Web of Things (WoT) Thing Description



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Abstract

Thing Description. A Thing Description describes the metadata and interfaces of <u>Things</u>, where a <u>Thing</u> is an abstraction of a physical or virtual entity that provides interactions to and participates in the Web of Things. Thing Descriptions provide a set of interactions based on a small vocabulary that makes it possible both to integrate diverse devices and to allow diverse applications to interoperate. Thing Descriptions, by default, are encoded in a JSON format that also allows JSON-LD processing. The latter provides a powerful foundation to represent knowledge about <u>Things</u> in a machine-understandable way. A Thing Description instance can be hosted by the <u>Thing</u> itself or hosted externally when a <u>Thing</u> has resource restrictions (e.g., limited memory space) or when a Web of Things-compatible legacy device is retrofitted with a Thing Description.

Status of This Document

This section describes the status of this document at the time of its publication. Other documents may supersede this document. A list of current <u>W3C</u> publications and the latest revision of this technical report can be found in the <u>W3C</u> technical reports index at https://www.w3.org/TR/.

The following at-risk features (marked in yellow throughout this specification) may be removed due to insufficient implementation experience reported and/or comments received during the CR period: Whole sections related to the security schemes described in § 5.3.3.7 CertSecurityScheme , § 5.3.3.9 PublicSecurityScheme , and § 5.3.3.10 PoPSecurityScheme . Vocabulary terms and assertions related to the implicit , password , and client flows in § 5.3.3.11 OAuth2SecurityScheme . All default values related to the above in § 5.4 Default Value Definitions . A behavioral assertion for writeallproperties that allows rejection of incomplete writes. ↓ This document was published by the Web of Things Working Group as ↓a Candidate Recommendation. This document is intended to become a W3C Recommendation. ↓ ↑an Editor's Draft. ↑

GitHub Issues are preferred for discussion of this specification. Alternatively, you can send comments to our mailing list. Please send them to public-wot-wg@w3.org (\psubscribe , \psu \ \text{archives}).

↓W3C publishes a Candidate Recommendation to indicate that the document is believed to be stable and to encourage implementation by the developer community. This Candidate Recommendation is expected to advance to Proposed Recommendation no earlier than 4 December 2019. ↓ Please see the Working Group's implementation report.

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This document is governed by the 1 March 2019 W3C Process Document.

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1. Introduction

This section is non-normative.

The WoT Thing Description (TD) is a central building block in the <u>W3C</u> Web of Things (WoT) and can be considered as the entry point of a <u>Thing</u> (much like the *index.html* of a Web site). A TD instance has four main components: textual metadata about the <u>Thing</u> itself, a set of <u>Interaction Affordances</u> that indicate how the <u>Thing</u> can be used, <u>schemas</u> for the data exchanged with the <u>Thing</u> for machine-understandability, and, finally, <u>Web links</u> to express any formal or informal relation to other <u>Things</u> or documents on the Web.

The <u>Interaction Model of W3C</u> WoT defines three types of <u>Interaction Affordances</u>: Properties (
<u>PropertyAffordance class</u>) can be used for sensing and controlling parameters, such as getting the current value or setting an operation state. Actions (<u>ActionAffordance class</u>) model invocation of physical (and hence time-consuming) processes, but can also be used to abstract RPC-like calls of existing platforms. Events (<u>EventAffordance class</u>) are used for the push model of communication where notifications, discrete events, or streams of values are sent asynchronously to the receiver. See [
<u>WOT-ARCHITECTURE</u>] for details.

In general, the TD provides metadata for different Protocol Bindings identified by URI schemes [
RFC3986] (e.g., http , coap , etc. [IANA-URI-SCHEMES]), content types based on media types [
RFC2046] (e.g., application/json , application/xml , application/cbor , application/exi ,
etc. [IANA-MEDIA-TYPES]), and security mechanisms (for authentication, authorization,
confidentiality, etc.). Serialization of TD instances is based on JSON [RFC8259], where JSON names refer to terms of the TD vocabulary, as defined in this specification document. In addition the JSON serialization of TDs follows the syntax of JSON-LD 1.1 [JSON-LD11] to enable extensions and rich semantic processing.

<u>Example 1</u> shows a TD instance and illustrates the <u>Interaction Model</u> with Properties, Actions, and Events by describing a lamp Thing with the title *MyLampThing*.

{ "@context": "https://www.w3.org/2019/wot/td/v1",

EXAMPLE 1: THING DESCRIPTION SAMPLE

```
"id": "urn:dev:ops:32473-WoTLamp-1234",
    "title": "MyLampThing",
    "securityDefinitions": {
        "basic sc": {"scheme": "basic", "in":"header"}
    },
    "security": ["basic_sc"],
    "properties": {
        "status" : {
            "type": "string",
            "forms": [{"href": "https://mylamp.example.com/status"}]
        }
    },
    "actions": {
        "toggle" : {
            "forms": [{"href": "https://mylamp.example.com/toggle"}]
        }
    },
    "events":{
        "overheating":{
            "data": {"type": "string"},
            "forms": [{
                 "href": "https://mylamp.example.com/oh",
                 "subprotocol": "longpoll"
            }]
        }
    }
}
```

From this TD example, we know there exists one <u>Property affordance</u> with the title *status*. In addition, information is provided to indicate that this Property is accessible via (the secure form of) the HTTP protocol with a GET method at the URI https://mylamp.example.com/status (announced within the forms structure by the href member), and will return a string-based status value. The use of the GET method is not stated explicitly, but is one of the default assumptions defined by this document.

In a similar manner, an <u>Action affordance</u> is specified to toggle the switch status using the POST method on the https://mylamp.example.com/toggle resource, where POST is again a default assumption for invoking Actions.

The <u>Event affordance</u> enables a mechanism for asynchronous messages to be sent by a <u>Thing</u>. Here, a subscription to be notified upon a possible overheating event of the lamp can be obtained by using HTTP with its long polling subprotocol on https://mylamp.example.com/oh.

This example also specifies the basic security scheme, requiring a username and password for access.

Note that a security scheme is first given a name in <code>tattsecurityDefinition to the theorem to the </code>

The Thing Description offers the possibility to add contextual definitions in some namespace. This mechanism can be used to integrate additional semantics to the content of the Thing Description instance, provided that formal knowledge, e.g., logic rules for a specific domain of application, can be found under the given namespace. Contextual information can also help specify some configurations and behavior of the underlying communication protocols declared in the forms field. Example 2 extends the TD sample from Example 1 by introducing a second defintion in the @context to declare the prefix saref as referring to SAREF, the Smart Appliance Reference Ontology [SMARTM2M]. This IoT ontology includes terms interpreted as semantic labels that can be set as values of the @typefield, giving the semantics of Things and their Interaction Affordances. In the example below, the Thing is labelled with saref: UnoffState and the toggle Action with saref:ToggleCommand.

EXAMPLE 2: THING DESCRIPTION WITH TD CONTEXT EXTENSION FOR SEMANTIC ANNOTATIONS

```
{
    "@context": [
        "https://www.w3.org/2019/wot/td/v1",
        { "saref": "https://w3id.org/saref#" }
    ],
    "id": "urn:dev:ops:32473-WoTLamp-1234",
    "title": "MyLampThing",
    "@type": "saref:LightSwitch",
    "securityDefinitions": {"basic_sc": {
        "scheme": "basic",
        "in": "header"
    }},
    "security": ["basic_sc"],
    "properties": {
        "status": {
            "@type": "saref:OnOffState",
            "type": "string",
            "forms": [{
                 "href": "https://mylamp.example.com/status"
            }]
        }
    },
    "actions": {
        "toggle": {
            "@type": "saref:ToggleCommand",
            "forms": [{
                 "href": "https://mylamp.example.com/toggle"
            }]
        }
    },
    "events": {
        "overheating": {
            "data": {"type": "string"},
            "forms": [{
                "href": "https://mylamp.example.com/oh"
            }]
        }
    }
}
```

The declaration mechanism inside some @context is specified by JSON-LD. A TD instance complies to version 1.1 of that specification [<u>json-ld11</u>]. Hence, a TD instance can be also processed as an RDF document (for details about semantic processing, please refer to Appendix § D. JSON-LD Context Usage and the documentation under the namespace IRIs, e.g., https://www.w3.org/2019/wot/td).

2. Conformance

As well as sections marked as non-normative, all authoring guidelines, diagrams, examples, and notes in this specification are non-normative. Everything else in this specification is normative.

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

A Thing Description instance complies with this specification if it follows the normative statements in § 5. TD Information Model and § 6. TD Representation Format regarding Thing Description serialization.

A JSON Schema [<u>JSON-SCHEMA</u>] to validate Thing Description instances is provided in Appendix § B. JSON Schema for TD Instance Validation .

3. Terminology

This section is non-normative.

The fundamental WoT terminology such as *Thing*, *Consumer*, *Thing Description* (*TD*), *Interaction Model*, *Interaction Affordance*, *Property*, *Action*, *Event*, *Protocol Binding*, *Servient*, *WoT Interface*, *WoT Runtime*, etc. is defined in <u>Section 3</u> of the WoT Architecture specification [<u>WOT-ARCHITECTURE</u>].

In addition, this specification introduces the following definitions:

TD Context Extension

A mechanism to extend <u>Thing Descriptions</u> with additional <u>Vocabulary Terms</u>. It is the basis for semantic annotations and extensions to core mechanisms such as Protocol Bindings, Security Schemes, and Data Schemas.

TD Information Model

Set of <u>Class</u> definitions constructed from pre-defined <u>Vocabularies</u> on which constraints apply, thus defining the semantics of these <u>Vocabularies</u>. Class definitions are typically expressed in

terms of a <u>Signature</u> (a set of <u>Vocabulary Terms</u>) and functions over that <u>Signature</u>. The <u>TD</u> <u>Information Model</u> also includes <u>Default Values</u>, defined as a global function over <u>Classes</u>.

