable graph nodes. Containers are used by default to define serialization. References (foreign keys) are used when necessary to avoid data duplication and recursive structures.

Individuality:

All datatypes are distinguished only by their value, but some datatypes may be individually identified by having a primary key as part of their value. The terms used for non-individual types vary, but to avoid overloaded terms such as "class type" or "type type", types can be classified as either individual or fungible. People and bank accounts are examples of individual datatypes. Measurements, observations, mass-produced parts, currency, and IP addresses are examples of fungible datatypes. Coins are fungible unless grouped by mint; bills are fungible unless an application such as fraud detection requires identification by serial number.

These characteristics result in design guidelines for constructing an information graph from an ontology graph:

1. Fungible nodes may have more than one parent.

2. Each individual node should have exactly one parent. A node with no parent has nowhere for its instances to be serialized, so any references will be dead links. An individual node with more than one parent needs a mechanism to ensure that ids are unique and a mechanism to dereference an id to the correct parent.
3. The container associations in an information model must form a set of directed acyclic graphs. Any container cycles must be broken by converting a container association to a reference, which in turn may require converting an otherwise fungible contained node to a referenceable individual node.

Appendix E. Example Information Model Source

E.1 Music Library

E.1.1 Music Library JADN


```
{
  "info": {
    "title": "Music Library",
    "package": "http://fake-audio.org/music-lib",
    "version": "1.1",
    "description": "This information model defines a library of audio tracks, organized by album, with associated
metadata regarding each track. It is modeled on the types of library data maintained by common websites and music
file tag editors.",
    "license": "CC0-1.0",
    "roots": ["Library"]
  },
  "types": [
    ["Library", "MapOf", ["+Barcode", "*Album", "{1"], "Top level of the library is a map of CDs by barcode",
[]],
    ["Barcode", "String", ["%^\\d{12}$"], "A UPC-A barcode is 12 digits", []],
    ["Album", "Record", [], "model for the album", [
        [1, "album_artist", "Artist", [], "primary artist associated with this album"],
        [2, "album_title", "String", [], "publisher's title for this album"],
        [3, "pub_data", "Publication-Data", [], "metadata about the album's publication"],
        [4, "tracks", "Track", ["]0"], "individual track descriptions and content"],
        [5, "total_tracks", "Integer", ["{1"], "total track count"],
        [6, "cover_art", "Image", ["[0"], "cover art image for this album"]
      ]],
    ["Publication-Data", "Record", [], "who and when of publication", [
        [1, "publisher", "String", [], "record label that released this album"],
        [2, "release_date", "String", ["/date"], "and when did they let this drop"]
      ]],
    ["Image", "Record", [], "pretty picture for the album or track", [
        [1, "image_format", "Image-Format", [], "what type of image file?"],
        [2, "image_content", "Binary", [], "the image data in the identified format"]
      ]],
    ["Image-Format", "Enumerated", [], "can only be one, but can extend list", [
        [1, "PNG", ""],
        [2, "JPG", ""],
        [3, "GIF", ""]
      ]],
    ["Artist", "Record", [], "interesting information about a performer", [
        [1, "artist_name", "String", [], "who is this person"],
        [2, "instruments", "Instrument", ["q", "]0"], "and what do they play"]
      ]],
    ["Instrument", "Enumerated", [], "collection of instruments (non-exhaustive)", [
        [1, "vocals", ""],
        [2, "guitar", ""],
        [3, "bass", ""],
        [4, "drums", ""],
        [5, "keyboards", ""],
        [6, "percussion", ""],
        [7, "brass", ""],
        [8, "woodwinds", ""],
        [9, "harmonica", ""]
      ]],
    ["Track", "Record", [], "for each track there's a file with the audio and a metadata record", [
        [1, "location", "File-Path", [], "path to the audio file location in local storage"],
        [2, "metadata", "Track-Info", [], "description of the track"]
      ]],
    ["Track-Info", "Record", [], "information about the individual audio tracks", [
        [1, "track_number", "Integer", ["[1"], "track sequence number"],
        [2, "title", "String", [], "track title"],
        [3, "length", "Integer", ["{1"], "length of track in seconds; anticipated user display is mm:ss; minimum
length is 1 second"],
        [4, "audio_format", "Audio-Format", [], "format of the digital audio"],
        [5, "featured_artist", "Artist", ["q", "[0", "]0"], "notable guest performers"],
        [6, "track_art", "Image", ["[0"], "each track can have optionally have individual artwork"],
        [7, "genre", "Genre", [], ""]
      ]],
```

```
    ["Audio-Format", "Enumerated", [], "can only be one, but can extend list", [
        [1, "MP3", ""],
        [2, "OGG", ""],
        [3, "FLAC", ""],
        [4, "MP4", ""],
        [5, "AAC", ""],
        [6, "WMA", ""],
        [7, "WAV", ""]
      ]],
    ["Genre", "Enumerated", [], "Enumeration of common genres", [
        [1, "rock", ""],
        [2, "jazz", ""],
        [3, "hip_hop", ""],
        [4, "electronic", ""],
        [5, "folk_country_world", ""],
        [6, "classical", ""],
        [7, "spoken_word", ""]
      ]],
    ["File-Path", "String", [], "local storage location of file with directory path from root, filename, and
extension"]
  ]
}
```

