Specification for JSON Abstract Data Notation (JADN) Version 1.0

Committee Specification 01

17 August 2021

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This prose specification is one component of a Work Product that also includes:

- JSON schema for JADN documents: https://docs.oasis-open.org/openc2/jadn/v1.0/cs01/schemas/jadn-v1.0.json
- JADN schema for JADN documents: https://docs.oasis-open.org/openc2/jadn/v1.0/cs01/schemas/jadn-v1.0.jadn

Abstract:

JSON Abstract Data Notation (JADN) is a UML-based information modeling language that defines data structure independently of data format. Information models are used to define and generate physical data models, validate information instances, and enable lossless translation across data formats. A JADN specification consists of two parts: type definitions that comprise the information model, and serialization rules that define how information instances are represented as data. The information model is itself an information instance that can be serialized and transferred between applications. The model is documented using a compact and expressive interface definition language, property tables, or entity relationship diagrams, easing integration with existing design processes and architecture tools.

Status:

list, after subscribing to it by following the instructions at the "Send A Comment" button on the TC's web page at https://www.oasis-open.org/committees/openc2/.

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Key words:

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] and [RFC8174] when, and only when, they appear in all capitals, as shown here.

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Notices

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1 Introduction

RFC 3444, "Information Models and Data Models", notes that the main purpose of an information model is to model objects at a conceptual level, independent of specific implementations or protocols used to transport the data. RFC 8477, "IoT Semantic Interoperability Workshop 2016", describes a lack of consistency across Standards Developing Organizations in defining application layer data, attributing it to the lack of an encoding-independent standardization of the information represented by that data. This document defines an information modeling language intended to address that gap. 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.

As shown in Figure 1, industry has multiple, often conflicting definitions of data modeling terms, including the term "Information Engineering", which at one time referred to data modeling but is now more closely aligned with information theory and machine learning.

- Ackoff's Knowlege Hierarchy defines data as "symbols that are properties of observables" and informally calls information "descriptions inferred from data".
- UML defines DataTypes (simple classifiers where instances are distinguished only by value) and Classes (structured classifiers where instances have behavior, inheritance, roles, and other complex characteristics).
- Traditional data modeling defines conceptual, logical and physical data models without considering information at all.
- Information modeling formalizes the relationship between information and data, defining a technology-agnostic information layer that lies between the logical data model and multiple technology-specific physical data models.

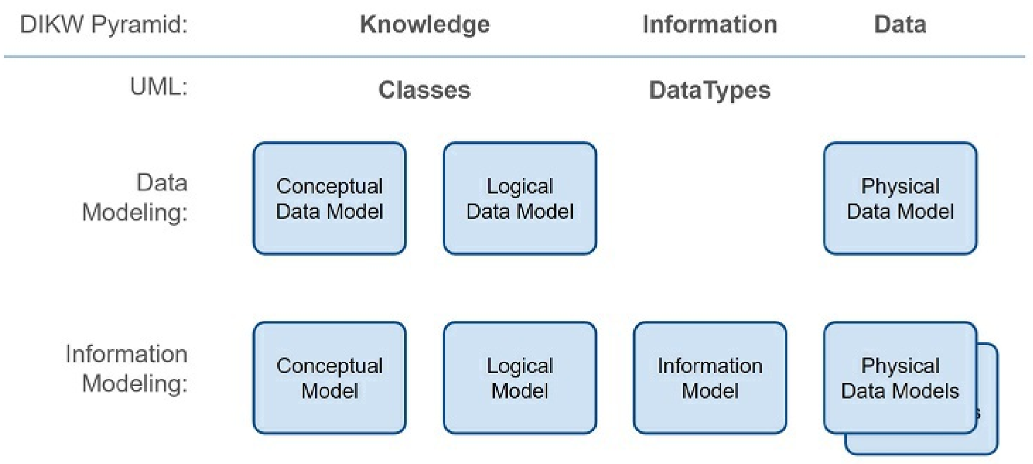


Figure 1: Information Engineering Terminology

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. A practical distinction is that class models are undirected graphs with an unlimited variety of classes and semantic relationships, while information models are directed graphs with a small predefined set of base datatypes and only two kinds of relationship: "contain" and "reference". Designing an information model from a class/logical model is largely a matter of assigning the kind and direction of each relationship, establishing identifiers for all referenceable datatypes, and selecting the kind of each datatype from among the base types defined by an information modeling language. Converting an information model to a data model means applying serialization rules for each base type that produce physical data in the desired format.

1.1 Changes from CSD 01

- Added serialization style description to Section 2.2.
- Removed the Null base type from Table 3.1.
- Added default values for type definition elements to Section 3.1.1
- Raised the default maximum length for type and field names from 32 to 64 characters (Section 3.1.2).

1.2 Glossary

1.2.1 Definitions of terms

- **Information**: A measure of the entropy (novelty, or "news value") of a message. Information is the minimum data needed to represent the essential meaning of a message, excluding data that is known *a priori* and data that does not affect meaning.

- **Information Model**: An abstract schema that defines the structure and value constraints of information used within and across applications, irrespective of data format.
- **Data Model**: A concrete schema that defines the structure and value constraints of serialized data. A single information model corresponds to multiple equivalent data models; two data models are equivalent if they represent the same information.
- **Graph**: A mathematical structure used to model pairwise relationships between objects. An information model is a graph where nodes are information type definitions and edges are relationships between types.
- **Package**: A container that defines a namespace for the set of types it contains. A type can reference types from another package using the referenced namespace.
- **Document**: A series of octets described by a data format applied to an information model, or equivalently, by a data model.
- **Well-formed**: A well-formed document follows the syntactic structure of the document's media type.
- **Valid**: An instance is valid if it satisfies the constraints defined in an information model. A document is valid if it is well-formed and also corresponds to a valid instance.
- **Data Format**: A data format, defined by serialization rules, specifies the media type (XML, JSON, Protobuf, ...), design goals (human readability, efficiency), and style preferences for documents in that format.
- **Instance**: An instance, or API value, is an item of information that satisfies the structure and value constraints defined by a type. Types are defined by an information modeling language; JADN built-in types are:
  - **Primitive:** Boolean, Binary, Integer, Number, String
  - **Enumeration:** Enumerated
  - **Specialization:** Choice
  - **Structured:** Array, ArrayOf, Map, MapOf, Record
- **Instance Equality**: Two instances are equal if and only if they are of the same type and have the same information value. Formatting differences, including a document's data format, are insignificant. An IPv4 address serialized as a JSON dotted-quad is equal to an IPv4 address serialized as a CBOR byte string if and only if they have the same 32 bit value. A Record instance serialized as an array is equal to a Record instance serialized as a map if and only if they have the same keys and the same value for each key.
- **Serialization**: Serialization, or encoding, converts application information into a document. De-serialization, or decoding, converts a document into information instances usable by applications.
- **Description**: Description elements are reserved for comments from schema authors to readers or maintainers of the schema, and are ignored by applications using the schema.

1.2.2 Acronyms and abbreviations

- **DAG**: Directed Acyclic Graph
- **DM**: Data Model
- **IM**: Information Model
- **UML**: Unified Modeling Language

2 Information vs. Data

Information is *what* needs to be communicated between applications, and data is *how*that information is represented when communicating. More formally, information is the unexpected data, or entropy, contained in a document. 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*. 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.

A variable that can take on 2^N different values conveys at most N bits of information. For example, an IPv4 address that can specify 2^32 different addresses 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 RFC791-style serialization): 0xc0a88df0 (4 bytes / 32 bits).

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 possibliities 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.

* *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 specification.*

2.1 Graph Modeling

A JADN information model is a set of type definitions (Section 3.1). Each field in a structured 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 in a model can be broken by converting one or more containers to references.

Logical models are undirected graphs, and a few results from graph theory are useful when constructing information models from logical models:

- A tree is a connected acyclic undirected graph, where any pair of nodes is connected by exactly one path.
- A directed (or rooted) tree is a hierarchy. A directed tree is constructed from an (undirected) tree by selecting one node as root and assigning all edge directions either toward or away from the root.
- A directed acyclic graph (DAG) is a directed graph with no directed cycles, or equivalently a directed graph with a topological ordering, a sequence of nodes such that every edge is directed from earlier to later in the sequence.
- A DAG differs from a directed tree in that nodes may have more than one parent.

A DAG can be refactored into another DAG having the same underlying undirected graph, and two information models with the same underlying graph correspond to the same logical model.

A DAG can be converted to a directed tree by denormalizing (copying subtrees below multi-parent nodes), and a directed tree can be converted to a DAG by normalizing (combining identical subtrees). Reuse of common types is an important goal in both design of information models and analysis of data. However, it is sometimes useful to have a tree-structured representation of a document's structure. Converting a DAG into a directed tree supports applications such as model queries that are otherwise difficult to implement, tree-structured content statistics, content transformations, and documentation.

2.2 Information Modeling

Data 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 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. Because an information model is a graph, information-centric design integrates easily with conceptual and logical models, allowing bottom-up and top-down approaches to meet in the middle.

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 structured 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. 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:

Style:	Verbose repeated name-value pairs	Compact element / property names-values	Concise 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. JSON and XML Transformations uses the terms "Friendly" for XML and JSON encodings that associate data types directly with variables and "Unfriendly" for encodings that use repeated variable names in name-value pairs. JADN uses Compact and Verbose respectively to refer to those styles. The name "Verbose" is intended to be descriptive rather than pejorative, as opposed to "Unfriendly". 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.

Reverse-engineering an information model from existing data models allows commonalities and incompatibilities to be identified, facilitating convergence across multiple specifications with similar goals.

2.3 Information Definition Formats

Google Protocol Buffers (Protobuf) is a typical data definition language. A Protobuf definition looks like:

```
message Person {
  required string name = 1;
  required int32 id = 2;
  optional string email = 3;
}
```

The corresponding JADN definiton in IDL format (Section 5) is structurally similar:

```
Person = Record
   1 name     String
   2 id       Integer
   3 email    String optional
```

Property tables (also Section 5) include the same content:

Type: Person (Record)

ID	Name	Type	#	Description
1	**name**	String	1	
2	**id**	Integer	1	
3	**email**	String	0..1	

The normative form of a JADN type definition (Section 3) is JSON data:

```
["Person", "Record", [], "", [
    [1, "name", "String", [], ""],
    [2, "id", "Integer", [], ""],
    [3, "email", "String", ["[0"], ""]
]]
```

IDL or property tables are preferred for use in documentation, but conformance is based on normative JSON data.