TD Processor

A system that can serialize some internal representation of a <u>Thing Description</u> in a given format and/or description that format. A <u>TD Processor</u> must detect semantically inconsistent <u>Thing Descriptions</u>, that is, <u>Thing Descriptions</u> that cannot satisfy constraints on the <u>Instance Relation</u> of the Thing class. For that purpose, a <u>TD Processor</u> may compute canonical forms of <u>Thing Descriptions</u> in which all possible <u>Default Values</u> are assigned. A <u>TD Processor</u> is typically a sub-system of a <u>WoT Runtime</u>. Implementations of a TD Processor may be a TD producer only (able to serialize to TD Documents) or a TD consumer only (able to description TD Documents).

TD Serialization or TD Document

Textual or binary representation of <u>Thing Descriptions</u> that can be stored and exchanged between <u>Servients</u>. A <u>TD Serialization</u> follows a given representation format, identified by a media type when exchanged over the network. The default representation format for <u>Thing Descriptions</u> is JSON-based as defined by this specification.

Vocabulary

A collection of Vocabulary Terms, identified by a namespace IRI.

Term and Vocabulary Term

A character string. When a <u>Term</u> is part of a <u>Vocabulary</u>, i.e., prefixed by a namespace IRI, it is called a <u>Vocabulary Term</u>. For the sake of readability, <u>Vocabulary Terms</u> present in this document are always written in a compact form and not as full IRIs.

These definitions are further developed in § 5.2 Preliminaries.

4. Namespaces

The version of the <u>TD Information Model</u> defined in § 5. <u>TD Information Model</u> of this specification is identified by the following IRI:

https://www.w3.org/2019/wot/td/v1

This IRI [<u>RFC3987</u>], which is also a URI [<u>RFC3986</u>], can be dereferenced to obtain a <u>JSON-LD</u> context file [<u>json-ld11</u>], allowing the compact strings in <u>TD Documents</u> to be expanded to full IRI-based <u>Vocabulary Terms</u>. However, this processing is only required when transforming JSON-based <u>TD Documents</u> to RDF, an optional feature of TD Processor implementations.

In the present specification, <u>Vocabulary Terms</u> are always presented in their compact form. Their expanded form can be accessed under the namespace IRI of the <u>Vocabulary</u> they belong to. These

namespaces follow the structure of § 5.3 Class Definitions. Each Vocabulary used in the TD Information Model has its own namespace IRI, as follows:

| Vocabulary | Namespace IRI |
|---------------------|--|
| Core | https://www.w3.org/2019/wot/td# |
| Data Schema | https://www.w3.org/2019/wot/json-schema# |
| Security | https://www.w3.org/2019/wot/security# |
| Hypermedia Controls | https://www.w3.org/2019/wot/hypermedia# |

The <u>Vocabularies</u> are independent from each other. They may be reused and extended in other <u>W3C</u> specifications. Every breaking change in the design of a <u>Vocabulary</u> will require the assignment of a new year-based namespace URI. Note that to maintain the general coherence of the <u>TD Information</u> <u>Model</u>, the associated JSON-LD context file is versioned such that every version has its own URI (v1, v1.1, v2, ...) to also identify non-breaking changes, in particular the addition of new <u>Terms</u>.

Because a <u>Vocabulary</u> under some namespace IRI can only undergo non-breaking changes, its content can be safely cached or embedded in applications. One advantage of exposing relatively static content under a namespace IRI is to optimize payload sizes of messages exchanged between constrained devices. It also avoids any privacy leakage resulting from devices accessing publicly available vocabularies from private networks (see also § 9.1 Context \perperencing \perperencing \perperencing \perperencing \perperencing \perperencing \perperence Privacy

<u>Risk</u>).

5. TD Information Model

This section introduces the <u>TD Information Model</u>. The <u>TD Information Model</u> serves as the conceptual basis for the processing of Thing Descriptions and their serialization, which is described separately in § 6. TD Representation Format.

5.1 Overview

The TD Information Model is built upon the following, independent Vocabularies:

• the *core* TD <u>Vocabulary</u>, which reflects the <u>Interaction Model</u> with the <u>Properties</u>, <u>Actions</u>, and Events Interaction Affordances [*WOT-ARCHITECTURE*]

- the *Data Schema* <u>Vocabulary</u>, including (a subset of) the terms defined by JSON Schema [<u>JSON-SCHEMA</u>]
- the WoT Security Vocabulary, identifying security mechanisms and requirements for their configuration
- the *Hypermedia Controls* <u>Vocabulary</u>, encoding the main principles of RESTful communication using Web links and forms

Each of these <u>Vocabularies</u> is essentially a set of <u>Terms</u> that can be used to build data structures, interpreted as objects in the traditional object-oriented sense. Objects are instances of classes and have properties. In the context of <u>W3C</u> WoT, they denote <u>Things</u> and their <u>Interaction Affordances</u>. A formal definition of objects is given in § 5.2 <u>Preliminaries</u>. The main elements of the <u>TD Information Model</u> are then presented in § 5.3 <u>Class Definitions</u>. Certain object properties may be omitted in a TD when Default Values exist. A list of defaults is given in § 5.4 <u>Default Value Definitions</u>.

The UML diagram shown next gives an overview of the <u>TD Information Model</u>. It represents all classes as tables and the associations that exist between classes, starting from the class <u>Thing</u>, as directed arrows. For the sake of readability, the diagram was split in four parts, one for each of the four base Vocabularies.

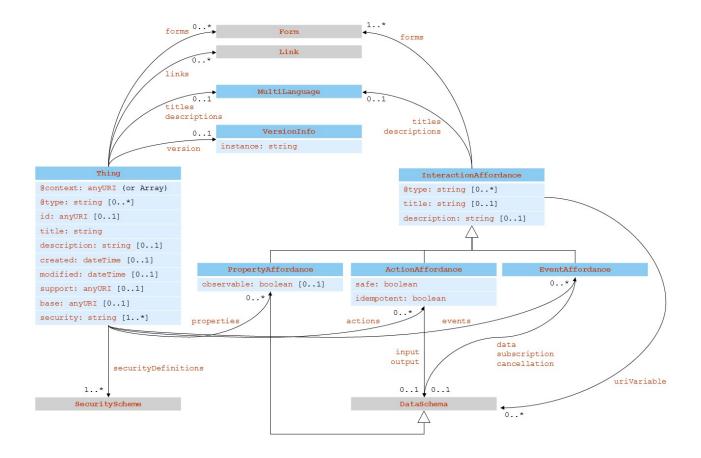


Figure 1 TD core vocabulary



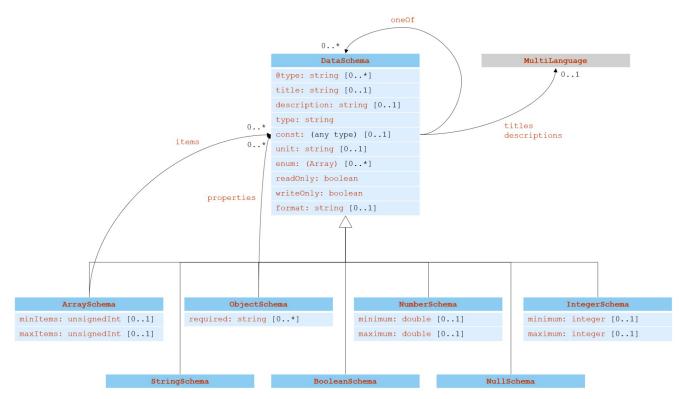


Figure 2 Data schema vocabulary



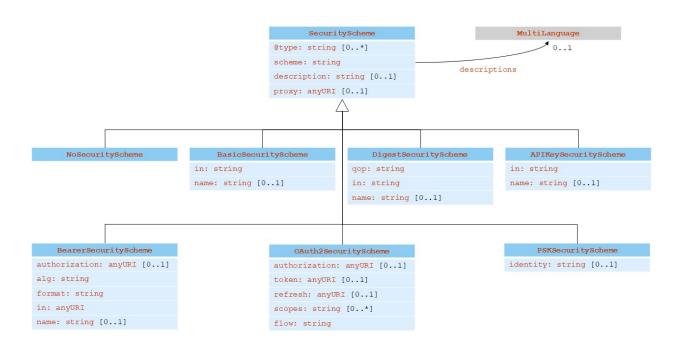


Figure 3 WoT security vocabulary

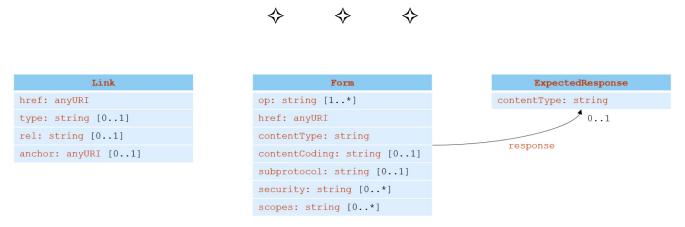


Figure 4 Hypermedia controls vocabulary

5.2 Preliminaries

To provide a model that can be easily processed by both, simple rules on a tree-based document (i.e.,

raw JSON processing) and rich Semantic Web tooling (i.e., JSON-LD processing), this document defines the following formal preliminaries to construct the <u>TD Information Model</u> accordingly.

All definitions in this section refer to *sets*, which intuitively are collections of elements that can themselves be sets. All arbitrarily complex data structures can be defined in terms of sets. In particular, an *Object* is a data structure recursively defined as follows:

- a Term, which may or may not belong to a Vocabulary, is an Object.
- a set of name-value pairs where the name is a <u>Term</u> and the value is another <u>Object</u>, is also an <u>Object</u>.