E.1.2 Music Library JIDL

```
      title: "Music Library"
    package: "http://fake-audio.org/music-lib"
    version: "1.1"
 description: "This information model defines a library of audio tracks, organized by album,
              with associated metadata regarding each track. It is modeled on the types of
              library data maintained by common websites and music file tag editors."
    license: "CC0-1.0"
    roots: ["Library"]

Library = MapOf(Barcode, Album){1..*}  // Top level of the library is a map of CDs by barcode

Barcode = String{pattern="^\d{12}$"}   // A UPC-A barcode is 12 digits

Album = Record                         // model for the album
   1 album_artist     Artist           // primary artist associated with this album
   2 album_title      String           // publisher's title for this album
   3 pub_data         Publication-Data // metadata about the album's publication
   4 tracks           Track [1..*]     // individual track descriptions and content
   5 total_tracks     Integer{1..*}    // total track count
   6 cover_art        Image optional   // cover art image for this album

Publication-Data = Record              // who and when of publication
   1 publisher        String           // record label that released this album
   2 release_date     String /date     // and when did they let this drop

Image = Record                         // pretty picture for the album or track
   1 image_format     Image-Format     // what type of image file?
   2 image_content    Binary           // the image data in the identified format

Image-Format = Enumerated              // can only be one, but can extend list
   1 PNG
   2 JPG
   3 GIF

Artist = Record                        // interesting information about a performer
   1 artist_name      String           // who is this person
   2 instruments      Instrument unique [1..*]  // and what do they play

Instrument = Enumerated                // collection of instruments (non-exhaustive)
   1 vocals
   2 guitar
   3 bass
   4 drums
   5 keyboards
   6 percussion
   7 brass
   8 woodwinds
   9 harmonica
```

```
Track = Record                               // for each track there's a file with the audio and a metadata record
   1 location         File-Path              // path to the audio file location in local storage
   2 metadata         Track-Info             // description of the track

Track-Info = Record                          // information about the individual audio tracks
   1 track_number     Integer                // track sequence number
   2 title            String                 // track title
   3 length           Integer{1..*}          // length of track in seconds; anticipated user display is mm:ss;
                                             // minimum length is 1 second
   4 audio_format     Audio-Format           // format of the digital audio
   5 featured_artist  Artist unique [0..*]   // notable guest performers
   6 track_art        Image optional         // each track can have optionally have individual artwork
   7 genre            Genre

Audio-Format = Enumerated                    // can only be one, but can extend list
   1 MP3
   2 OGG
   3 FLAC
   4 MP4
   5 AAC
   6 WMA
   7 WAV

Genre = Enumerated                           // Enumeration of common genres
   1 rock
   2 jazz
   3 hip_hop
   4 electronic
   5 folk_country_world
   6 classical
   7 spoken_word

File-Path = String     // local storage location of file with directory path from root, filename, and extension
```

E.1.3 Music Library Tables

Information Header

```
         title: "Music Library"
       package: "http://fake-audio.org/music-lib"
       version: "1.1"
   description: "This information model defines a library of audio tracks,
                 organized by album, with associated metadata regarding each
                 track. It is modeled on the types of library data maintained
                 by common websites and music file tag editors."
       license: "CC0-1.0"
       roots: ["Library"]
```