2.4 Implementation

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

1. Translate the IM to a data-format-specific schema language such Relax-NG, 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.

3 JADN Types

An information modeling language's types are defined in terms of the characteristics they provide to applications. JADN's base types are:

Table 3-1. JADN Base Types

Type	Definition
Primitive	
Binary	A sequence of octets. Length is the number of octets.
Boolean	An element with one of two values: true or false.
Integer	A positive or negative whole number.
Number	A real number.
String	A sequence of characters, each of which has a Unicode codepoint. Length is the number of characters.
Enumeration	
Enumerated	A vocabulary of items where each item has an id and a string value
Specialization	
Choice	A discriminated union: one type selected from a set of named or labeled types.
Structured	
Array	An ordered list of labeled fields with positionally-defined semantics. Each field has a position, label, and type.
ArrayOf(*vtype*)	A collection of fields with the same semantics. Each field has type *vtype*. Ordering and uniqueness are specified by a collection option.
Map	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.
MapOf(*ktype*, *vtype*)	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*.
Record	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.

- An application that uses JADN types MUST exhibit the behavior specified in Table 3-1. Applications MAY use any programming language data types or mechanisms that exhibit the required behavior.
- An instance of a Map, MapOf, or Record type MUST NOT have more than one occurrence of each key.
- An instance of a Map, MapOf, or Record type MUST NOT have a key of the null type.
- An instance of a Map, MapOf, or Record type with a key mapped to a null value MUST compare as equal to an otherwise identical instance without that key.
- The length of an Array, ArrayOf or Record instance MUST not include null values after the last non-null value.
- Two Array, ArrayOf or Record instances that differ only in the number of trailing nulls MUST compare as equal.

As described in Table 3-1, JADN structured types define if their members are *Ordered* and/or *Unique*. They also distinguish between homogeneous collections where all members have the same type and heterogeneous collections where each member has a specified type. For homogeneous collections JADN uses the single "ArrayOf" type with a *set*, *unique* or *unordered* option (Section 3.2.1) rather than defining separate names for each collection type.

Ordered	Unique	Traditional Name	JADN Same Type	JADN Specified Type
false	true	Set	ArrayOf+set, MapOf	Map
true	false	Sequence	ArrayOf	Array

Ordered	Unique	Traditional Name	JADN Same Type	JADN Specified Type
true	true	OrderedSet	ArrayOf+unique	Record
false	false	Bag	ArrayOf+unordered	none

Accessing an element of a collection whose values are neither ordered nor unique returns an arbitrarily-chosen element. Elements of other collections are deterministically accessed by position, value, or for the Record type either position or value.

3.1 Type Definitions

JADN type definitions have a fixed structure designed to be easily describable, easily processed, stable, and extensible.

- Every definition has five elements:
    1. **TypeName:** the name of the type being defined
    2. **BaseType:** the JADN predefined type (Table 3-1) of the type being defined
    3. **TypeOptions:** an array of zero or more **TypeOption** (Section 3.2.1) applicable to **BaseType**
    4. **TypeDescription:** a non-normative comment
    5. **Fields:** an array of **Item** or **Field** definitions
- If BaseType is a Primitive type, ArrayOf, or MapOf, the **Fields** array MUST be empty:
- If BaseType is Enumerated, each item definition in the **Fields** array MUST have 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 BaseType is Array, Choice, Map, or Record, each field definition in the **Fields** array MUST have 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** (Section 3.2.2) or **TypeOption** (Section 3.2.1) applicable to the field
    5. **FieldDescription:** a non-normative comment

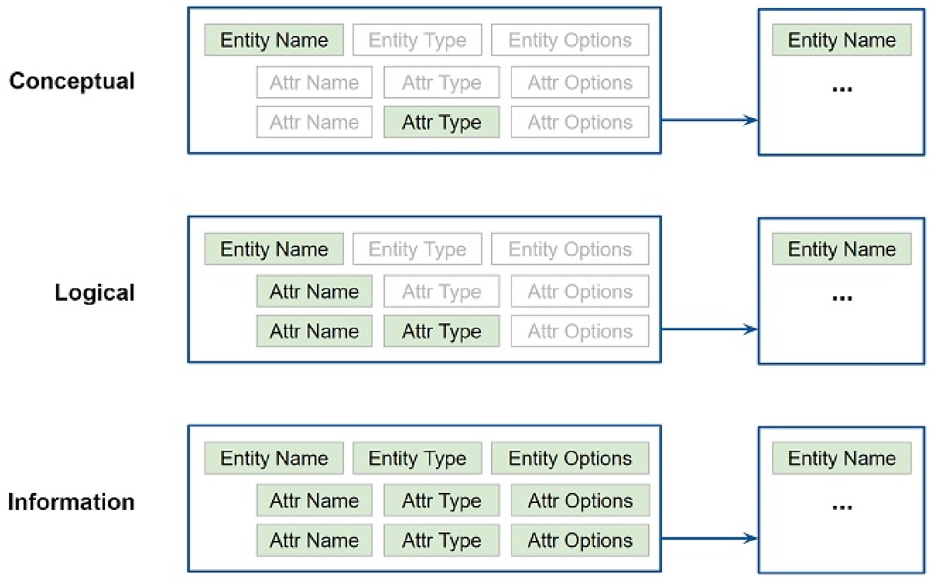
The elements are serialized in JSON format as:

```
[TypeName, BaseType, [TypeOption, ...], TypeDescription, []]                    (primitive)

[TypeName, BaseType, [TypeOption, ...], TypeDescription, [                      (enumerated)
    [ItemId, ItemValue, ItemDescription],
    ...
]]

[TypeName, BaseType, [TypeOption, ...], TypeDescription, [                      (structured)
    [FieldID, FieldName, FieldType, [FieldOption, TypeOption, ...], FieldDescription],
    ...
]]
```

The same type definition structure can be populated with various levels of detail. At the conceptual level, only TypeName is present, along with FieldType for attributes that reference other model-defined types. At the logical level FieldName is populated for both base and reference attribute types. In a full information model, all Type and Options elements are defined:



3.1.1 Requirements

- TypeName MUST NOT be a JADN predefined type
- BaseType MUST be a JADN predefined type
- FieldID and FieldName values MUST be unique within a type definition.
- If BaseType is Array or Record, FieldID MUST be the ordinal position of the field within the type, numbered consecutively starting at 1.
- If BaseType is Enumerated, Choice, or Map, FieldID MAY be any nonconflicting integer tag.
- FieldType MUST be a Primitive type, ArrayOf, MapOf, or a model-defined type.
- If FieldType is a model-defined type, FieldOptions MUST NOT contain any TypeOption.
- ItemValue MAY be any string or MAY be constrained to hold a valid FieldName.
- If the Derived Enumerations or Pointers extensions are present in type options, the Fields array MUST be empty.
- The default value of TypeOptions, Fields, and FieldOptions is the empty Array. The default value of TypeDescription and FieldDescription is the empty String. When serializing, default values MAY be included or omitted in the serialized document. When deserializing, default values MUST be available from the API instance if not present in the document.

Including TypeOption values within FieldOptions is an extension (Section 3.3.1).

3.1.2 Name Formats

JADN does not restrict the syntax of TypeName and FieldName, but naming conventions can aid readability of specifications.

- JADN specifications MAY override the default name formats by defining one or more of:
  - The permitted format for TypeName
  - The permitted format for FieldName
  - The permitted format for the Namespace Identifier (NSID) used in type references
  - A "System" character used in tool-generated or specially-processed type names
- Schema authors MUST NOT create FieldNames containing the JSON Pointer field separator "/", which is reserved for use in the Pointers extension
- Schema authors SHOULD NOT create TypeNames containing the System character, but schema processing tools MAY do so
- Specifications that do not define alternate name formats MUST use the definitions in Figure 3-1 expressed as ABNF and Regular Expression:

```
ABNF:
TypeName   = UC *63("-" / Sys / UC / LC / DIGIT)    ; PascalCase / Train-Case, 1-64 characters
FieldName  = LC *63("_" / UC / LC / DIGIT)          ; camelCase / snake_case, 1-64 characters
NSID       = (UC / LC) *7(UC / LC / DIGIT)          ; Namespace ID, length = 1-8 characters
TypeRef    = [NSID ":"] TypeName                    ; Reference to a defined type with optional namespace prefix

Sys        = "$"      ; 'DOLLAR SIGN', Used in tool-generated type names, e.g., Color$values.
```

```
UC         = %x41-5A  ; A-Z
LC         = %x61-7A  ; a-z
DIGIT      = %x30-39  ; 0-9

Regular Expression:
TypeName:  ^[A-Z][-$A-Za-z0-9]{0,63}$
FieldName: ^[a-z][_A-Za-z0-9]{0,63}$
NSID:      ^[A-Za-z][A-Za-z0-9]{0,7}$
```

Figure 3-1: JADN Default Name Syntax in ABNF and Regular Expression Formats

Specifications MAY use the same syntax for TypeName and FieldName. Using distinct formats may aid understanding but does not affect the meaning of type definitions.

3.1.3 Upper Bounds

Type definitions for variable-length types may include maximum size limits using the *maxv* option defined in Section 3.2.1. If an individual type does not define an explicit limit, it uses the limit shown in the package's $MaxBinary, $MaxString, or $MaxElements configuration variable (Section 6). If the specification does not define a limit, the definition defaults to the values shown here, which are deliberately conservative to encourage specification authors to define limits based on application requirements.

- JADN specifications SHOULD define size limits on the variable-length types shown in Figure 3-2.
- Specifications that do not define alternate size limits SHOULD use the limits shown in Figure 3-2.

```
Type                Name           Limit   Description
-----               -----          -----   -----------
Binary              $MaxBinary     255     Maximum number of octets
String              $MaxString     255     Maximum number of characters
Array, ArrayOf,     $MaxElements   100     Maximum number of items/properties
Map, MapOf, Record
```

Figure 3-2: JADN Default Size Limits

3.1.4 Descriptions

Description elements (TypeDescription, ItemDescription and FieldDescription) are reserved for comments from schema authors to readers or maintainers of the schema.

- The description value MUST be a string, which MAY be empty.
- Implementations MUST NOT present this string to end users.
- Tools for editing schemas SHOULD support displaying and editing descriptions.
- Implementations MUST NOT take any other action based on the presence, absence, or content of description values.

Description values MAY be used in debug or error output which is intended for developers making use of schemas. Tools that translate other media types or programming languages to and from a JADN schema MAY choose to convert that media type or programming language's native comments to or from description values. Implementations MAY strip description values at any point during processing.