Though this definition does not prevent <u>Objects</u> to include multiple name-value pairs with the same name, they are generally not considered in this specification. An <u>Object</u> whose elements only have numbers as names is called an *Array*. Similarly, an <u>Object</u> whose elements only have <u>Term</u> s (that do not belong to any <u>Vocabulary</u>) as names is called a *Map*. All names appearing in some name-value pair in a Map are assumed to be *unique* within the scope of the Map.

Moreover, <u>Object</u> s can be instances of some *Class*. A <u>Class</u>, which is denoted by a <u>Vocabulary Term</u>, is first defined by a set of <u>Vocabulary Terms</u> called a *Signature*. A <u>Class</u> whose <u>Signature</u> is empty is called a *Simple Type*.

The <u>Signature</u> of a <u>Class</u> allows to construct two functions that further define <u>Classes</u>: an <u>Assignment Function</u> and a <u>Type Function</u>. The <u>Assignment Function</u> of a <u>Class</u> takes a <u>Vocabulary Term</u> of the <u>Class</u>'s <u>Signature</u> as input and returns either true or false as output. Intuitively, the <u>Assignment Function</u> indicates whether an element of the <u>Signature</u> is mandatory or optional when instantiating the <u>Class</u>. The <u>Type Function</u> of a <u>Class</u> also takes a <u>Vocabulary Term</u> of the <u>Class</u>'s <u>Signature</u> as input and returns another <u>Class</u> as output. These functions are <u>partial</u>: their domain is limited to the <u>Signature</u> of the <u>Class</u> being defined.

On the basis of these two functions, an *Instance Relation* can be defined for a pair composed of an Object and a Class. This relation is defined as constraints to be satisfied. That is, an Object is an instance of a Class if the two following constraints are *both* satisfied:

- if for every <u>Term</u> for which the <u>Assignment Function</u> of the <u>Class</u> returns true, the <u>Object</u> includes a name-value pair with the Vocabulary Term as name.
- if for every <u>Vocabulary Term</u> in the <u>Signature</u> of the <u>Class</u> used as name in some name-value pair of the <u>Object</u>, the value of that pair is an instance of the <u>Class</u> returned by the <u>Type Function</u> of the <u>Class</u> for the given <u>Vocabulary Term</u>.

According to the definition above, an <u>Object</u> would be an instance of every <u>Simple Type</u>, regardless of its structure. Instead, another definition for the Instance Relation is introduced for Simple Types: an

<u>Object</u> is an instance of a <u>Simple Type</u> if it is a <u>Term</u> with a given lexical form (e.g., true , false for the boolean type, 1 , 2 , 3 , ... for the unsignedInt type, etc.).

Moreover, additional <u>Classes</u>, called *Parameterized Classes*, can be derived from the generic <u>Map</u> and <u>Array</u> structures. An <u>Object</u> is a <u>Map</u> of some <u>Class</u>, that is, an instance of the <u>Map</u> type *parameterized* with some <u>Class</u>, if it is a <u>Map</u> such that the value in all the name-value pairs it contains is an instance of this <u>Class</u>. The same applies to <u>Arrays</u>.

Finally, a <u>Class</u> is a *Subclass* of some other <u>Class</u> if every instance of the former is also an instance of the latter.

Given all definitions above, the <u>TD Information Model</u> is to be understood as a set of <u>Class</u> definitions, which include a <u>Class</u> name (a <u>Vocabulary Term</u>), a <u>Signature</u> (a set of <u>Vocabulary Terms</u>), an <u>Assignment Function</u>, and a <u>Type Function</u>. These <u>Class</u> definitions are provided as tables in § <u>5.3</u> <u>Class Definitions</u>. For each table, the values "mandatory" (respectively, "optional") in the assignment column indicates that the <u>Assignment Function</u> returns true (respectively, false) for the corresponding <u>Vocabulary Term</u>.

By convention, <u>Simple Types</u> are denoted by names starting with lowercase. The <u>TD Information</u> <u>Model references</u> the following <u>Simple Types</u> defined in XML Schema [<u>XMLSCHEMA11-2-20120405</u>]: string, anyURI, dateTime, integer, unsignedInt, double, and boolean. Their definition (i.e., the specification of their lexical form) is outside of the scope of the TD Information Model.

In addition, the <u>TD Information Model</u> defines a global function on pairs of <u>Vocabulary Terms</u>. The function takes a <u>Class</u> name and another <u>Vocabulary Term</u> as input and returns an <u>Object</u>. If the returned <u>Object</u> is different from null, it represents the <u>Default Value</u> for some assignment on the input <u>Vocabulary Term</u> in an instance of the input <u>Class</u>. This function allows to relax the constraint defined above on the <u>Assignment Function</u>: an <u>Object</u> is an instance of a <u>Class</u> if it includes all mandatory assignments *or* if <u>Default Value</u> exist for the missing assignments. All <u>Default Values</u> are given in the table of § <u>5.4 Default Value Definitions</u>. In each table of § <u>5.3 Class Definitions</u>, the assignment column contains the value "with default" if a <u>Default Value</u> is available for the corresponding combination of Class and Vocabulary Term in the TD Information Model.

The formalization introduced here does not consider the possible relation between <u>Objects</u> as abstract data structures and physical world objects such as <u>Things</u>. However, care was given to the possibility of re-interpreting all <u>Vocabulary Terms</u> involved in the <u>TD Information Model</u> as RDF resources, so as to integrate them in a larger model of the physical world (an ontology). For details about semantic processing, please refer to <u>↑</u>§ <u>↑</u>↑ <u>D.</u> ↑↑ <u>JSON-LD Context Usage</u> ↑↑ and ↑ the documentation under the namespace IRIs, e.g., https://www.w3.org/2019/wot/td. Added a Cross

5.3 Class Definitions

A <u>TD Processor MUST</u> satisfy the <u>Class instantiation constraints on all Classes defined in § 5.3.1 Core Vocabulary Definitions, § 5.3.2 Data Schema Vocabulary Definitions, § 5.3.3 Security Vocabulary Definitions, and § 5.3.4 Hypermedia Controls Vocabulary Definitions.</u>

5.3.1 Core Vocabulary Definitions

5.3.1.1 Thing

An abstraction of a physical or a virtual entity whose metadata and interfaces are described by a WoT Thing Description, whereas a virtual entity is the composition of one or more Things.

| Vocabulary term | Description | Assignment | Туре |
|-----------------|--|------------|---------------------------|
| @context | JSON-LD keyword to define short-hand names called terms that are used throughout a TD document. | mandatory | anyURI or Array |
| @type | JSON-LD keyword to label the object with semantic tags (or types). | optional | string or Array of string |
| id | Identifier of the Thing in form of a URI [<u>RFC3986</u>] (e.g., stable URI, temporary and mutable URI, URI with local IP address, URN, etc.). | optional | <u>anyURI</u> |
| title | Provides a human- readable title (e.g., display a text for UI representation) based on a default language. | mandatory | <u>string</u> |

| Vocabulary term | Description | Assignment | Туре |
|-----------------|--|------------|-----------------|
| titles | Provides multi-language human-readable titles (e.g., display a text for UI representation in different languages). | optional | MultiLanguage |
| description | Provides additional (human-readable) information based on a default language. | optional | <u>string</u> |
| descriptions | Can be used to support (human-readable) information in different languages. | optional | MultiLanguage |
| version | Provides version information. | optional | VersionInfo |
| created | Provides information when the TD instance was created. | optional | <u>dateTime</u> |
| modified | Provides information when the TD instance was last modified. | optional | <u>dateTime</u> |
| support | Provides information about the TD maintainer as URI scheme (e.g., mailto [<u>RFC6068</u>], tel [<u>RFC3966</u>], https). | optional | <u>anyURI</u> |
| base | Define the base URI that is used for all relative URI references throughout a TD | optional | <u>anyURI</u> |

| <u>Vocabulary term</u> | Description | Assignment | Туре |
|------------------------|---|------------|--------------------|
| | document. In TD instances, all relative | | |
| | URIs are resolved | | |
| | relative to the base URI | | |
| | using the algorithm | | |
| | defined in [<u>RFC3986</u>]. | | |
| | base does not affect the | | |
| | URIs used in @context | | |
| | and the IRIs used within | | |
| | Linked Data [<u>LINKED-</u> | | |
| | <u>DATA</u>] graphs that are | | |
| | relevant when semantic | | |
| | processing is applied to | | |
| | TD instances. | | |
| properties | All Property-based | optional | Map of |
| | Interaction Affordances | | PropertyAffordance |
| | of the Thing. | | |
| actions | All Action-based | optional | Map of |
| | Interaction Affordances | | ActionAffordance |
| | of the Thing. | | |
| events | All Event-based | optional | Map of |
| | Interaction Affordances | | EventAffordance |
| | of the Thing. | | |
| links | Provides Web links to | optional | Array of Link |
| | arbitrary resources that | | |
| | relate to the specified | | |
| | Thing Description. | | |
| forms | Set of form hypermedia | optional | Array of Form |
| | controls that describe | | |
| | how an operation can be | | |
| | performed. Forms are | | |

| Vocabulary term | Description | Assignment | Туре |
|---------------------|----------------------------|------------|--------------------|
| | serializations of | | |
| | Protocol Bindings. In | | |
| | this version of TD, all | | |
| | operations that can be | | |
| | described at the Thing | | |
| | level are concerning | | |
| | how to interact with the | | |
| | Thing's Properties | | |
| | collectively at once. | | |
| security | Set of security definition | mandatory | string or Array of |
| | names, chosen from | | string |
| | those defined in | | |
| | securityDefinitions | | |
| | . These must all be | | |
| | satisfied for access to | | |
| | resources. | | |
| securityDefinitions | Set of named security | mandatory | Map of |
| | configurations | | SecurityScheme |
| | (definitions only). Not | | |
| | actually applied unless | | |
| | names are used in a | | |
| | security name-value | | |
| | pair. | | |
| | - | | |

The @context name-value pair MUST contain the anyURI https://www.w3.org/2019/wot/td/v1 either directly when of type anyURI or as first element when of type \underline{Array} . When @context is an \underline{Array} , the anyURI https://www.w3.org/2019/wot/td/v1 MAY be followed by elements of type anyURI or type \underline{Map} in any order, while it is RECOMMENDED to include only one \underline{Map} with all the name-value pairs in the @context \underline{Array} . \underline{Maps} contained in an @context \underline{Array} \underline{MAY} contain name-value pairs, where the value is a namespace identifier of type anyURI and the name a \underline{Term} or prefix denoting that namespace. One \underline{Map} contained in an @context \underline{Array} \underline{SHOULD} contain a name-value pair that defines the default language for the Thing Description, where the name is the \underline{Term} @language and the value is a well-formed language tag as defined by [$\underline{BCP47}$] (e.g., en , de-AT , gsw-CH , zh-Hans , zh-Hant-HK , sl-nedis).