Type Name	Type Definition	Description
Library	MapOf(Barcode, Album){1..*}	Top level of the library is a map of CDs by barcode

Type Name	Type Definition	Description
Barcode	String{pattern="^\d{12}$"}	A UPC-A barcode is 12 digits

model for the album

Type: Album (Record)

ID	Name	Type	#	Description
1	**album_artist**	Artist	1	primary artist associated with this album

ID	Name	Type	#	Description
2	**album_title**	String	1	publisher's title for this album
3	**pub_data**	Publication-Data	1	metadata about the album's publication
4	**tracks**	Track	1..*	individual track descriptions and content
5	**total_tracks**	Integer{1..*}	1	total track count
6	**cover_art**	Image	0..1	cover art image for this album

who and when of publication

Type: Publication-Data (Record)

ID	Name	Type	#	Description
1	**publisher**	String	1	record label that released this album
2	**release_date**	String /date	1	and when did they let this drop

pretty picture for the album or track

Type: Image (Record)

ID	Name	Type	#	Description
1	**image_format**	Image-Format	1	what type of image file?
2	**image_content**	Binary	1	the image data in the identified format

can only be one, but can extend list

Type: Image-Format (Enumerated)

ID	Item	Description
1	**PNG**	
2	**JPG**	
3	**GIF**	

interesting information about a performer

Type: Artist (Record)

ID	Name	Type	#	Description
1	**artist_name**	String	1	who is this person
2	**instruments**	Instrument unique	1..*	and what do they play

collection of instruments (non-exhaustive)

Type: Instrument (Enumerated)

ID	Item	Description
1	**vocals**	
2	**guitar**	
3	**bass**	
4	**drums**	
5	**keyboards**	
6	**percussion**	
7	**brass**	
8	**woodwinds**	
9	**harmonica**	

for each track there's a file with the audio and a metadata record

Type: Track (Record)

ID	Name	Type	#	Description
1	**location**	File-Path	1	path to the audio file location in local storage
2	**metadata**	Track-Info	1	description of the track

information about the individual audio tracks

Type: Track-Info (Record)

ID	Name	Type	#	Description
1	**track_number**	Integer	1	track sequence number
2	**title**	String	1	track title
3	**length**	Integer{1..*}	1	length of track in seconds; anticipated user display is mm:ss; minimum length is 1 second
4	**audio_format**	Audio-Format	1	format of the digital audio
5	**featured_artist**	Artist unique	0..*	notable guest performers
6	**track_art**	Image	0..1	each track can have optionally have individual artwork
7	**genre**	Genre	1	

Type Name	Type Definition	Description
File-Path	String	local storage location of file with directory path from root, filename, and extension

can only be one, but can extend list

Type: Audio-Format (Enumerated)

ID	Item	Description
1	**MP3**	
2	**OGG**	
3	**FLAC**	
4	**MP4**	
5	**AAC**	
6	**WMA**	
7	**WAV**	

Enumeration of common genres

Type: Genre (Enumerated)

ID	Item	Description
1	**rock**	
2	**jazz**	
3	**hip_hop**	
4	**electronic**	
5	**folk_country_world**	
6	**classical**	
7	**spoken_word**	