3.2 Options

This section defines the mechanism used to support a varied set of information needs within the strictly regular structure of Section 3.1. New requirements can be accommodated by defining new options without modifying that structure. Type and Field options are classifiers that, along with the base type, determine whether data values are instances of the defined type.

Each option is a text string that may be included in TypeOptions or FieldOptions, encoded as follows:

- The first character is the option ID. Its Unicode codepoint is the numeric value (FieldID) shown in Section 3.2.1 and Section 3.2.2.
- The remaining characters are the option value. Boolean options have no additional characters; if the option ID is present the value of that option is True.

3.2.1 Type Options

Type options apply to the type definition as a whole. The *id*, *vtype*, *ktype*, *enum*, and *pointer* options are intrinsic components of the types to which they apply. Other options specify value constraints on the type.

```
TypeOption = Choice
   61 id        Boolean    // '=' Items and Fields are denoted by FieldID rather than FieldName (Section 3.2.1.1)
   42 vtype     String     // '*' Value type for ArrayOf and MapOf (Section 3.2.1.2)
   43 ktype     String     // '+' Key type for MapOf (Section 3.2.1.3)
   35 enum      String     // '#' Extension: Enumerated type derived from a specified type (Section 3.3.3)
   62 pointer   String     // '>' Extension: Enumerated type pointers derived from a specified type (Section 3.3.5)
   47 format    String     // '/' Semantic validation keyword (Section 3.2.1.5)
   37 pattern   String     // '%' Regular expression used to validate a String type (Section 3.2.1.6)
  121 minf      Number     // 'y' Minimum real number value (Section 3.2.1.7)
  122 maxf      Number     // 'z' Maximum real number value
  123 minv      Integer    // '{' Minimum integer value, octet or character count, or element count (Section 3.2.1.7)
  125 maxv      Integer    // '}' Maximum integer value, octet or character count, or element count
  113 unique    Boolean    // 'q' ArrayOf instance must not contain duplicate values (Section 3.2.1.8)
  115 set       Boolean    // 's' ArrayOf instance is unordered and unique (Section 3.2.1.9)
   98 unordered Boolean    // 'b' ArrayOf instance is unordered (Section 3.2.1.10)
   88 extend    Boolean    // 'X' Type is extensible; new Items or Fields may be appended (Section 3.2.1.11)
   33 default   String     // '!' Default value (Section 3.2.1.12)
```

- TypeOptions MUST contain zero or one instance of each TypeOption.
- TypeOptions MUST contain only TypeOption instances allowed for BaseType as shown in Table 3-3, plus a default value.
- If BaseType is ArrayOf, TypeOptions MUST include the *vtype* option and MUST NOT include more than one collection option (*set*, *unique*, or *unordered*).
- If BaseType is MapOf, TypeOptions MUST include *ktype* and *vtype* options.

Table 3-3. Allowed Options

BaseType	Allowed Options
Binary	minv, maxv, format
Boolean	
Integer	minv, maxv, format
Number	minf, maxf, format
String	minv, maxv, format, pattern
Enumerated	id, enum, pointer, extend
Choice	id, extend
Array	extend, format, minv, maxv
ArrayOf	vtype, minv, maxv, unique, set, unordered
Map	id, extend, minv, maxv
MapOf	vtype, ktype, minv, maxv
Record	extend, minv, maxv

3.2.1.1 Field Identifiers

The *id* option used with Enumerated, Choice, and Map types determines how fields are specified in API instances of these types. If the *id* option is absent, API instances use the FieldName string and the type is referred to as "named". If the *id* option is present, API instances use the FieldID tag and the type is referred to as "labeled". The Record type is always named and has no *id* option; the Array type is its labeled equivalent.

- In named types, FieldName is a defined name that is included in the semantics of the type, must be populated in the type definition, and may appear in serialized data depending on serialization format.
- In labeled types, FieldName is a suggested label that is not included in the semantics of the type, may be empty in the type definition, and never appears in serialized data regardless of data format.

For example an Enumerated list of HTTP status codes could include the field [403, "Forbidden"]. If the type definition does not include an *id* option, the API value is "Forbidden" and serialization rules determine whether FieldID or FieldName is used in serialized data. With the *id* option the API and serialized values are always the FieldID 403. The label "Forbidden" may be displayed in messages or user interfaces, as could customized labels such as "NotAllowed", "Verboten", or "Interdit".

3.2.1.2 Value Type

The *vtype* option specifies the type of each field in an ArrayOf or MapOf type. It may be any JADN type or Defined type.

- An ArrayOf or MapOf instance MUST be considered invalid if any of its elements is not an instance of *vtype*.

3.2.1.3 Key Type

The *ktype* option specifies the type of each key in a MapOf type.

- *ktype* SHOULD be a Defined type, either an enumeration or a type with constraints such as a pattern or semantic valuation keyword that specify a fixed subset of values that belong to a category.
- A MapOf instance MUST be considered invalid if any of its keys is not an instance of *ktype*.

3.2.1.4 Derived Enumeration

The *enum* (Section 3.3.3) and *pointer* (Section 3.3.5) options are extensions that create an Enumerated type derived from a referenced Array, Choice, Map or Record type.

3.2.1.5 Semantic Validation

The *format* option value is a semantic validation keyword. Each keyword specifies validation requirements for a fixed subset of values that are accurately described by authoritative resources. The *format* option may also affect how values are serialized, see Section 4.

Table 3-4. Semantic Validation Keywords

Keyword	Type	Requirement
JSON Schema formats	String	All semantic validation keywords defined in Section 7.3 of JSON Schema.
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
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
i8	Integer	Signed 8 bit integer, value must be between -128 and 127.
i16	Integer	Signed 16 bit integer, value must be between -32768 and 32767.
i32	Integer	Signed 32 bit integer, value must be between -2147483648 and 2147483647.
u<*n*>	Integer	Unsigned integer or bit field of <*n*> bits, value must be between 0 and 2^<*n*> - 1.

3.2.1.6 Pattern

The *pattern* option specifies a regular expression used to validate a String instance.

- The *pattern* value SHOULD conform to the Pattern grammar of ECMAScript Section 21.2.
- A String instance MUST be considered invalid if it does not match the regular expression specified by *pattern*.

3.2.1.7 Size and Value Constraints

The *minv* and *maxv* options specify size or integer value limits. The *minf* and *maxf* options specify real number value limits.

- For Binary, String, Array, ArrayOf, Map, MapOf, and Record types:
  - if *minv* is not present, it defaults to zero.
  - if *maxv* is not present or is zero, it defaults to the upper bound specified in Section 3.1.3.
  - a Binary instance MUST be considered invalid if its number of bytes is less than *minv* or greater than *maxv*.
  - a String instance MUST be considered invalid if its number of characters is less than *minv* or greater than *maxv*.
  - an Array, ArrayOf, Map, MapOf, or Record instance MUST be considered invalid if its number of elements is less than *minv* or greater than *maxv*.
- For Integer types:
  - if *minv* is present, an instance MUST be considered invalid if its value is less than *minv*.

- if *maxv* is present, an instance MUST be considered invalid if its value is greater than *maxv*.
- For Number types:
  - if *minf* is present, an instance MUST be considered invalid if its value is less than *minf*.
  - if *maxf* is present, an instance MUST be considered invalid if its value is greater than *maxf*.

3.2.1.8 Unique Values

The *unique* option specifies that values in an array must not be repeated.

- For the ArrayOf type, if *unique* is present an instance MUST be considered invalid if it contains duplicate values.

3.2.1.9 Set

The *set* option specifies that an ArrayOf type is unordered and unique.

- For the ArrayOf type, if *set* is present an instance MUST be considered invalid if it contains duplicate values.

3.2.1.10 Unordered

The *unordered* option specifies that an ArrayOf type may contain duplicate values and that its values have no defined order. Because values cannot be selected by value or position, it has the semantics of a "bag" or "urn" from which elements are picked at random.

3.2.1.11 Extension Point

The *extend* option is an assertion that an Enumerated, Choice, Array, Map or Record type MAY be incomplete and that future versions MAY add new fields that do not change the definitions of existing fields. This option does not affect the validity of data with respect to a specific schema, it is an indicator that applications may be able to obtain a newer version of the same package for which the data is valid. Types without this option assert that the package identifier will be changed if any field is added, modified, or deleted.

3.2.1.12 Default Value

The *default* option specifies the initial or default value of a field. Applications deserializing a document MUST initialize an unspecified type with its default value. Serialization behavior is not defined; applications MAY omit or populate fields whose values equal the default.

3.2.2 Field Options

Field options may be specified for each field within a structured type definition.

```
FieldOption = Choice
   91 minc      Integer    // '[' Minimum cardinality, default = 1, 0 = optional (Section 3.2.2.1)
   93 maxc      Integer    // ']' Maximum cardinality, default = 1, 0 = default max, >1 = array
   38 tagid     Enumerated // '&' Field containing an explicit tag for this Choice type (Section 3.2.2.2)
   60 dir       Boolean    // '<' Pointer enumeration treats field as a group of items (Extension: Section 3.3.5)
   75 key       Boolean    // 'K' Field is a primary key for this type (Extension: Section 3.3.6)
   76 link      Boolean    // 'L' Field is a foreign key reference to a type instance (Extension: Section 3.3.6)
```

- FieldOptions MUST NOT include more than one of each option.
- All TypeOption values (Section 3.2.1) included in FieldOptions are extensions. Each TypeOption MUST apply to FieldType as defined in Table 3-3.

3.2.2.1 Multiplicity

Cardinality is the number of elements in a group, and multiplicity is the range of allowed cardinalities for that group. The *minc* and *maxc* options specify the minimum and maximum cardinality in a field of an Array, Choice, Map, or Record type:

minc	maxc	Multiplicity	Description	Keywords
0	1	0..1	No instances or one instance	optional
1	1	1	Exactly one instance	required
0	0	0..*	Zero or more instances	optional, repeated
1	0	1..*	At least one instance	required, repeated
m	n	m..n	At least m but no more than n instances	required, repeated

- if *minc* is not present, it defaults to 1.
- if *maxc* is not present, it defaults to the greater of 1 or *minc*.
- if *maxc* is 0, it defaults to the MaxElements upper bound specified in Section 3.1.3.
- if *maxc* is less than *minc*, the field definition MUST be considered invalid.