The computation of the base direction of all human-readable text strings is defined by the following set of rules:

- If no language tag is given, the base direction *SHOULD* be inferred through first-strong heuristics or detection algorithms such as the CLDR Likely Subtags [*LDML*].
- Outside of MultiLanguage Maps, the base direction MAY be inferred from the language tag of the default language.
- Inside of MultiLanguage Maps, the base direction of each value of the name-value pairs MAY be inferred from the language tag given in the corresponding name.
- In cases where a language can be written in more than one script with different base directions, the corresponding language tag given in @language or MultiLanguage Maps MUST include a script subtag, so that an appropriate base direction can be inferred. An example is Azeri, which is written LTR when Latin script is used (specified using az-Latn) and RTL when Arabic script is used (specified using az-Arab).

<u>TD Processors</u> should be aware of certain special cases when processing bidirectional text. They should take care to use bidi isolation when presenting strings to users, particularly when embedding in surrounding text (e.g., for Web user interface). Mixed direction text can occur in any language, even when the language is properly identified.

TD producers should attempt to provide mixed direction strings in a way that can be displayed successfully by a naive user agent. For example, if an RTL string begins with an LTR run (such as a number or a brand or trade name in Latin script), including an RLM character at the start of the string or wrapping opposite direction runs in bidi controls can assist in proper display.

Strings on the Web: Language and Direction Metadata [<u>string-meta</u>] provides some guidance and illustrates a number of pitfalls when using bidirectional text.

In addition to the explicitly provided Interaction Affordances in the properties , actions , and events Arrays, a Thing can also provide meta-interactions, which are indicated by Form instances in its optional forms Array. When the forms Array of a Thing instance contains Form instances, the string values assigned to the name op , either directly or within an Array , MUST be one of the following $\frac{1}{1}$ operation $\frac{1}{1}$ types: readallproperties , writeallproperties , readmultipleproperties , or writemultipleproperties . (See an example for an usage of form in a Thing instance.)

The data schema for each of these meta-interactions is constructed by combining the data schemas of each PropertyAffordance instance in a single ObjectSchema instance, where the properties Map of the ObjectSchema instance contains each data schema of the PropertyAffordances identified by the name of the corresponding PropertyAffordances instance.

Typo

If not specified otherwise (e.g., through a <u>TD Context Extension</u>), the request data of the readmultipleproperties operation is an <u>Array</u> that contains the intended PropertyAffordances instance names, which is serialized to the content type specified by the Form instance.

5.3.1.2 InteractionAffordance

Metadata of a Thing that shows the possible choices to <u>Consumers</u>, thereby suggesting how <u>Consumers</u> may interact with the Thing. There are many types of potential affordances, but <u>W3C</u> WoT defines three types of Interaction Affordances: Properties, Actions, and Events.

| Vocabulary term | Description | Assignment | Туре |
|-----------------|---|------------|---------------------------|
| @type | JSON-LD keyword to label the object with semantic tags (or types). | optional | string or Array of string |
| title | Provides a human- readable title (e.g., display a text for UI representation) based on a default language. | optional | string |
| titles | Provides multi- language human- readable titles (e.g., display a text for UI representation in different languages). | optional | MultiLanguage |
| description | Provides additional (human-readable) information based on a default language. | optional | <u>string</u> |
| descriptions | Can be used to support (human-readable) information | optional | MultiLanguage |

| Vocabulary term | Description | Assignment | Туре |
|-----------------|---|------------|-------------------|
| | in different languages. | | |
| forms | Set of form hypermedia controls that describe how an operation can be performed. Forms are serializations of Protocol Bindings. | mandatory | Array of Form |
| uriVariables | Define URI template variables as collection based on DataSchema declarations. | optional | Map of DataSchema |

The class InteractionAffordance has the following subclasses:

- PropertyAffordance
- <u>ActionAffordance</u>
- EventAffordance

5.3.1.3 PropertyAffordance

An Interaction Affordance that exposes state of the Thing. This state can then be retrieved (read) and optionally updated (write). Things can also choose to make Properties observable by pushing the new state after a change.

| Vocabulary term | Description | Assignment | Туре |
|-----------------|--|------------|---------|
| observable | A hint that indicates whether Servients hosting the Thing and Intermediaries should provide a Protocol Binding that supports the | optional | boolean |
| | | | |

| Vocabulary term | Description | Assignment | Туре |
|-----------------|--|------------|------|
| | observeproperty operation for this Property. | | |

NOTE

Property instances are also instances of the class $\underline{DataSchema}$. Therefore, it can contain the type , unit , readOnly and writeOnly members, among others.

PropertyAffordance is a <u>Subclass</u> of the InteractionAffordance <u>Class</u> and the DataSchema <u>Class</u>. When a Form instance is within a PropertyAffordance instance, the value assigned to op MUST be one of readproperty, writeproperty, observe property, unobserve property or an <u>Array</u> containing a combination of these terms.

5.3.1.4 ActionAffordance

An Interaction Affordance that allows to invoke a function of the Thing, which manipulates state (e.g., toggling a lamp on or off) or triggers a process on the Thing (e.g., dim a lamp over time).

| Vocabulary term | Description | Assignment | Туре |
|-----------------|---|--------------|-------------------|
| input | Used to define the input data schema of the Action. | optional | <u>DataSchema</u> |
| output | Used to define the output data schema of the Action. | optional | <u>DataSchema</u> |
| safe | Signals if the Action is safe (=true) or not. Used to signal if there is no internal state (cf. resource state) is changed when | with default | boolean |

| Vocabulary term | Description | Assignment | Туре | |
|-----------------|---|--------------|----------------|--|
| | invoking an Action. In that case responses can be cached as example. | | | |
| idempotent | Indicates whether the Action is idempotent (=true) or not. Informs whether the Action can be called repeatedly with the same result, if present, based on the same input. | with default | <u>boolean</u> | |

ActionAffordance is a <u>Subclass</u> of the InteractionAffordance <u>Class</u>. When a Form instance is within an ActionAffordance instance, the value assigned to op MUST be invokeaction .

5.3.1.5 EventAffordance

An Interaction Affordance that describes an event source, which asynchronously pushes event data to Consumers (e.g., overheating alerts).

| Vocabulary term | Description | Assignment | Туре |
|-----------------|--|------------|-------------------|
| subscription | Defines data that needs to be passed upon subscription, e.g., filters or message format for setting up Webhooks. | optional | <u>DataSchema</u> |
| data | Defines the data schema of the Event | optional | <u>DataSchema</u> |

| Vocabulary term | Description | Assignment | Туре |
|-----------------|---|------------|-------------------|
| | instance messages pushed by the Thing. | | |
| cancellation | Defines any data that needs to be passed to cancel a subscription, e.g., a specific message to remove a Webhook. | optional | <u>DataSchema</u> |

EventAffordance is a <u>Subclass</u> of the InteractionAffordance <u>Class</u>. When a Form instance is within an EventAffordance instance, the value assigned to op MUST be either subscribeevent, unsubscribeevent, or both terms within an Array.

5.3.1.6 VersionInfo

Metadata of a Thing that provides version information about the TD document. If required, additional version information such as firmware and hardware version (term definitions outside of the TD namespace) can be extended via the TD Context Extension mechanism.

| Vocabulary term | Description | Assignment | Туре |
|-----------------|---|------------|---------------|
| instance | Provides a version indicator of this TD instance. | mandatory | <u>string</u> |

It is recommended that the values within instances of the VersionInfo <u>Class</u> follow the semantic versioning pattern, where a sequence of three numbers separated by a dot indicates the major version, minor version, and patch version, respectively. See [<u>SEMVER</u>] for details.

5.3.1.7 MultiLanguage

A <u>Map</u> providing a set of human-readable texts in different languages identified by language tags described in [*BCP47*]. See § 6.3.2 Human-Readable Metadata for example usages of this container in

a Thing Description instance.

Each name of the MultiLanguage Map MUST be a language tag as defined in [BCP47]. Each value of the MultiLanguage Map MUST be of type string.