E.2 Inheritance Example JIDL

```
       title: "Inheritance Example"
     package: "http://inheritance/v2"
 description: "Example illustrating the application of JADN v2 inheritance features. Very loosely based on
CityGML concepts."
     roots: ["Location"]

Coordinate = Array                                    // A single geographic point (latitude / longitude)
   1  Number=[-90.0, 90.0]               // latitude::
   2  Number=[-180.0, 180.0]             // longitude::

PolUnit = String                                      // the name of the political area where the feature
exists (city / county / state level, as appropriate)

Location = Record abstract
   1 geoCenter        Coordinate                      // geographic center of the feature of interest at the
location
   2 politicalUnit    PolUnit optional                // the name of the political area where the location
exists

Endpoint = Record restricts(Location)                 // politicalUnit is required for an endpoint
   2 politicalUnit    PolUnit                         // the name of the political area where the endpoint
exists

Endpoints = ArrayOf(Endpoint){2..2} unique            // center of start/end points of a linear feature, in
lat/long

Coordinates = ArrayOf(Coordinate)                     // A list of geographic points
```

```
OpenSpace = Record extends(Location)                    // a defined area of open space
   3 boundary         Coordinates                       // an array of lat/long points defining the line segments
around the boundary of an OpenSpace, equivalent to the gml:LinearRing; the first and last Coordinates in the
array MUST match

Road = Record extends(Location) abstract                // essential information about any road
   3 endpoints        Endpoints                         // center of start/end points of a road, in lat/long +
political unit
   4 waypoints        Coordinates                       // list of center points (lat/long) of a road that
defines its route; curvature is approximated as straight line segments between waypoints, enabling arbitrary
precision about the route
   5 width            Number{1.0..*}                    // Width of the road in meters. MUST be >0
   6 name             String                            // official (or commonly used) name of the road
   7 maintainedBy     Maintainer                        // what level of government is responsible for
maintenance

LocalRoad = Record extends(Road)                        // a local, unnumbered road
   8 surfaceType      Surface                           // Choice identifying the type of road surface

NumberedRoad = Record extends(Road)                     // A road with an identifying number (e.g., MD32, US1)
   8 routeNumber      RouteNumber                       // State or U.S. identifying number of the road

Interstate = Record  extends(Road)                      // A road in the Interstate highway system
   8 interstateNumber Integer{1..999}                   // Interstate number of the road

RouteNumber = Array
   1  String{pattern="[A-Z]{2}"}        // owningEntity:: "US" or 2-character State portion of road number
   2  Integer{1..1000}                  // routeNum:: numeric portion of road identifier

Surface = Choice                                        // (oneOf) possible road surfaces
   1 dirt             String
   2 gravel           String
   3 macadam          String
   4 concrete         String
   5 asphalt          String

Maintainer = Enumerated                                 // level of government responsible for maintaining a road
   1 local             // town or city
   2 county
   3 state
   4 federal

BridgePurpose = Enumerated
   1 vehicular
   2 pedestrian
   3 railroad

Construction = Record extends(Location) abstract        // Bridge type from location to constructed types, no
unique fields

Bridge = Record extends(Construction)
   3 endpoints        Endpoints                         // center of start and end points of a bridge, in
lat/long plus political unit
   4 waypoints        Coordinates                       // list of center points (lat/long) of a bridge that
defines its route; curvature is approximated as straight line segments between waypoints, enabling arbitrary
precision about the route
   5 width            Number                            // width of the bridge in meters, must be >0
   6 maxHeight        Number                            // maximum height of the bridge in meters
   7 name             String                            // official (or commonly used) name of the bridge
   8 purpose          BridgePurpose                     // purpose of this bridge

Tunnel = Record extends(Construction)
   3 endpoints        Endpoints                         // center of start and end points of a tunnel, in
lat/long plus political unit
   4 waypoints        Coordinates                       // list of center points (lat/long) of a tunnel that
defines its route; curvature is approximated as straight line segments between waypoints, enabling arbitrary
precision about the route
   5 width            Number                            // width of the tunnel in meters, must be >0
   6 height           Number                            // height of a tunnel from road surface to ceiling, in
meters
   7 depth            Number                            // lowest elevation of a tunnel's road surface, in meters
   8 name             String                            // official (or commonly used) name of the tunnel
   9 purpose          TunnelPurpose                     // purpose of this tunnel

Building = Record extends(Construction)
```

```
   3 address          Address
   4 perimeter        Coordinates                       // an array of lat/long points defining the line segments
around the perimeter of a building, equivalent to the gml:LinearRing; the first and last Coordinates in the array
MUST match
   5 maxHeight        Number                            // maximum height of the building in meters
   6 function         BuildingFunction

Address = Map                                           // A street / postal address associated with a building
   1 street           String
   2 apartment        String optional
   3 suite            String optional
   4 county           String optional
   5 city             String
   6 state            String{pattern="[A-Z]{2}"}
   7 zipCode          String{pattern="\d{5}(\-\d{4}){0,1}"} // zip+4 format implies a U.S. postal code

TunnelPurpose = Enumerated
   1 vehicular
   2 pedestrian
   3 railroad
   4 water

BuildingFunction = Enumerated
   1 Single-Family Dwelling
   2 Multi-Family Dwelling
   3 Commercial-Office
   4 Commercial-Retail
   5 Medical
   6 Government
```

Appendix F. Notices