If *minc* is 0, the field is optional, otherwise it is required.
If *maxc* is 1 the field is a single element, otherwise it is an array of elements as described in Section 3.3.2.

Within a Choice type *minc* values of 0 and 1 are equivalent because all fields are optional and exactly one must be present. Values greater than 1 specify an array of elements.

3.2.2.2 Discriminated Union with Explicit Tag

The Choice type represents a Discriminated Union, a data structure that could take on several different, but fixed, types. By default a Choice is a Map with exactly one key-value pair, where the key determines the value type. But if the *tagid* option is present on a Choice field in an Array or Record container, it indicates that a separate Tag field within that container determines the value type.

- The Tag field MUST be an Enumerated type derived from the Choice. It MAY contain a subset of fields from the Choice.

Example:

```
Product = Choice                        // Discriminated union
   1 furniture    Furniture
   2 appliance    Appliance
   3 software     Software

Dept = Enumerated                       // Explicit Tag values derived from the Choice
   1 furniture
   2 appliance
   3 software

Software = String /uri

Stock1 = Record                         // Discriminated union with intrinsic tag
   1 quantity     Integer
   2 product      Product               // Value = Map with one key/value

Stock2 = Record                         // Container with explicitly-tagged discriminated union
   1 dept         Dept                  // Tag = one key from Choice
   2 quantity     Integer
   3 product      Product(TagId[dept])  // Choice specifying an explicit tag field
```

Example JSON serializations of these types are:

Stock1 - Choice with intrinsic tag:

```
{
    "quantity": 395,
    "product": {"software": "http://www.example.com/B902D1P0W37"}
}
```

Stock2 - Choice with explicit tag:

```
{
    "dept": "software",
    "quantity": 395,
    "product": "http://www.example.com/B902D1P0W37"
}
```

Intrinsic tags:

When discriminated unions are grouped the distinction between intrinsic and explicit tags becomes more apparent. A collection with intrinsic tags is simply a Map, which results in what the W3C JSON and XML Transformations Workshop called "Friendly" encodings.

```
    Hashes = Map{1..*}            // Multiple discriminated unions with intrinsic tag is a Map
```

```
       1 md5          Binary{16..16} /x optional
       2 sha1         Binary{20..20} /x optional
       3 sha256       Binary{32..32} /x optional
```

Hashes Example:

```
{
    "sha256": "C9004978CF5ADA526622ACD4EFED005A980058B7B9972B12F9B3A5D0DA46B7D9",
    "md5": "B64CF5EAF07E86D1697D4EEE96A670B6"
}
```

Explicit tags:

A collection with explicit tags is an array of tag-value pairs. It is more complex to specify, and it results in "UnFriendly" encodings with repeated tag and value keys. Yet because some specifications are written in this style, the *tagid* option exists to designate an explicit field to be used to specify the value type.

```
    Hashes2 = ArrayOf(HashVal)    // Multiple discriminated unions with explicit tags is an Array

    HashVal = Record
       1 algorithm    Enumerated(Enum[HashAlg])  // Tag - one key from Choice
       2 value        HashAlg(TagId[algorithm])  // Value selected from Choice by 'algorithm' field

    HashAlg = Choice
       1 md5          Binary{16..16} /x
       2 sha1         Binary{20..20} /x
       3 sha256       Binary{32..32} /x
```

Hashes2 Example:

```
[
  {
    "algorithm": "md5",
    "value": "B64CF5EAF07E86D1697D4EEE96A670B6"
  },{
    "algorithm": "sha256",
    "value": "C9004978CF5ADA526622ACD4EFED005A980058B7B9972B12F9B3A5D0DA46B7D9"
  }
]
```

3.3 JADN Extensions

JADN consists of a set of core definition elements, plus several extensions that make type definitions more compact or support the DRY software design principle. Extensions are syntactic sugar that can be replaced by core definitions without changing their meaning. Unfolding definitions into core format simplifies the code needed to serialize and validate data and may clarify their meaning, but creates additional definitions that must be kept in sync.

The following extensions can be converted to core definitions:

- Anonymous type definition within a field
- Field multiplicity other than required/optional
- Derived enumeration
- MapOf type with Enumerated key type
- Pointers
- Links

3.3.1 Type Definition Within Fields

A type without fields (Primitive types, ArrayOf, MapOf) may be defined anonymously within a field of a structure definition. Unfolding converts all anonymous type definitions to explicit named types and excludes all TypeOption values (Section 3.2.1) from FieldOptions.

Example:

```
Member = Record
```

```
   1 name         String
   2 email        String /email
```

Unfolding replaces this with:

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

Member$email = String /email           // Tool-generated type definition.
```

3.3.2 Field Multiplicity

Fields may be defined to have multiple values of the same type. Unfolding converts each field that can have more than one value to a separate ArrayOf type. The minimum and maximum cardinality (*minc* and *maxc*) FieldOptions (Section 3.2.2) are moved from FieldOptions to the minimum and maximum size (*minv* and *maxv*) TypeOptions of the new ArrayOf type, except that if *minc* is 0 (field is optional), it remains in FieldOptions and the new ArrayOf type defaults to a minimum size of 1.

Example:

```
Roster = Record
   1 org_name     String
   2 members      Member [0..*]         // Optional and repeated: minc=0, maxc=0
```

Unfolding replaces this with:

```
Roster = Record
   1 org_name     String
   2 members      Roster$members optional// Optional: minc=0, maxc=1

Roster$members = ArrayOf(Member){1..*} // Tool-generated array: minv=1, maxv=0
```

If a list with no elements should be represented as an empty array rather than omitted, its type definition must include an explicit ArrayOf type rather than using the field multiplicity extension:

```
Roster = Record
   1 org_name     String
   2 members      Members       // members field is required: default minc = 1, maxc = 1

Members = ArrayOf(Member)       // Explicitly-defined array: default minv = 0, maxv = 0
```

3.3.3 Derived Enumerations

An Enumerated type defined with the *enum* option has fields copied from the type referenced in the option rather than being listed individually in the definition. Unfolding removes *enum* from Type Options and adds fields containing FieldID, FieldName, and FieldDescription from each field of the referenced type.

In JADN-IDL (Section 5.1) the *enum* option is represented as a function string: "Enum(<referenced-type>)". Within ArrayOf and MapOf types, the *ktype* and *vtype* options may contain an enum option. As an example the IDL value "ArrayOf(Enum(Pixel))" corresponds to the JADN vtype option "*#Pixel".

Unfolding references an explicit Enumerated type if it exists, otherwise it creates an explicit Enumerated type. It then replaces the type reference with the name of the explicit Enumerated type.

Example:

```
Pixel = Map
   1 red          Integer
   2 green        Integer
   3 blue         Integer

Channel = Enumerated(Enum[Pixel])       // Derived Enumerated type

ChannelMask = ArrayOf(Enum[Pixel])      // ArrayOf(derived enumeration)
```

Unfolding replaces the Channel and ChannelMask definitions with:

```
Channel2 = Enumerated
   1 red
   2 green
   3 blue

ChannelMask2 = ArrayOf(Channel)
```

3.3.4 MapOf With Enumerated Key

A MapOf type where *ktype* is Enumerated is equivalent to a Map. Unfolding replaces the MapOf type definition with a Map type with keys from the Enumerated *ktype*. This is the complementary operation to derived enumeration. In order to use this extension, each ItemValue of the Enumerated type must be a valid FieldName.

Example:

```
Channel3 = Enumerated
   1 red
   2 green
   3 blue

Pixel3 = MapOf(Channel3, Integer)
```

Unfolding replaces the Pixel MapOf with the explicit Pixel Map shown under Derived Enumerations.

3.3.5 Pointers

Applications may need to model both individual types and collections of types, similar to the way filesystems have files and directories. The "dir" option (Section 3.2.2) marks a field as a collection of types. The dir option has no effect on the structure or serialization of information; its sole purpose is to support pathname generation using the Pointer extension.

A recursive filesystem listing contains pathnames of all files in and under the current directory. The Pointer extension (Section 3.2.1) generates a list of all type definitions in and under the specified type. Unfolding replaces the Pointer extension with an Enumerated type containing a JSON Pointer pathname for each type. If no fields in the specified type are marked with the "dir" option, the Pointer extension has the same fields as the Derived Enumeration extension except that IDs are sequential rather than copied from the referenced type.

Example:

```
Catalog = Record
   1 a            TypeA
   2 b/           TypeB

TypeA = Record
   1 x            Number
   2 y            Number

TypeB = Record
   1 foo          String
   2 bar          Integer

Paths = Enumerated(Pointer[Catalog])
```

In this example, Catalog field "a" is a single type and field "b" is designated as a collection by the "dir" option (shown as "b/"). Unfolding replaces Paths with an Enumerated type containing JSON Pointers to all leaf types in and under Catalog:

```
Paths2 = Enumerated
   1 a                                   // Item 1
   2 b/foo                               // Item 2
   3 b/bar                               // Item 3
```

This is useful when an application 1) needs a category of types, e.g., "Items", 2) defines these types in multiple locations in a hierarchy, and 3) needs identifiers for each type in the category.

It also allows referencing type definitions across specifications. If TypeB is defined in Specification B, its subtypes can be referenced from

Specification A under field name "b". This facilitates distributed development of packages regardless of whether the underlying data format has native namespace support.

The structure of a "Catalog" instance is not affected by this extension. Although "a/x" is a valid JSON Pointer to a specific value (57.9), "Catalog" does not define "a" as a dir so "a/x" is not listed in Paths and its value is not considered an "Item":

```
{
  "a": {"x": 57.9, "y": 4.841},     <-- "a" is Item 1 (TypeA)
  "b": {                            <-- "b" is a dir or namespace mount point, not an Item.
    "foo": "Elephant",              <-- "b/foo" is Item 2 (String)
    "bar": 762                      <-- "b/bar" is Item 3 (TypeC)
  }
}
```

Note that the *enum* and *pointer* extensions create shallow dependencies: the referenced types are needed in order to unfold them but types below the direct references are not.

3.3.6 Links

The container graph of an information model cannot have cycles, meaning that an instance of a type cannot recursively contain other instances of that type either directly or indirectly through other types. But a type can contain references to itself or to other types without restriction, as long as the referenced type contains a primary key that identifies instances of that type.

The link extension supports references: the *key* option designates a field as a primary key, and the *link* option designates a field as a foreign key that references an instance of the specified type. The *key* and *link* options do not affect serialization or validation of data, but they MAY be used by applications to perform relationship-aware operations such as checking referential integrity.

As an example, a Person type might include family, friend, and employment relationships:

```
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..*]
    7 employer  Link(Organization) optional

Organization = Record
    1 name      String
    2 ein       Key(String{10..10})
```

Unfolding creates an explicit type for each key and replaces links with that type. Unfolded types support syntactic validation of individual instances but do not include an explicit indication of identifier uniqueness or relationships between instances:

```
Person = Record
    1 id        Person$id
    2 name      String
    3 mother    Person$id
    4 father    Person$id
    5 siblings  Person$id [0..*]
    6 friends   Person$id [0..*]
    7 employer  Organization$ein optional

Organization = Record
    1 name      String
    2 ein       Organization$ein

Person$id = Integer
Organization$ein = String{10..10}
```

4 Serialization

Applications may use any internal information representation that exhibits the characteristics defined in Table 3-1. Serialization rules define how to represent instances of each type using a specific format. Several serialization formats are defined in this section. In order to be usable with JADN, serialization formats defined elsewhere must:

- 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

4.1 Verbose JSON Serialization

The following serialization rules represent JADN data types in a human-readable JSON format using name-value encoding for tabular data.

- When using JSON serialization, instances of JADN types without a format option listed in this section MUST be serialized as:

JADN Type	JSON Serialization Requirement
Binary	JSON **string** containing Base64url encoding of the binary value as defined in Section 5 of RFC 4648.
Boolean	JSON **true** or **false**
Integer	JSON **number**
Number	JSON **number**
String	JSON **string**
Enumerated	JSON **string** ItemValue
Enumerated with "id"	JSON **integer** ItemID
Choice	JSON **object** with one property. Property key is FieldName.
Choice with "id"	JSON **object** with one property. Property key is FieldID converted to string.
Array	JSON **array** of values with types specified by FieldType. Omitted optional values are **null** if before the last specified value, otherwise omitted.
ArrayOf	JSON **array** of values with type *vtype*, or JSON **null** if *vtype* is null.
Map	JSON **object**. Property keys are FieldNames.
Map with "id"	JSON **object**. Property keys are FieldIDs converted to strings.
MapOf	JSON **object** if *ktype* is a String type, JSON **array** if *ktype* is not a String type, or JSON **null** if *vtype* is null. Properties have key type *ktype* and value type *vtype*. MapOf types with non-string keys are serialized as in CBOR: a JSON **array** of keys and cooresponding values [key1, value1, key2, value2, ...].
Record	JSON **object**. Property keys are FieldNames.

Format options that affect JSON serialization

- When using JSON serialization, instances of JADN types with one of the following format options MUST be serialized as:

Option	JADN Type	JSON Serialization Requirement
x	Binary	JSON **string** containing Base16 (hex) encoding of a binary value as defined in RFC 4648 Section 8. Note that the Base16 alphabet does not include lower-case letters.
ipv4-addr	Binary	JSON **string** containing a "dotted-quad" as specified in RFC 2673 Section 3.2.

Option	JADN Type	JSON Serialization Requirement
ipv6-addr	Binary	JSON **string** containing the text representation of an IPv6 address as specified in RFC 4291 Section 2.2.
ipv4-net	Array	JSON **string** containing the text representation of an IPv4 address range as specified in RFC 4632 Section 3.1.
ipv6-net	Array	JSON **string** containing the text representation of an IPv6 address range as specified in RFC 4291 Section 2.3.

Specifications MAY define additional format options for textual representation of Binary, Integer, Number or Array data.

4.2 Compact JSON Serialization:

The following serialization rules represent JADN types in a human-readable JSON format using positional encoding for tabular data.

- When using Compact JSON serialization, instances of JADN types MUST be serialized as in section 4.1 except:

JADN Type	Concise JSON Serialization Requirement
Record	JSON **array** of values with types specified by FieldType. Omitted optional values are **null** if before the last specified value, otherwise omitted.

4.3 Concise JSON Serialization:

Concise JSON serialization rules represent JADN data types in a format optimized for minimum size. JSON data in this format may be used directly for communication or to visualize the content of CBOR-serialized data.

- When using Concise JSON serialization, instances of JADN types MUST be serialized as in section 4.1 except:

JADN Type	Concise JSON Serialization Requirement
Enumerated	JSON **integer** ItemID
Choice	JSON **object** with one property. Property key is the FieldID converted to string.
Map	JSON **object**. Property keys are FieldIDs converted to strings.
MapOf	JSON **object** if *ktype* is a String type, JSON **array** if *ktype* is not a String type. Members have key type *ktype* and value type *vtype*. MapOf types with non-string keys are serialized as in CBOR: a JSON **array** of keys and cooresponding values [key1, value1, key2, value2, ...].
Record	JSON **array** of values with types specified by FieldType. Omitted optional values are **null** if before the last specified value, otherwise omitted.

All formats specifying a textual representation for Binary, Integer, Number, or Array types are ignored when using Concise serialization.

4.4 CBOR Serialization

The following serialization rules are used to represent JADN data types in Concise Binary Object Representation (CBOR) format, where CBOR type #x.y = Major type x, Additional information y.

CBOR type names from Concise Data Definition Language (CDDL) are shown for reference.

- When using CBOR serialization, instances of JADN types without a format option listed in this section MUST be serialized as:

JADN Type	CBOR Serialization Requirement
Binary	**bstr**: a byte string (#2).
Boolean	**bool**: a Boolean value (False = #7.20, True = #7.21).

JADN Type	CBOR Serialization Requirement
Integer	**int**: an unsigned integer (#0) or negative integer (#1)
Number	**float64**: IEEE 754 Double-Precision Float (#7.27).
String	**tstr**: a text string (#3).
Enumerated	**int**: an unsigned integer (#0) or negative integer (#1) ItemID.
Choice	**struct**: a map (#5) containing one pair. The first item is a FieldID, the second item has the corresponding FieldType.
Array	**record**: an array of values (#4) with types specified by FieldType. Omitted optional values are **null** (#7.22) if before the last specified value, otherwise omitted.
ArrayOf	**vector**: an array of values (#4) of type *vtype*, or **null** (#7.22) if vtype is null.
Map	**struct**: a map (#5) of pairs. In each pair the first item is a FieldID, the second item has the corresponding FieldType.
MapOf	**table**: a map (#5) of pairs, or **null** if *vtype* is null. In each pair the first item has type *ktype*, the second item has type *vtype*.
Record	Same as **Array**.

Format options that affect CBOR Serialization

- When using CBOR serialization, instances of JADN types with one of the following format options MUST be serialized as:

Option	JADN Type	CBOR Serialization Requirement
f16	Number	**float16**: IEEE 754 Half-Precision Float (#7.25).
f32	Number	**float32**: IEEE 754 Single-Precision Float (#7.26).

5 Definition Formats

Section 3.1 defines the normative JSON format of JADN type definitions. Although JSON data is unambiguous, it is not ideal as a documentation format. This section suggests several more readable ways of describing and documenting information models.

This section is informative

5.1 JADN-IDL Format

JADN Interface Definition Language (IDL) is a textual representation of JADN type definitions. It replicates the structure of Section 3.1 but combines each type and its options into a single string formatted for readability. The conversion between JSON and JADN-IDL formats is lossless in both directions, meaning that the IDL described here is unambiguous and complete. But it is not intended to be immutable; syntactic details may be updated to accommodate new use cases or improve usability without affecting the JADN standard.

The JADN-IDL definition formats are:

Primitive types:

```
    TypeName = TYPESTRING                    // TypeDescription
```

Enumerated type:

```
    TypeName = TYPESTRING                    // TypeDescription
        ItemID ItemValue                     // ItemDescription
        ...
```

Structured types without the *id* option:

```
    TypeName = TYPESTRING                    // TypeDescription
        FieldID FieldName[/] FIELDSTRING     // FieldDescription
        ...
```

If a field includes the *dir* FieldOption, the SOLIDUS character (/) as specified in RFC 6901 is appended to FieldName.

Structured types with the *id* option treat the item/field name as an informative label (see Section 3.2.1.1) and display it in the description followed by a label terminator ("::"):

```
    /* Enumerated.ID */
    TypeName = TYPESTRING                    // TypeDescription
        ItemID                               // ItemValue:: ItemDescription

    /* Choice.ID, Map.ID */
    TypeName = TYPESTRING                    // TypeDescription
        FieldID FIELDSTRING                  // FieldName[/]:: FieldDescription
        ...
```

Type Options:

TYPESTRING is the value of BaseType or FieldType, followed by string representations of the type options, if applicable to TYPE as specified in Table 3-3.

- TYPEREF is a type name with optional namespace prefix as specified in Section 3.1.2.
- FMTNAME is the name of a semantic validation function as specified in Section 3.2.1.5.

```
    TYPESTRING  = TYPE [ID] [FUNC] [RANGEPAT] [FORMAT] [KW]     ; TYPE is BaseType or FieldType
    ID          = ".ID"
    FUNC        = "(" TYPEREF ["," TYPEREF] ")"         ; if TYPE is MapOf, ArrayOf
                | "(" FUNCNAME "[" TYPEREF "])"         ; if TYPE is Enumerated
    RANGEPAT    = "{" NUM [".." NUM] "}"
                | "{pattern=" DQUOTE 1*STR DQUOTE "}"   ; if TYPE is String. *STR should be a valid regular
expression
    FORMAT      = " /" FMTNAME
    FUNCNAME    = "Enum" | "Pointer"
    KW          = "unique" | "set" | "unordered"        ; if TYPE is ArrayOf
    DQUOTE      = %x22                              ; Double-quote character (")
    STR         = %x20-%x7e                         ; Visible characters plus space
```

Field Options:

Type and Field options affect the entire line of a field's IDL text:

```
    FIELDLINE   = INT FIELDSTRING
    FIELDSTRING = [FIELDNAME] [DIR] TYPE [MULT | TAGID] [FIELDDESC]
    INT         = 1*DIGIT
    DIR         = "/"
    TYPE        = TYPESTRING
                | "Key(" TYPESTRING ")"
                | "Link(" TYPESTRING ")"
    MULT        = "[" INT [".." INT] "]"
    TAGID       = "(TagId[" (INT | FIELDNAME) "])"
    FIELDDESC   = "//" [FIELDNAME "::"] STR
```

5.2 Table Style

Some specifications present type definitions in property table form, using varied style conventions. This specification does not define a normative property table format, but this section shows one example of how JADN definitions may be displayed as property tables.

This style is structurally similar to JADN-IDL and uses its TYPESTRING syntax, but breaks out the MULTIPLICITY field options into a separate column:

```
+----------+------------+-----------------+
| TypeName | TYPESTRING | TypeDescription |
+----------+------------+-----------------+
```

followed by (for structured types without the *id* option):

```
+---------+---------------+-------------+--------+------------------+
| FieldID | FieldName[/]  | FIELDSTRING | [m..n] | FieldDescription |
+---------+---------------+-------------+--------+------------------+
```

or (for structured types with the *id* option):

```
+---------+-------------+--------+---------------------------------+
| FieldID | FIELDSTRING | [m..n] | FieldName[/]:: FieldDescription  |
+---------+-------------+--------+---------------------------------+
```

Example Markdown Table:

Type: Person (Record)

ID	Name	Type	#	Description
1	**name**	String	1	
2	**id**	Integer	1	
3	**email**	String	0..1	

5.3 Entity Relationship Diagrams

Information models extend the Conceptual/Logica/Physical design process. While UML defines a class diagram format that has been adopted for use in that process, it does not define a datatype diagram format suitable for representing information models. As noted in the introduction, logical/class models are undirected graphs with semantic relationships while information/datatype models are directed graphs with two relationship types: contain and reference. Information models may be represented as entity relationship diagrams using the following conventions:

1. Solid edges represent container relationships, dashed edges represent references.
2. All edges are directed, from container to contained type or from referencing to referenced type.

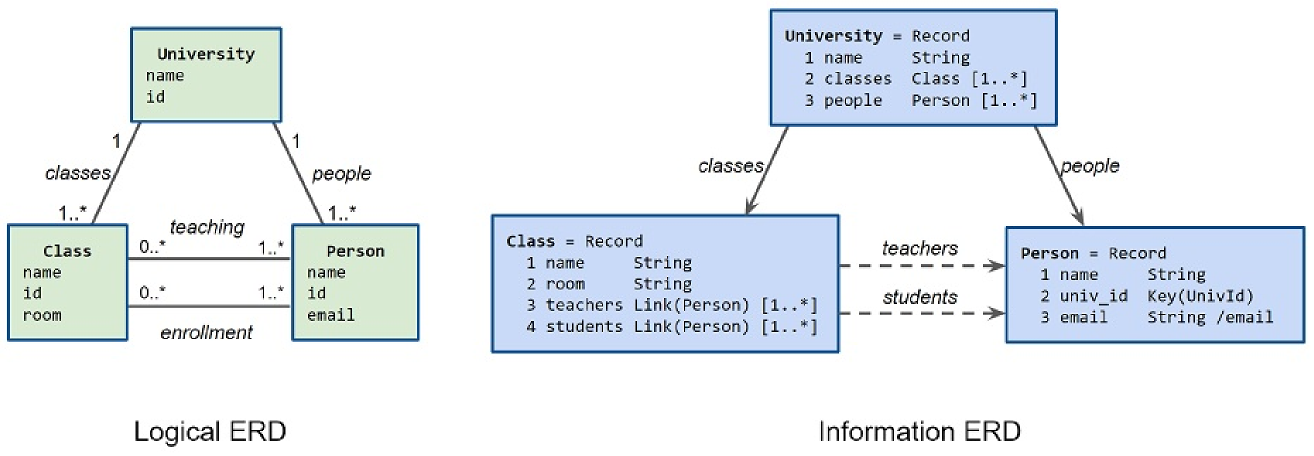


Figure 5-1: Logical and Information Entity Relationship Diagrams

The edge type and direction show how instances are serialized, in this case using references from Class to Person. An alternate information model derived from the same logical model might use references "teaches" and "enrolled_in" from Person to Class.

Figure 5-2 is a GraphViz "dot" file generated from the University information model showing a conceptual level of detail. Dot diagrams may be viewed at, for example, https://sketchviz.com.

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

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

  n0 [label="University"]
    n0 -> n1 [label="classes", headlabel="1..*", taillabel="1"]
    n0 -> n2 [label="people", headlabel="1..*", taillabel="1"]
  n1 [label="Class"]
    n1 -> n2 [style="dashed", label="teachers", headlabel="1..*", taillabel="1"]
    n1 -> n2 [style="dashed", label="students", headlabel="1..*", taillabel="1"]
  n2 [label="Person"]
}
```

Figure 5-2: GraphViz Source for University Conceptual ERD

Figure 5-3 is an example instance of the University type serialized in verbose and compact JSON data formats:

```
{
  "name": "Faber College",
  "classes": [
    {
      "name": "ECE1010",
      "room": "DRGN 105",
      "teachers": ["U-004932"],
      "students": ["U-194325", "U-029437"]
    },
    {
      "name": "ECE1750",
      "room": "FLRS 102",
      "teachers": ["U-004932"],
      "students": ["U-127439", "U-194325", "U-029437"]
    }
  ],
  "people": [
    {
      "name": "Damien Braun",
      "univ_id": "U-004932",
      "email": "d.braun@faber.edu"
    },
    {
      "name": "Ellie Osborne",
      "univ_id": "U-194325",
      "email": "ellie.osborne@faber.edu"
    },
    {
      "name": "Pierre Cox",
      "univ_id": "U-029437",
      "email": "pc9000@outlook.com"
    },
    {
      "name": "Alden Cantrel",
      "univ_id": "U-127439",
      "email": "alden.cantrel@faber.edu"
    }
  ]
}
```

```
[
  "Faber College",
  [
    ["ECE1010", "DRGN 105", ["U-004932"], ["U-194325", "U-029437"]],
    ["ECE1750", "FLRS 102", ["U-004932"], ["U-127439", "U-194325", "U-029437"]]
  ],
  [
    ["Damien Braun", "U-004932", "d.braun@faber.edu"],
    ["Ellie Osborne", "U-194325", "ellie.osborne@faber.edu"],
    ["Pierre Cox", "U-029437", "pc9000@outlook.com"],
    ["Alden Cantrel", "U-127439", "alden.cantrel@faber.edu"]
  ]
]
```

Figure 5-3: JSON instance of University

6 Schema Packages

JADN schemas are organized into packages. A package consists of an optional information section and a list of type definitions:

```
Schema = Record                            // Definition of a JADN package
   1 info         Information optional     // Information about this package
   2 types        Types                    // Types defined in this package
```

If the info section is present the *package* field is required to establish the package's namespace; other fields are optional.

- **package:** A namespace URI that allows type definitions in this package to be unambiguously referenced from other packages. This is an identifier but not necessarily a locator for accessible resources. The namespace may include major or major.minor versioning information, such as http://example.com/acme2 or http://example.com/acme/v1.3.
- **version:** Incremental version of this package, a string that compares lexicographically higher than previous versions. The *namespaces* field references only package namespaces. Version may be used to determine the most recent definition of a namespace.
- **title:** A short name for this package.
- **description:** A brief description of purpose or capabilities of this package
- **comment:** Any other information applicable to the package.
- **copyright:** A copyright notice.
- **license:** License for this package. Value is an SPDX licenseId, CC0-1.0 is recommended.
- **namespaces:** Local map of NSIDs (short names) to namespaces. Used within this package to reference types defined in other packages.
- **exports:** Root types. There are no private type definitions in a package; all types can be referenced using the package's namespace. Exports allows authors to designate public types and allows schema tools to detect unused types.
- **config:** Values such as name formats and size limits that are customized for this package. See package for the list of configuration variables.

7 Conformance

Conformance targets: This document defines two conformance levels for JADN implementations: Core and Extensions.

This document defines several data formats. Conformance claims are made with respect to a specified data format, and conforming implementations must support at least one data format.

- Core JADN
    - Validate schema packages according to Section 3.1, Section 3.2 and section 6
    - Validate API values against a schema package
    - Encode and decode documents according to serialization rules for data format <X> defined in Section Section 4
- JADN Extensions
    - Satisfy all Core requirements
    - Perform all extension unfolding operations defined in Section 3.3

This document describes information modeling functions but defines no corresponding conformance requirements:

- JADN Schema Translator
    - Translate JADN packages to and from documentation formats (IDL, table, diagram) described in Section 5.
- JADN Concrete Schema Generators
    - Generate format-specific concrete schemas per serialization rules in Section 4.x.
- JADN Extensions
    - Recognize opportunities to fold related types into extensions, i.e., given a core schema package, generate syntactic sugar where possible.

Appendix A. References

This appendix contains the normative and informative references that are used in this document. Normative references are specific (identified by date of publication and/or edition number or version number) and Informative references are either specific or non-specific.

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. Safety, Security and Privacy Considerations

This document presents a language for expressing the information needs of communicating applications, and rules for generating data structures to satisfy those needs. As such, it does not inherently introduce security issues, although protocol specifications based on JADN naturally need security analysis when defined. Such specifications need to follow the guidelines in RFC 3552.

Additional security considerations applicable to JADN-based specifications:

- The JADN language could cause confusion in a way that results in security issues. Clarity and unambiguity of this specification could always be improved through operational experience and developer feedback.
- Where a JADN data validator is part of a system, the security of the system benefits from automatic data validation but depends on both the specificity of the JADN specification and the correctness of the validation implementation. Tightening the specification (e.g., by defining upper bounds and other value constraints) and testing the validator against unreasonable data instances can address both concerns.

Security and bandwidth efficiency are benefits of using an information model. Enumerating strings and map keys defines the information content of those values, which greatly reduces opportunities for exploitation. A firewall with a security policy of "Allow specific things I understand plus everything I don't understand" is less secure than a firewall that allows only things that are understood. The "Must-Ignore" policy of RFC 7493 compromises security by allowing everything that is not understood. Information modeling's "Must-Understand" approach enhances security and accommodates new protocol elements by adding them to the IM's enumerated lists of things that are understood. An executable IM format such as JADN provides the agility required to support evolving protocols.

Writers of JADN specifications are strongly encouraged to value simplicity and transparency of the specification. Although JADN makes it easier to both define and understand complex specifications, complexity that is not essential to satisfying operational requirements is itself a security concern.