5.3.2 Data Schema Vocabulary Definitions

English The data schema <u>↑vocabulary</u> <u>↑</u> definition is reflecting a very common subset of the terms defined by JSON Schema [JSON-SCHEMA]. It is noted that data schema definitions within Thing Description instances are not limited to this defined subset and may use additional terms found in JSON Schema using a TD Context Extension for the additional terms as described in § 7. TD Context Extensions, otherwise these terms are semantically ignored by TD Processors (for details about semantic processing, please refer to ↑§ ↑↑ D. ↑↑ JSON-LD Context Usage ↑↑ and ↑ the documentation under the namespace IRIs, e.g., https://www.w3.org/2019/wot/td). Added a Cross Reference



†A data schema is an abstract notation for data contained in data formats. In a TD, concrete data formats are specified in Forms (see $\uparrow \uparrow \S \uparrow \uparrow 5.3.4.2 \uparrow \uparrow Form \uparrow \uparrow$) using content types. When the value of a content type in an instance of the Form is \\ \emptyset \ application/json \\ \emptyset,\emptyset the data schema can be processed directly by JSON Schema processors. Otherwise, Web of Things (WoT) Binding Templates [↑↑ WOT-BINDING-TEMPLATES ↑↑] defines data schema's available mappings to other content types such as XML [$\uparrow \uparrow xml \uparrow \uparrow$]. If the content type in an instance of the Form is not $\uparrow \uparrow$ application/json ↑↑ and if no mapping is defined for the content type, specifying a data schema does not make sense for the content type. ↑

5.3.2.1 DataSchema

Metadata that describes the data format used. It can be used for validation.

| Vocabulary term | Description | Assignment | Туре |
|-----------------|--|------------|---------------------------|
| @type | JSON-LD keyword to label the object with semantic tags (or types) | optional | string or Array of string |
| title | Provides a human-readable title (e.g., | optional | string |

| Vocabulary term | Description | Assignment | Туре |
|-----------------|---|------------|--|
| | display a text for UI representation) based on a default language. | | |
| titles | Provides multi- language human- readable titles (e.g., display a text for UI representation in different languages). | optional | <u>MultiLanguage</u> |
| description | Provides additional (human-readable) information based on a default language. | optional | string |
| descriptions | Can be used to support (human-readable) information in different languages. | optional | <u>MultiLanguage</u> |
| type | Assignment of JSON-based data types compatible with JSON Schema (one of boolean, integer, number, string, object, array, or null). | optional | <pre>string (one of object , array , string , number , integer , boolean , or null)</pre> |
| const | Provides a constant value. | optional | any type |
| unit | Provides unit information that is used, e.g., in international science, engineering, and | optional | <u>string</u> |

| Vocabulary term | Description | Assignment | Туре |
|-----------------|---|--------------|-----------------------------------|
| | business. | | |
| oneOf | Used to ensure that the data is valid against one of the specified schemas in the array. | optional | <u>Array</u> of <u>DataSchema</u> |
| enum | Restricted set of values provided as an array. | optional | Array of any type |
| readOnly | Boolean value that is a hint to indicate whether a property interaction / value is read only (=true) or not (=false). | with default | boolean |
| writeOnly | Boolean value that is a hint to indicate whether a property interaction / value is write only (=true) or not (=false). | with default | boolean |
| format | Allows validation based on a format pattern such as "date- time", "email", "uri", etc. (Also see below.) | optional | <u>string</u> |

The class DataSchema has the following subclasses:

- <u>ArraySchema</u>
- BooleanSchema
- NumberSchema

- IntegerSchema
- ObjectSchema
- StringSchema
- NullSchema

The format string values are known from a fixed set of values and their corresponding format rules defined in [<u>JSON-SCHEMA</u>] (Section 7.3 Defined Formats in particular). Servients <u>MAY</u> use the format value to perform additional validation accordingly. When a value that is not found in the known set of values is assigned to format, such a validation <u>SHOULD</u> succeed.

5.3.2.2 ArraySchema

Metadata describing data of type <u>Array</u>. This <u>Subclass</u> is indicated by the value array assigned to type in DataSchema instances.

| Vocabulary term | Description | Assignment | Туре |
|-----------------|---|------------|--|
| items | Used to define the characteristics of an array. | optional | <u>DataSchema</u> or <u>Array</u> of <u>DataSchema</u> |
| minItems | Defines the minimum number of items that have to be in the array. | optional | unsignedInt |
| maxItems | Defines the maximum number of items that have to be in the array. | optional | unsignedInt |

5.3.2.3 BooleanSchema

Metadata describing data of type boolean \cdot . This <u>Subclass</u> is indicated by the value boolean assigned to type in DataSchema instances.

5.3.2.4 NumberSchema

 $\label{eq:metadata} \mbox{Metadata describing data of type number } \mbox{. This } \mbox{\underline{Subclass}} \mbox{ is indicated by the value number } \mbox{assigned to type } \mbox{in DataSchema } \mbox{instances}.$

| Vocabulary term | Description | Assignment | Туре |
|-----------------|--|------------|---------------|
| minimum | Specifies a minimum numeric value. Only applicable for associated number or integer types. | optional | <u>double</u> |
| maximum | Specifies a maximum numeric value. Only applicable for associated number or integer types. | optional | <u>double</u> |

5.3.2.5 IntegerSchema

Metadata describing data of type integer $\,$. This <u>Subclass</u> is indicated by the value integer $\,$ assigned to type in DataSchema instances.

| Vocabulary term | Description | Assignment | Туре |
|-----------------|--|------------|---------|
| minimum | Specifies a minimum numeric value. Only applicable for associated number or integer types. | optional | integer |
| maximum | Specifies a maximum numeric value. Only applicable for associated number or integer types. | optional | integer |

5.3.2.6 ObjectSchema

Metadata describing data of type object . This <u>Subclass</u> is indicated by the value object assigned to type in DataSchema instances.

| Vocabulary term | Description | Assignment | Туре |
|-----------------|---|------------|-------------------------------|
| properties | Data schema nested definitions. | optional | Map of DataSchema |
| required | Defines which members of the object type are mandatory. | optional | <u>Array</u> of <u>string</u> |

5.3.2.7 StringSchema

Metadata describing data of type string . This <u>Subclass</u> is indicated by the value string assigned to type in DataSchema instances.

5.3.2.8 NullSchema

Metadata describing data of type null . This <u>Subclass</u> is indicated by the value null assigned to type in DataSchema instances. This Subclass describes only one acceptable value, namely null . It can be used as part of a oneOf declaration, where it is used to indicate, that the data can also be null .

5.3.3 Security Vocabulary Definitions

This specification provides a selection of well-established security mechanisms that are directly built into protocols eligible as Protocol Bindings for W3C WoT or are widely in use with those protocols. The current set of HTTP security schemes is partly based on OpenAPI 3.0.1 (see also [OPENAPI)). However while the HTTP security schemes, Vocabulary, and syntax given in this specification share many similarities with OpenAPI, they are not compatible.

5.3.3.1 SecurityScheme

Metadata describing the configuration of a security mechanism. The value assigned to the name scheme *MUST* be defined within a <u>Vocabulary included</u> in the <u>Thing Description</u>, either in the standard <u>Vocabulary defined</u> in § 5. TD Information Model or in a <u>TD Context Extension</u>.

| Vocabulary term | Description | Assignment | Туре |
|-----------------|---|------------|--|
| @type | JSON-LD keyword to label the object with semantic tags (or types). | optional | string or Array of string |
| scheme | Identification of the security mechanism being configured. | mandatory | <pre>string (e.g., nosec , basic , ↓cert , ↓ digest , bearer , ↓pop , ↓ psk , ↓public , ↓ oauth2 , or apikey)</pre> |
| description | Provides additional (human-readable) information based on a default language. | optional | <u>string</u> |
| descriptions | Can be used to support (human-readable) information in different languages. | optional | MultiLanguage |
| proxy | URI of the proxy server this security configuration provides access to. If not given, the corresponding security configuration is for the endpoint. | optional | <u>anyURI</u> |

The class $SecurityScheme\ has\ the\ following\ subclasses:$

- NoSecurityScheme
- BasicSecurityScheme
- <u>DigestSecurityScheme</u>
- APIKeySecurityScheme
- BearerSecurityScheme
- |CertSecurityScheme | PSKSecurityScheme
- \propto \propto PublicSecurityScheme \propto OAuth2SecurityScheme \propto OAuth2SecurityScheme

5.3.3.2 NoSecurityScheme

A security configuration corresponding to identified by the <u>Vocabulary Term</u> nosec (i.e., "scheme": "nosec"), indicating there is no authentication or other mechanism required to access the resource.

5.3.3.3 BasicSecurityScheme

Basic Authentication [<u>RFC7617</u>] security configuration identified by the <u>Vocabulary Term</u> basic (i.e., "scheme": "basic"), using an unencrypted username and password. This scheme should be used with some other security mechanism providing confidentiality, for example, TLS.

| Vocabulary term | Description | Assignment | Туре |
|-----------------|--|--------------|---|
| in | Specifies the location of security authentication information. | with default | <pre>string (one of header , query , body , or cookie)</pre> |
| name | Name for query, header, or cookie parameters. | optional | string |

5.3.3.4 DigestSecurityScheme

Digest Access Authentication [<u>RFC7616</u>] security configuration identified by the <u>Vocabulary Term</u> digest (i.e., "scheme": "digest"). This scheme is similar to basic authentication but with added features to avoid man-in-the-middle attacks.

| Vocabulary term | Description | Assignment | Туре |
|-----------------|--|--------------|---|
| qop | Quality of protection. | with default | <pre>string (one of auth , or auth-int)</pre> |
| in | Specifies the location of security authentication information. | with default | <pre>string (one of header , query , body , or cookie)</pre> |
| name | Name for query, header, or cookie parameters. | optional | <u>string</u> |

5.3.3.5 APIKeySecurityScheme

API key authentication security configuration identified by the <u>Vocabulary Term</u> apikey (i.e., "scheme": "apikey"). This is for the case where the access token is opaque and is not using a standard token format.

| Vocabulary term | Description | Assignment | Туре |
|-----------------|--|--------------|---|
| in | Specifies the location of security authentication information. | with default | <pre>string (one of header , query , body , or cookie)</pre> |
| name | Name for query, header, or cookie parameters. | optional | string |

5.3.3.6 BearerSecurityScheme

Bearer Token [<u>RFC6750</u>] security configuration identified by the <u>Vocabulary Term</u> bearer (i.e., "scheme": "bearer") for situations where bearer tokens are used independently of OAuth2. If the oauth2 scheme is specified it is not generally necessary to specify this scheme as well as it is implied. For format, the value jwt indicates conformance with [<u>RFC7519</u>], jws indicates conformance with