Appendix C. Acknowledgments

C.1 Special Thanks

The following individuals shared their expertise during creation of this specification and are gratefully acknowledged:

First Name	Last Name	Company
Carsten	Bormann	Universität Bremen
Hans-Jürgen	Rennau	parsQube GmbH

C.2 Participants

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

First Name	Last Name	Company
Brian	Berliner	Symantec
Joseph	Brule	National Security Agency
Toby	Considine	University of North Carolina
Jason	Romano	General Dynamics
Duncan	Sparrell	sFractal Consulting

Appendix D. Revision History

Revision	Date	Editor	Changes Made
WD-01	2020-10-18	David Kemp	Initial working draft
WD-02	2021-06-16	David Kemp	Re-written description, serialization and documentation formats

Appendix E. JSON Schema for JADN Documents

A JADN package has the following structure:

```
{
  "$schema": "https://json-schema.org/draft/2019-09/schema",
  "$id": "https://oasis-open.org/openc2/jadn/v1.0",
  "description": "Validates structure of a JADN schema, does not check values",
  "type": "object",
  "required": ["types"],
  "additionalProperties": false,
  "properties": {
    "info": {
      "type": "object",
      "required": ["package"],
      "additionalProperties": false,
      "properties": {
        "package": {"type": "string"},
        "version": {"type": "string"},
        "title": {"type": "string"},
        "description": {"type": "string"},
        "comment": {"type":  "string"},
        "copyright": {"type": "string"},
        "license": {"type": "string"},
        "namespaces": {"$ref": "#/definitions/Namespaces"},
        "exports": {"$ref": "#/definitions/Exports"},
        "config": {"$ref": "#/definitions/Config"}
      }
    },
    "types": {
      "type": "array",
      "items": {
        "type": "array",
        "minItems": 2,
        "maxItems": 5,
        "items": [
          {"$ref": "#/definitions/TypeName"},
          {"$ref": "#/definitions/BaseType"},
          {"$ref": "#/definitions/Options"},
          {"$ref": "#/definitions/Description"},
          {"$ref": "#/definitions/Fields"}
        ]
      }
    }
  },
  "definitions": {
    "Namespaces": {
      "type": "object",
      "propertyNames": {"$ref": "#/definitions/NSID"},
      "patternProperties": {
        "": {
          "type": "string",
          "format": "uri"
        }
      }
    },
    "Exports": {
      "type": "array",
      "items": {"type": "string"}
    },
    "Config": {
      "type": "object",
      "additionalProperties": false,
      "properties": {
```

```
      "$MaxBinary": {"type": "integer", "minValue": 1},
      "$MaxString": {"type": "integer", "minValue": 1},
      "$MaxElements": {"type": "integer", "minValue": 1},
      "$Sys": {"type": "string", "minLength": 1, "maxLength": 1},
      "$TypeName": {"type": "string", "minLength": 1, "maxLength": 127},
      "$FieldName": {"type": "string", "minLength": 1, "maxLength": 127},
      "$NSID": {"type": "string", "minLength": 1, "maxLength": 127}
    }
  },
  "Fields": {
    "type": "array",
    "items": [
      {"anyOf": [
        {"$ref": "#/definitions/Item"},
        {"$ref": "#/definitions/Field"}
      ]}
    ]
  },
  "Item": {
    "type": "array",
    "minItems": 2,
    "maxItems": 3,
    "items": [
      {"type": "integer"},
      {"type": "string"},
      {"$ref": "#/definitions/Description"}
    ]
  },
  "Field": {
    "type": "array",
    "minItems": 3,
    "maxItems": 5,
    "items": [
      {"type": "integer"},
      {"$ref": "#/definitions/FieldName"},
      {"$ref": "#/definitions/TypeRef"},
      {"$ref": "#/definitions/Options"},
      {"$ref": "#/definitions/Description"}
    ]
  },
  "NSID": {
    "type": "string"
  },
  "TypeName": {
    "type": "string"
  },
  "TypeRef": {
    "type": "string"
  },
  "FieldName": {
    "type": "string"
  },
  "BaseType": {
    "type": "string",
    "enum": ["Binary", "Boolean", "Integer", "Number", "String",
             "Enumerated", "Choice",
             "Array", "ArrayOf", "Map", "MapOf", "Record"]
  },
  "Options": {
    "type": "array",
    "items": {"type": "string"}
  },
  "Description": {
    "type": "string"
  }
}
```

```
}
```

Appendix F. JADN Meta-schema for JADN Documents

A meta-schema is a schema against which other schemas can be validated. The JADN meta-schema validates itself and other JADN schemas. In order to validate itself, the meta-schema requires a name format change from the JADN default (Section 3.1.2):

- FieldName needs to allow configuration variables beginning with '$' and capitalized JADN types

```
"config": {
  "$FieldName": "^[$A-Za-z][_A-Za-z0-9]{0,63}$"
}
```

F.1 Package

A package is a collection of type definitions along with information about the package.

```
       title: "JADN Metaschema"
     package: "http://oasis-open.org/jadn/v1.0/schema"
 description: "Syntax of a JSON Abstract Data Notation (JADN) package."
     license: "CC0-1.0"
     exports: ["Schema"]
      config: {"$FieldName": "^[$A-Za-z][_A-Za-z0-9]{0,63}$"}

Schema = Record                             // Definition of a JADN package
   1 info         Information optional      // Information about this package
   2 types        Types                     // Types defined in this package

Information = Map                           // Information about this package
   1 package      Namespace                 // Unique name/version of this package
   2 version      String{1..*} optional     // Incrementing version within package
   3 title        String{1..*} optional     // Title
   4 description  String{1..*} optional     // Description
   5 comment      String{1..*} optional     // Comment
   6 copyright    String{1..*} optional     // Copyright notice
   7 license      String{1..*} optional     // SPDX licenseId (e.g., 'CC0-1.0')
   8 namespaces   Namespaces optional       // Referenced packages
   9 exports      Exports optional          // Type defs exported by this package
  10 config       Config optional           // Configuration variables

Namespaces = MapOf(NSID, Namespace){1..*}   // Packages with referenced type defs

Exports = ArrayOf(TypeName){1..*}           // Type defs intended to be referenced

Config = Map{1..*}                          // Config vars override JADN defaults
   1 $MaxBinary   Integer{1..*} optional    // Schema default max octets
   2 $MaxString   Integer{1..*} optional    // Schema default max characters
   3 $MaxElements Integer{1..*} optional    // Schema default max items/properties
   4 $Sys         String{1..1} optional     // System character for TypeName
   5 $TypeName    String{1..127} optional   // TypeName regex
   6 $FieldName   String{1..127} optional   // FieldName regex
   7 $NSID        String{1..127} optional   // Namespace Identifier regex
```

F.2 Type Definitions

The structure of JADN type definitions (Section 3.1) is intended to remain stable, with options providing extensibility.

```
Types = ArrayOf(Type)
Type = Array
   1  TypeName                              // type_name::
   2  BaseType                              // base_type::
   3  Options                               // type_options::
   4  Description                           // type_description::
   5  JADN-Type(TagId[base_type])           // fields::

BaseType = Enumerated
```

```
   1 Binary
   2 Boolean
   3 Integer
   4 Number
   5 String
   6 Enumerated
   7 Choice
   8 Array
   9 ArrayOf
  10 Map
  11 MapOf
  12 Record

JADN-Type = Choice
   1 Binary       Empty
   2 Boolean      Empty
   3 Integer      Empty
   4 Number       Empty
   5 String       Empty
   6 Enumerated   Items
   7 Choice       Fields
   8 Array        Fields
   9 ArrayOf      Empty
  10 Map          Fields
  11 MapOf        Empty
  12 Record       Fields

Empty = Array{0..0}
Items = ArrayOf(Item)
Item = Array
   1  FieldID                              // item_id::
   2  String                               // item_value::
   3  Description                          // item_description::

Fields = ArrayOf(Field)
Field = Array
   1  FieldID                              // field_id::
   2  FieldName                            // field_name::
   3  TypeRef                              // field_type::
   4  Options                              // field_options::
   5  Description                          // field_description::

FieldID = Integer{0..*}
Options = ArrayOf(Option){0..10}
Option = String{1..*}
Description = String
Namespace = String /uri                    // Unique name of a package
NSID = String{pattern="$NSID"}             // Default = ^[A-Za-z][A-Za-z0-9]{0,7}$
TypeName = String{pattern="$TypeName"}     // Default = ^[A-Z][-$A-Za-z0-9]{0,63}$
FieldName = String{pattern="$FieldName"}   // Default = ^[a-z][_A-Za-z0-9]{0,63}$
TypeRef = String                           // Autogenerated pattern ($NSID ':')? $TypeName
```

Appendix G. JADN Type Definitions From This Document

This appendix contains the JADN type definitions corresponding to all examples in this document.

Section 2.3 Example Definitions:

```
["Person", "Record", [], "", [
    [1, "name", "String", [], ""],
    [2, "id", "Integer", [], ""],
    [3, "email", "String", ["[0"], ""]
]]
```

Section 3.2.2.2 Discriminated Union with Explicit Tag:

```
[
  ["Product", "Choice", [], "Discriminated union", [
    [1, "furniture", "Furniture", [], ""],
    [2, "appliance", "Appliance", [], ""],
    [3, "software", "Software", [], ""]
  ]],
  ["Dept", "Enumerated", [], "Explicit Tag values derived from the Choice", [
    [1, "furniture", ""],
    [2, "appliance", ""],
    [3, "software", ""]
  ]],
  ["Software", "String", ["/uri"], "", []],
  ["Stock1", "Record", [], "Discriminated union with intrinsic tag", [
    [1, "quantity", "Integer", [], ""],
    [2, "product", "Product", [], "Value = Map with one key/value"]
  ]],
  ["Stock2", "Record", [], "Container with explicitly-tagged discriminated union", [
    [1, "dept", "Dept", [], "Tag = one key from Choice"],
    [2, "quantity", "Integer", [], ""],
    [3, "product", "Product", ["&1"], "Choice specifying an explicit tag field"]
  ]],
  ["Hashes", "Map", ["{1"], "Multiple discriminated unions with intrinsic tags is a Map", [
    [1, "md5", "Binary", ["/x", "{16", "}16", "[0"], ""],
    [2, "sha1", "Binary", ["/x", "{20", "}20", "[0"], ""],
    [3, "sha256", "Binary", ["/x", "{32", "}32", "[0"], ""]
  ]],
  ["Hashes2", "ArrayOf", ["*HashVal"], "Multiple discriminated unions with explicit tags is an Array", []],
  ["HashVal", "Record", [], "", [
    [1, "algorithm", "Enumerated", ["#HashAlg"], "Tag - one key from Choice"],
    [2, "value", "HashAlg", ["&1"], "Value selected from Choice by 'algorithm' field"]
  ]],
  ["HashAlg", "Choice", [], "", [
    [1, "md5", "Binary", ["/x", "{16", "}16"], ""],
    [2, "sha1", "Binary", ["/x", "{20", "}20"], ""],
    [3, "sha256", "Binary", ["/x", "{32", "}32"], ""]
  ]]
]
```

Section 3.3.1 Type Definition Within Fields:

```
[
  ["Member", "Record", [], "", [
    [1, "name", "String", [], ""],
    [2, "email", "String", ["/email"], ""]
  ]],
  ["Member2", "Record", [], "", [
    [1, "name", "String", [], ""],
    [2, "email", "Member2$email", [], ""]
  ]],
  ["Member2$email", "String", ["/email"], "Tool-generated type definition.", []]
]
```

Section 3.3.2 Field Multiplicity:

```
[
  ["Roster", "Record", [], "", [
    [1, "org_name", "String", [], ""],
    [2, "members", "Member", ["[0", "]0"], "Optional and repeated: minc=0, maxc=0"]
  ]],
  ["Roster2", "Record", [], "", [
    [1, "org_name", "String", [], ""],
    [2, "members", "Roster2$members", ["[0"], "Optional: minc=0, maxc=1"]
  ]],
  ["Roster2$members", "ArrayOf", ["*Member", "{1"], "Tool-generated array: minv=1, maxv=0", []],
  ["Roster3", "Record", [], "", [
    [1, "org_name", "String", [], ""],
    [2, "members", "Members", [], "members field is required: default minc = 1, maxc = 1"]
  ]],
  ["Members", "ArrayOf", ["*Member"], "Explicitly-defined array: default minv = 0, maxv = 0", []]
]
```

Section 3.3.3 Derived Enumerations:

```
[
  ["Channel", "Enumerated", ["#Pixel"], "Derived Enumerated type", []],
  ["ChannelMask", "ArrayOf", ["*#Pixel"], "ArrayOf(derived enumeration)", []],
  ["Channel2", "Enumerated", [], "", [
    [1, "red", ""],
    [2, "green", ""],
    [3, "blue", ""]
  ]],
  ["ChannelMask2", "ArrayOf", ["*Channel"], "", []]
]
```

Section 3.3.4 MapOf with Enumerated Key:

Note that the order of elements in **TypeOptions** and **FieldOptions** is not significant.

```
[
  ["Channel3", "Enumerated", [], "", [
    [1, "red", ""],
    [2, "green", ""],
    [3, "blue", ""]
  ]],
  ["Pixel3", "MapOf", ["+Channel3", "*Integer"], "", []]
]
```

Section 3.3.5 Pointers:

```
[
  ["Catalog", "Record", [], "", [
    [1, "a", "TypeA", [], ""],
    [2, "b", "TypeB", ["<"], ""]
  ]],
  ["TypeA", "Record", [], "", [
    [1, "x", "Number", [], ""],
    [2, "y", "Number", [], ""]
  ]],
  ["TypeB", "Record", [], "", [
    [1, "foo", "String", [], ""],
    [2, "bar", "Integer", [], ""]
  ]],
  ["Paths", "Enumerated", [">Catalog"], "", []],
  ["Paths2", "Enumerated", [], "", [
    [1, "a", "Item 1"],
    [2, "b/foo", "Item 2"],
    [3, "b/bar", "Item 3"]
  ]]
]
```

Section 3.3.6 Links:

```
[
  ["Person", "Record", [], "", [
    [1, "id", "Integer", ["K"], ""],
    [2, "name", "String", [], ""],
    [3, "mother", "Person", ["L"], ""],
    [4, "father", "Person", ["L"], ""],
    [5, "siblings", "Person", ["[0", "]0", "L"], ""],
    [6, "friends", "Person", ["[0", "]0", "L"], ""],
    [7, "employer", "Organization", ["[0", "L"], ""]
  ]],
  ["Person", "Record", [], "", [
    [1, "id", "Person$id", [], ""],
    [2, "name", "String", [], ""],
    [3, "mother", "Person$id", [], ""],
    [4, "father", "Person$id", [], ""],
    [5, "siblings", "Person$id", ["[0", "]0"], ""],
    [6, "friends", "Person$id", ["[0", "]0"], ""],
    [7, "employer", "Organization$ein", ["[0"], ""]
  ]],
  ["Person$id", "Integer", [], "", []],
  ["Organization$ein", "String", ["{10", "}10"], "", []]
]
```

Section 5.3. Entity Relationship Diagrams:

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

 "types": [
  ["University", "Record", [], "", [
    [1, "name", "String", [], ""],
    [2, "classes", "Class", ["]0"], ""],
    [3, "people", "Person", ["]0"], ""]
  ]],

  ["Class", "Record", [], "", [
    [1, "name", "String", [], ""],
    [2, "room", "String", [], ""],
    [3, "teachers", "Person", ["L", "]0"], ""],
    [4, "students", "Person", ["L", "]0"], ""]
  ]],

  ["Person", "Record", [], "", [
    [1, "name", "String", [], ""],
    [2, "univ_id", "UnivId", ["K"], ""],
    [3, "email", "String", ["/email"], ""]
  ]],

  ["UnivId", "String", ["%^U-\\d{6}$"], "", []]
 ]
}
```

Appendix F. JADN Meta-schema:

```
{
 "info": {
  "title": "JADN Metaschema",
  "package": "http://oasis-open.org/jadn/v1.0/schema",
  "description": "Syntax of a JSON Abstract Data Notation (JADN) package.",
  "license": "CC0-1.0",
  "exports": ["Schema"],
  "config": {
   "$FieldName": "^[$A-Za-z][_A-Za-z0-9]{0,63}$"
  }
 },
 "types": [
  ["Schema", "Record", [], "Definition of a JADN package", [
    [1, "info", "Information", ["[0"], "Information about this package"],
    [2, "types", "Types", [], "Types defined in this package"]
  ]],
  ["Information", "Map", [], "Information about this package", [
    [1, "package", "Namespace", [], "Unique name/version of this package"],
    [2, "version", "String", ["{1", "[0"], "Incrementing version within package"],
    [3, "title", "String", ["{1", "[0"], "Title"],
    [4, "description", "String", ["{1", "[0"], "Description"],
    [5, "comment", "String", ["{1", "[0"], "Comment"],
    [6, "copyright", "String", ["{1", "[0"], "Copyright notice"],
    [7, "license", "String", ["{1", "[0"], "SPDX licenseId (e.g., 'CC0-1.0')"],
    [8, "namespaces", "Namespaces", ["[0"], "Referenced packages"],
    [9, "exports", "Exports", ["[0"], "Type defs exported by this package"],
    [10, "config", "Config", ["[0"], "Configuration variables"]
  ]],
  ["Namespaces", "MapOf", ["*Namespace", "+NSID", "{1"], "Packages with referenced type defs", []],
  ["Exports", "ArrayOf", ["*TypeName", "{1"], "Type defs intended to be referenced", []],
  ["Config", "Map", ["{1"], "Config vars override JADN defaults", [
    [1, "$MaxBinary", "Integer", ["{1", "[0"], "Schema default max octets"],
    [2, "$MaxString", "Integer", ["{1", "[0"], "Schema default max characters"],
    [3, "$MaxElements", "Integer", ["{1", "[0"], "Schema default max items/properties"],
    [4, "$Sys", "String", ["{1", "}1", "[0"], "System character for TypeName"],
    [5, "$TypeName", "String", ["{1", "}127", "[0"], "TypeName regex"],
    [6, "$FieldName", "String", ["{1", "}127", "[0"], "FieldName regex"],
    [7, "$NSID", "String", ["{1", "}127", "[0"], "Namespace Identifier regex"]
  ]],
  ["Types", "ArrayOf", ["*Type"], "", []],
  ["Type", "Array", [], "", [
    [1, "type_name", "TypeName", [], ""],
    [2, "base_type", "BaseType", [], ""],
    [3, "type_options", "Options", [], ""],
    [4, "type_description", "Description", [], ""],
    [5, "fields", "JADN-Type", ["&2"], ""]
  ]],
  ["BaseType", "Enumerated", [], "", [
    [1, "Binary", ""],
    [2, "Boolean", ""],
    [3, "Integer", ""],
    [4, "Number", ""],
    [5, "String", ""],
    [6, "Enumerated", ""],
    [7, "Choice", ""],
    [8, "Array", ""],
    [9, "ArrayOf", ""],
    [10, "Map", ""],
    [11, "MapOf", ""],
    [12, "Record", ""]
  ]],
  ["JADN-Type", "Choice", [], "", [
    [1, "Binary", "Empty", [], ""],
    [2, "Boolean", "Empty", [], ""],
    [3, "Integer", "Empty", [], ""],
    [4, "Number", "Empty", [], ""],
    [5, "String", "Empty", [], ""],
    [6, "Enumerated", "Items", [], ""],
    [7, "Choice", "Fields", [], ""],
    [8, "Array", "Fields", [], ""],
    [9, "ArrayOf", "Empty", [], ""],
    [10, "Map", "Fields", [], ""],
    [11, "MapOf", "Empty", [], ""],
    [12, "Record", "Fields", [], ""]
  ]],
  ["Empty", "Array", ["}0"], "", []],
  ["Items", "ArrayOf", ["*Item"], "", []],
  ["Item", "Array", [], "", [
    [1, "item_id", "FieldID", [], ""],
    [2, "item_value", "String", [], ""],
    [3, "item_description", "Description", [], ""]
  ]],
  ["Fields", "ArrayOf", ["*Field"], "", []],
  ["Field", "Array", [], "", [
    [1, "field_id", "FieldID", [], ""],
    [2, "field_name", "FieldName", [], ""],
    [3, "field_type", "TypeRef", [], ""],
    [4, "field_options", "Options", [], ""],
    [5, "field_description", "Description", [], ""]
  ]],
  ["FieldID", "Integer", ["{0"], "", []],
  ["Options", "ArrayOf", ["*Option", "}10"], "", []],
  ["Option", "String", ["{1"], "", []],
  ["Description", "String", [], "", []],
  ["Namespace", "String", ["/uri"], "Unique name of a package", []],
  ["NSID", "String", ["%$NSID"], "Default = ^[A-Za-z][A-Za-z0-9]{0,7}$", []],
  ["TypeName", "String", ["%$TypeName"], "Default = ^[A-Z][-$A-Za-z0-9]{0,63}$", []],
  ["FieldName", "String", ["%$FieldName"], "Default = ^[a-z][_A-Za-z0-9]{0,63}$", []],
  ["TypeRef", "String", [], "Autogenerated pattern ($NSID ':')? $TypeName", []]
 ]
}
```

Appendix H. Notices