[<u>RFC7797</u>], cwt indicates conformance with [<u>RFC8392</u>], and jwe indicates conformance with [<u>RFC7516</u>], with values for alg interpreted consistently with those standards. Other formats and algorithms for bearer tokens MAY be specified in vocabulary $\frac{1}{2}$ extensions $\frac{1}{2}$.

whitespaces

| Vocabulary term | Description | Assignment | Туре |
|-----------------|--|--------------|---|
| authorization | URI of the authorization server. | optional | <u>anyURI</u> |
| alg | Encoding, encryption, or digest algorithm. | with default | string (e.g., MD5 , ES256 , or ES512-256) |
| format | Specifies format of security authentication information. | with default | <pre>string (e.g., jwt , cwt , jwe , or jws)</pre> |
| in | Specifies the location of security authentication information. | with default | <pre>string (one of header , query , body , or cookie)</pre> |
| name | Name for query, header, or cookie parameters. | optional | <u>string</u> |

\$\\$\\$5.3.3.7 CertSecurityScheme This section is at risk. Certificate-based asymmetric key security configuration conformant with [X509V3] identified by the Vocabulary Term cert (i.e., "scheme": "cert"). Vocabulary term Description Assignment Type identity Identifier providing information which can be used for selection or confirmation. optional string \$\\$\$

$\downarrow 5.3.3.8 \downarrow \uparrow 5.3.3.7 \uparrow$ PSKSecurityScheme

Pre-shared key authentication security configuration identified by the <u>Vocabulary Term</u> psk (i.e., "scheme": "psk").

| Vocabulary term | Description | Assignment | Туре | |
|-----------------|-------------|------------|------|--|
|-----------------|-------------|------------|------|--|

| <u>Vocabulary term</u> | Description | Assignment | Туре |
|------------------------|---|------------|---------------|
| identity | Identifier providing information which can be used for selection or confirmation. | optional | <u>string</u> |

$\downarrow 5.3.3.11 \downarrow \uparrow 5.3.3.8 \uparrow OAuth2SecurityScheme$

OAuth2 authentication security configuration for systems conformant with [<u>RFC6749</u>] and [<u>RFC8252</u>], identified by the <u>Vocabulary Term</u> oauth2 (i.e., "scheme": "oauth2"). *** For the implicit flow authorization MUST be included. For the password and client flows token MUST be included. *** For the code flow both authorization and token <u>MUST</u> be included. If no scopes are defined in the SecurityScheme then they are considered to be empty.

| Vocabulary term | Description | Assignment | Туре |
|-----------------|----------------------------------|------------|--------|
| authorization | URI of the authorization server. | optional | anyURI |
| token | URI of the token server. | optional | anyURI |
| refresh | URI of the refresh server. | optional | anyURI |

| Vocabulary term | Description | Assignment | Туре |
|-----------------|--|------------|---------------------------|
| scopes | Set of authorization scope identifiers provided as an array. These are provided in tokens returned by an authorization server and associated with forms in order to identify what resources a client may access and how. The values associated with a form should be chosen from those defined in an OAuth2SecurityScheme active on that form. | optional | string or Array of string |
| flow | Authorization flow. | mandatory | <pre>string</pre> |

5.3.4 Hypermedia Controls Vocabulary Definitions

The present model provides a representation for (typed) Web links and Web forms exposed by a <u>Thing</u>. The Link class definition is reflecting a very common subset of the terms defined in Web Linking [
<u>RFC8288</u>]. The defined terms can be used, e.g., to describe the relation to another <u>Thing</u> such as a <u>Lamp Thing</u> is controlled by a <u>Switch Thing</u>. The Form class corresponds to a newly introduced form of hypermedia control to manipulate the state of <u>Things</u> (and other Web resources).

5.3.4.1 Link

A link can be viewed as a statement of the form " *link context* has a *relation type* resource at *link target* ", where the optional *target attributes* may further describe the resource.

| <u>Vocabulary term</u> | Description | Assignment | Туре |
|------------------------|--|------------|---------------|
| href | Target IRI of a link or submission target of a form. | mandatory | <u>anyURI</u> |
| type | Target attribute providing a hint indicating what the media type [<u>RFC2046</u>] of the result of dereferencing the link should be. | optional | string |
| rel | A link relation type identifies the semantics of a link. | optional | string |
| anchor | Overrides the link context (by default the Thing itself identified by its id) with the given URI or IRI. | optional | <u>anyURI</u> |

5.3.4.2 Form

A form can be viewed as a statement of "To perform an *operation type* operation on *form context*, make a *request method* request to *submission target* " where the optional *form fields* may further describe the required request. In Thing Descriptions, the *form context* is the surrounding Object, such as Properties, Actions, and Events or the Thing itself for meta-interactions.

| <u>Vocabulary</u> <u>term</u> | Description | Assignment | Туре |
|----------------------------------|---|--------------|---|
| ор | Indicates the semantic intention of performing the operation(s) described | with default | <pre>string or Array of string (one of readproperty , writeproperty ,</pre> |

| Vocabulary term | Description | Assignment | Туре |
|--------------------|--|--------------|---|
| | by the form. For example, the Property interaction allows get and set operations. The protocol binding may contain a form for the get operation and a different form for the set operation. The op attribute indicates which form is for which and allows the client to select the correct form for the operation required. op can be assigned one or more interaction verb(s) each representing a semantic intention of an operation. | | observeproperty , unobserveproperty , invokeaction , subscribeevent , unsubscribeevent , readallproperties , writeallproperties , readmultipleproperties , or writemultipleproperties) |
| href | Target IRI of a link or submission target of a form. | mandatory | anyURI |
| contentType | Assign a content type based on a media type (e.g., text/plain) and potential parameters (e.g., charset=utf-8) for the media type [<u>RFC2046</u>]. | with default | <u>string</u> |
| contentCoding | Content coding values indicate an encoding transformation that has been or can be applied to | optional | string |

| Description | Assignment | Туре |
|--|---|---|
| a representation. Content codings are primarily used to allow a representation to be compressed or otherwise usefully transformed without losing the identity of its underlying media type and without loss of information. Examples of content coding include "gzip", "deflate", etc. | | |
| Indicates the exact mechanism by which an interaction will be accomplished for a given protocol when there are multiple options. | optional | <pre>string (e.g., longpoll , websub , or sse)</pre> |
| For example, for HTTP and Events, it indicates which of several available mechanisms should be used for asynchronous notifications such as long polling (longpoll), WebSub [websub] (websub] (websub], Server-Sent Events \(\frac{1}{2} \sec \frac{1}{2} \cdot \frac{1}{2} \sec \frac{1}{2} \s | | eference was changed specification. |
| | a representation. Content codings are primarily used to allow a representation to be compressed or otherwise usefully transformed without losing the identity of its underlying media type and without loss of information. Examples of content coding include "gzip", "deflate", etc Indicates the exact mechanism by which an interaction will be accomplished for a given protocol when there are multiple options. For example, for HTTP and Events, it indicates which of several available mechanisms should be used for asynchronous notifications such as long polling (longpoll), WebSub [websub] (websub] (websub), Server-Sent Events \(\(\frac{1}{2} \) sse \(\frac{1}{2} \) \(\ | a representation. Content codings are primarily used to allow a representation to be compressed or otherwise usefully transformed without losing the identity of its underlying media type and without loss of information. Examples of content coding include "gzip", "deflate", etc. Indicates the exact optional mechanism by which an interaction will be accomplished for a given protocol when there are multiple options. For example, for HTTP and Events, it indicates which of several available mechanisms should be used for asynchronous notifications such as long polling (longpoll), WebSub [websub] (websub), Server-Sent Events 1(1 see 1) [SSE's Reteventsource 1 thind 1] (sse). 1 (also known as EventSource). Please |

| <u>Vocabulary</u> <u>term</u> | Description | Assignment | Туре |
|----------------------------------|--|------------|---------------------------|
| | subprotocol selection and other mechanisms can also be announced by this subprotocol term. | | |
| security | Set of security definition names, chosen from those defined in securityDefinitions. These must all be satisfied for access to resources. | optional | string or Array of string |
| scopes | Set of authorization scope identifiers provided as an array. These are provided in tokens returned by an authorization server and associated with forms in order to identify what resources a client may access and how. The values associated with a form should be chosen from those defined in an OAuth2SecurityScheme active on that form. | optional | string or Array of string |
| response | This optional term can be used if, e.g., the output communication metadata differ from input metadata (e.g., output contentType differ from the input contentType). | optional | ExpectedResponse |

| Vocabulary term | Description | Assignment | Туре |
|--------------------|---|------------|------|
| | The response name contains metadata that is only valid for the response messages. | | |

Possible values for the contentCoding property can be found, e.g., in the $\underline{IANA\ HTTP\ content}$ coding registry .

The list of possible operation types of a form is fixed. As of this version of the specification, it only includes the well-known types necessary to implement the WoT interaction model described in [<u>WOT-ARCHITECTURE</u>]. Future versions of the standard may extend this list but operations types <u>SHOULD</u> NOT be arbitrarily set by servients.

The optional response name-value pair can be used to provide metadata for the expected response message. With the core vocabulary, it only includes content type information, but TD Context Extensions could be applied. If no response name-value pair is provided, it *MUST* be assumed that the content type of the response is equal to the content type assigned to the Form instance. Note that contentType within an ExpectedResponse <u>Class</u> does not have a <u>Default Value</u>. For instance, if the value of the content type of the form is application/xml the assumed value of the content type of the response will be also application/xml.

In some use cases, input and output data might be represented in a different form, for instance an Action that accepts JSON, but returns an image. In such a case, the optional response name-value pair can describe the content type of the expected response. If the content type of the expected response differs from the content type of the form, the Form instance *MUST* include a name-value pair with the name response. For instance, an ActionAffordance could only accept application/json for its input data, while it will respond with an image/jpeg content type for its output data. In that case the content types differ and the response name-value pair has to be used to provide response content type (image/jpeg) information to the Consumer.

5.3.4.3 ExpectedResponse

Communication metadata describing the expected response message.

| Vocabulary term | Description | Assignment | Туре |
|-----------------|--|------------|---------------|
| contentType | Assign a content type based on a media type | mandatory | <u>string</u> |
| | (e.g., text/plain) and potential parameters (e.g., charset=utf-8) for the media type [<u>RFC2046</u>]. | | |

5.4 Default Value Definitions

When assignments in a TD are missing, a <u>TD Processor MUST</u> follow the <u>Default Value</u> assignments expressed in the table of § 5.4 Default Value Definitions.

The following table gives all <u>Default Values</u> defined in the <u>TD Information Model</u>.



↓PoPSecurityScheme This feature is at risk. in header ↓↓PoPSecurityScheme This feature is at risk. alg ES256 ↓↓PoPSecurityScheme This feature is at risk. format jwt ↓

| <u>Class</u> | <u>Vocabulary</u> <u>Term</u> | <u>Default Value</u> | Comment |
|------------------|----------------------------------|--|---|
| Form | contentType | application/json | |
| DataSchema | readOnly | false | |
| DataSchema | writeOnly | false | |
| ActionAffordance | safe | false | |
| ActionAffordance | idempotent | false | |
| Form | ор | Array of string with the elements readproperty and writeproperty | If defined within an instance of PropertyAffordance |
| Form | ор | invokeaction | If defined within an instance of |

| Class | <u>Vocabulary</u> <u>Term</u> | <u>Default Value</u> | Comment |
|----------------------|----------------------------------|----------------------|--|
| | | | ActionAffordance |
| Form | ор | subscribeevent | If defined within an instance of EventAffordance |
| BasicSecurityScheme | in | header | |
| DigestSecurityScheme | in | header | |
| BearerSecurityScheme | in | header | |
| APIKeySecurityScheme | in | query | |
| DigestSecurityScheme | qop | auth | |
| BearerSecurityScheme | alg | ES256 | |
| BearerSecurityScheme | format | jwt | |

6. TD Representation Format

WoT Thing Descriptions represent Things and are modeled and structured based on § 5. TD Information Model. This section defines a JSON-based representation format for Things, a serialization of instances of the Class Thing defined by the TD Information Model.

A <u>TD Processor MUST</u> be able to serialize <u>Thing Descriptions</u> into the JSON format [<u>RFC8259</u>] and/or descriptions from that format, according to the rules noted in § 6.1 <u>Mapping</u> to JSON Types and § 6.3 Information Model Serialization.

The JSON serialization of the <u>TD Information Model</u> is aligned with the syntax of JSON-LD 1.1 [*json-ld11*] in order to streamline semantic evaluation. Hence, the TD representation format can be processed either as raw JSON or with a JSON-LD 1.1 processor (for details about semantic processing, please refer to \(\frac{1}{2}\) \(\

In order to support interoperable internationalization, TDs MUST be serialized according to the

requirements defined in Section 8.1 of RFC8259 [<u>RFC8259</u>] for open ecosystems. In summary, this requires the following:

- TDs MUST be encoded using UTF-8 [RFC3629].
- Implementations *MUST NOT* add a byte order mark (U+FEFF) to the beginning of a TD document.
- TD Processors MAY ignore the presence of a byte order mark rather than treating it as an error.

6.1 Mapping to JSON Types

The <u>TD Information Model</u> is constructed, so that there is an easy mapping between model <u>Objects</u> and JSON types. Every <u>Class</u> instances maps to a JSON object, where each name-value pair of the <u>Class</u> instance is a member of the JSON object.

Every <u>Simple Type</u> mentioned in § 5.3 Class <u>Definitions</u> (i.e., string, anyURI, dateTime, integer, unsignedInt, double, and boolean) maps to a primitive JSON type (string, number, boolean), as per the rules listed below. These rules apply to values in name-value pairs:

- Values that are of type string or any URI *MUST* be serialized as JSON strings.
- Values that are of type dateTime *MUST* be serialized as JSON strings following the "date-time" format specified by [<u>RFC3339</u>]. Examples would include 2019-05-24T13:12:45Z and 2015-07-11T09:32:26+08:00. Values that are of type dateTime <u>SHOULD</u> use the literal Z representing the UTC time zone instead of an offset.
- Values that are of type integer or unsignedInt *MUST* be serialized as JSON numbers without a fraction or exponent part.
- Values that are of type double MUST be serialized as JSON number.
- Values that are of type boolean MUST be serialized as JSON boolean.

Every complex type of the <u>TD Information Model</u> (i.e., <u>Arrays</u>, <u>Maps</u>, and <u>Class</u> instances) maps to a structured JSON type (array and object), as per the rules listed below:

- A value of type <u>Array MUST</u> be serialized as JSON array, with each value of the name-value pairs as element of the JSON array ordered by the numeric name of the pair.
- A value of type <u>Map MUST</u> be serialized as JSON object, with each name-value pair as member of the JSON object.
- A <u>Class</u> instance *MUST* be serialized as JSON object, following the detailed rules given individually in § 6.3 Information Model Serialization.

6.2 Omitting Default Values

A Thing Description serialization may omit <u>Vocabulary Term</u> for which <u>Default Values</u> are defined, as listed in the table given in § 5.4 Default Value Definitions.

The following example shows the TD instance from <u>Example 1</u> with a checkbox to also include the members with <u>Default Values</u> (=checkbox checked). These members can be omitted (=checkbox unchecked) to simplify the TD serialization. Note that a <u>TD Processor</u> interprets these omitted members identically as if they were explicitly present with a given <u>Default Value</u>.

EXAMPLE 3

```
\square with Default Values
{
    "@context": "https://www.w3.org/2019/wot/td/v1",
    "id": "urn:dev:ops:32473-WoTLamp-1234",
    "title": "MyLampThing",
    "securityDefinitions": {
        "basic_sc": {
            "scheme": "basic"
        }
    },
    "security": [
        "basic_sc"
    ],
    "properties": {
        "status": {
            "type": "string",
            "forms": [{
                 "href": "https://mylamp.example.com/status"
            }]
        }
    },
    "actions": {
        "toggle": {
            "forms": [{
                 "href": "https://mylamp.example.com/toggle"
            }]
        }
    },
    "events": {
        "overheating": {
            "data": {
                 "type": "string"
            },
            "forms": [{
                 "href": "https://mylamp.example.com/oh",
                 "subprotocol": "longpoll"
            }]
        }
    }
}
```

```
{
    "@context": "https://www.w3.org/2019/wot/td/v1",
    "id": "urn:dev:ops:32473-WoTLamp-1234",
    "title": "MyLampThing",
    "securityDefinitions": {
        "basic_sc": {
            "scheme": "basic",
            "in": "header"
        }
    },
    "security": [
        "basic_sc"
    ],
    "properties": {
        "status": {
            "type": "string",
            "readOnly" : false,
            "writeOnly" : false,
            "forms": [{
                "op": [
                     "readproperty",
                     "writeproperty"
                 "href": "https://mylamp.example.com/status",
                 "contentType": "application/json"
            }]
        }
    },
    "actions": {
        "toggle": {
            "safe": false,
            "idempotent": false,
            "forms": [{
                 "op": "invokeaction",
                "href": "https://mylamp.example.com/toggle",
                 "contentType": "application/json"
            }]
        }
    },
    "events": {
        "overheating": {
            "data": {
                 "type": "string",
```

Please note that, depending on the <u>Protocol Binding</u> used, additional protocol-specific <u>Vocabulary</u> <u>Terms</u> may apply. They may also have associated <u>Default Values</u>, and hence can also be omitted as explained in this subsection. Further information can be found in § 8.3 Protocol Bindings.

6.3 Information Model Serialization

6.3.1 Thing Root Object

A Thing Description is a data structure rooted at an <u>Object</u> of type <u>Thing</u>. In turn, a JSON serialization of the Thing Description is a JSON object, which is the root of a syntax tree constructed from the TD Information Model.

The root element of a <u>TD Serialization MUST</u> be a JSON object that includes a member with the name @context and a value of type string or array that equals or respectively contains https://www.w3.org/2019/wot/td/v1.

In general, this URI is used to identify the TD representation format version defined by this specification. For JSON-LD processing [<u>json-ld11</u>], this URI specifies the Thing Description context file. An @context of type array indicates <u>TD Context Extensions</u> (see § 7. <u>TD Context Extensions</u> for details).

```
EXAMPLE 4
{
    "@context": "https://www.w3.org/2019/wot/td/v1",
    ...
}
```

All name-value pairs of an instance of Thing , where the name is a $\underline{\text{Vocabulary Term}}$ in the $\underline{\text{Signature}}$ of Thing , \underline{MUST} be serialized as JSON members of the root object.

A TD snippet for a serialized root object including all mandatory and optional members is given below:

```
EXAMPLE 5: SAMPLE OF THING SERIALIZATIONS
{
    "@context": "https://www.w3.org/2019/wot/td/v1",
    "@type": "Thing",
    "id": "urn:dev:ops:32473-Thing-1234",
    "title": "MyThing",
    "titles": {...},
    "description": "Human readable information.",
    "descriptions": {...},
    "support": "mailto:support@example.com",
    "version" : \{\ldots\},
    "created": "2018-11-14T19:10:23.824Z",
    "modified": "2019-06-01T09:12:43.124Z",
    "securityDefinitions": {...},
    "security": ...,
    "base": "https://servient.example.com/",
    "properties": {...},
    "actions": {...},
    "events": {...},
    "links": [...],
    "forms": [...]
}
```

All values assigned to version , securityDefinitions , properties , actions , and events in an instance of the Class Thing MUST be serialized as JSON objects.

All values assigned to links, and forms in an instance of the <u>Class</u> Thing MUST be serialized as JSON arrays containing JSON objects as defined in § 6.3.8 links and § 6.3.9 forms, respectively.

The value assigned to security in an instance of <u>Class</u> Thing *MUST* be serialized as JSON string or as JSON array whose elements are JSON strings.

6.3.2 Human-Readable Metadata

JSON members named title and description are used within a TD document to provide human-readable metadata. They can be used as comments for developers inspecting a TD document or as display texts for user interface.

As defined in § 5.3.1.1 Thing, the base text direction used to display human-readable metadata can either be estimated using heuristics such as the first-strong rule or inferred from language information. In TD documents the default language is defined by a value assigned to @language in the @context, and this, along with a script subtag if necessary, can be used to determine a base text direction. However, when interpreting human-readable text, each human-readable string value *MUST* be processed independently. In other words, a <u>TD Processor</u> cannot carry forward changes in direction from one string to another, or infer direction for one string from another one elsewhere in the TD.

NOTE

Strings on the Web [<u>STRING-META</u>] suggests both strong-first and language-based inferencing as means to determine the base text direction. Given that the Thing Description format is based on JSON-LD 1.1 [<u>json-ld11</u>], which currently lacks explicit direction metadata, these approaches are currently considered appropriate at the time of this publication. However, if JSON-LD 1.1 adopts support for explicit base direction metadata as recommended by [<u>STRING-META</u>], the Thing Description format should be updated to take advantage of that feature.

A TD snippet using title and description is shown below. The default language is set to en through the definition of the @language member within a JSON object in the @context array.

```
EXAMPLE 6
{
    "@context": [
        "https://www.w3.org/2019/wot/td/v1",
        { "@language" : "en" }
    ],
    "title": "MyThing",
    "description": "Human readable information.",
    "properties": {
        "on": {
            "title" : "On/Off",
            "type": "boolean",
            "forms": [...]
        },
        "status": {
            "title" : "Status",
            "type": "object",
            "forms": [...]
        }
    },
}
```

The JSON members named titles and descriptions are used within the TD document to provide human-readable metadata in multiple languages within a single TD document. All name-value pairs of a MultiLanguage Map MUST be serialized as members of a JSON object, where the name is a well-formed language tag as defined by [BCP47] and the value is a human-readable string in the language indicated by the tag. See § 5.3.1.7 MultiLanguage for details. All MultiLanguage object within a TD document SHOULD contain the same set of language members.

A TD snippet using titles and descriptions at different levels is given below:

EXAMPLE 7

```
{
    "@context": "https://www.w3.org/2019/wot/td/v1",
    "title": "MyThing",
    "titles": {
        "en":"MyThing",
       "de": "MeinDing",
        "ja": "私の物",
        "zh-Hans": "我的东西",
       "zh-Hant" : "我的東西"
    },
    "descriptions": {
        "en": "Human readable information.",
        "de": "Menschenlesbare Informationen.",
       "ja": "人間が読むことができる情報",
       "zh-Hans": "人们可阅读的信息",
        "zh-Hant": "人們可閱讀的資訊"
    },
    "properties": {
        "on": {
           "titles": {
               "en": "On/Off",
               "de": "An/Aus",
               "ja": "オンオフ",
               "zh-Hans": "开关",
               "zh-Hant": "開關" },
           "type": "boolean",
           "forms": [...]
       },
        "status": {
           "titles": {
               "en": "Status",
               "de": "Zustand",
               "ja": "状態",
               "zh-Hans": "状态",
               "zh-Hant": "狀態" },
           "type": "object",
           "forms": [...]
       }
    },
```

} ...

TD instances may also combine the use of title and description with titles and descriptions . When title and titles or description and descriptions are present within the same JSON object, the values of title and description MAY be seen as the default text. When title and titles or description and descriptions are present in a TD document, each title and description member SHOULD have a corresponding titles and descriptions member, respectively. The language of the default text is indicated by the default language, which is usually set by the creator of the Thing Description instance.

EXAMPLE 8

```
{
    "@context": [
        "https://www.w3.org/2019/wot/td/v1",
       { "@language" : "de" }
    ],
    "title": "MyThing",
    "titles": {
        "en": "MyThing",
        "de": "MeinDing",
       "ja": "私の物",
        "zh-Hans": "我的东西",
       "zh-Hant" : "我的東西"
    },
    "description": "Menschenlesbare Informationen.",
    "descriptions": {
        "en": "Human readable information.",
        "de": "Menschenlesbare Informationen.",
       "ja": "人間が読むことができる情報",
        "zh-Hans": "人们可阅读的信息",
        "zh-Hant" : "人們可閱讀的資訊"
    },
    "properties": {
        "on": {
           "title" : "An/Aus",
           "titles": {
               "en": "On/Off",
               "de": "An/Aus",
               "ia": "オンオフ",
               "zh-Hans": "开关",
               "zh-Hant": "開關" },
           "type": "boolean",
           "forms": [...]
       },
        "status": {
           "title" : "Zustand",
            "titles": {
               "en": "Status",
               "de": "Zustand",
               "ja": "状態",
               "zh-Hans": "状态",
```

```
"zh-Hant": "狀態" },
"type": "object",
...
"forms": [...]
}
},
...
```

Another possibility to set the default language is through a language negotiation mechanism, such as the Accept-Language header field of HTTP. In cases where the default language has been negotiated, an @language member MUST be present to indicate the result of the negotiation and the corresponding default language of the returned content. When the default language has been negotiated successfully, TD documents SHOULD include the appropriate matching values for the members title and description in preference to MultiLanguage objects in titles and descriptions members. Note however that Things MAY choose to not support such dynamically-generated TDs nor to support language negotiation (e.g., because of resource constraints).

6.3.3 version

All name-value pairs of an instance of VersionInfo , where the name is a <u>Vocabulary Term</u> included in the <u>Signature</u> of VersionInfo , *MUST* be serialized as JSON members with the <u>Vocabulary Term</u> as name.

A TD snippet of a version information object is given below:

```
EXAMPLE 9
{
    ...
    "version": { "instance": "1.2.1" },
    ...
}
```

The version member is intended as container for additional application- and/or device-specific version information based on TD Context Extensions . See § 7.1 Semantic Annotations for details.

6.3.4 securityDefinitions and security

In a Thing instance, the value assigned to securityDefinitions is a $\underline{\text{Map}}$ of instances of SecurityScheme . All name-value pairs of a $\underline{\text{Map}}$ of SecurityScheme instances MUST be serialized as members of the JSON object that results from serializing the $\underline{\text{Map}}$; the name of a pair MUST be serialized as a JSON string and the value of the pair, an instance of SecurityScheme , MUST be serialized as a JSON object.

All name-value pairs of an instance of one of the <u>Subclasses</u> of SecurityScheme , where the name is a <u>Vocabulary Term</u> included in the <u>Signature</u> of that <u>Subclass</u> or in the <u>Signature</u> of SecurityScheme , *MUST* be serialized as members of the JSON object that results from serializing the SecurityScheme Subclass 's instance, with the Vocabulary Term as name.

The following TD snippet shows a simple security configuration specifying basic username/password authentication in the header. The value given for in is actually the <u>Default Value</u> (header) and could be omitted. A named security configuration must be given in the securityDefinitions map. That definition must be activated by including its JSON name in the security member, which can be of type string when only one definition is activated.

```
EXAMPLE 10

...
"securityDefinitions": {
    "basic_sc": {
        "scheme": "basic",
        "in": "header"
    }
},
"security": "basic_sc",
...
```

Here is a more complex example: a TD snippet showing digest authentication on a proxy combined with bearer token authentication on the <u>Thing</u>. In the digest scheme, the <u>Default Value</u> of in (i.e., header) is omitted, but still applies. Note that the corresponding private security configuration such as username/password and tokens must be configured in the <u>Consumer</u> to interact successfully. When activating multiple security definitions, the security member becomes an array.

EXAMPLE 11

},

}

},

"bearer_sc": {

"in": "header",

"securityDefinitions": { "proxy_sc": {

"proxy": "https://portal.example.com/"

"scheme": "digest",

"scheme": "bearer", "format": "jwt", "alg": "ES256",

"security": ["proxy_sc", "bearer_sc"],

```
Security configuration in the TD is mandatory. At least one security definition MUST be activated through the security array at the Thing level (i.e., in the TD root object). This configuration can be seen as the default security mechanism required to interact with the <u>Thing</u>. Security definitions MAY also be activated at the form level by including a security member in form objects, which overrides (i.e., completely replace) all definitions activated at the Thing level.
```

"authorization": "https://servient.example.com:8443/"

The nosec security scheme is provided for the case that no security is needed. The minimal security configuration for a <u>Thing</u> is activation of the nosec security scheme at the Thing level, as shown in the following example:

```
EXAMPLE 12

{
    "@context": "https://www.w3.org/2019/wot/td/v1",
    "id": "urn:dev:ops:32473-Thing-1234",
    "title": "MyThing",
    "description": "Human readable information.",
    "support": "https://servient.example.com/contact",
    "securityDefinitions": { "nosec_sc": { "scheme": "nosec" }},
    "security": "nosec_sc",
    "properties": {...},
    "actions": {...},
    "events": {...},
    "links": [...]
}
```

To give a more complex example, suppose we have a <u>Thing</u> where all <u>Interaction Affordances</u> require basic authentication except for one, for which no authentication is required. For the status Property and the toggle Action, basic authentication is required and defined at the Thing level. For the overheating Event, however, no authentication is required, and hence the security configuration is overridden at the form level.

```
EXAMPLE 13
{
    "securityDefinitions": {
        "basic_sc": {"scheme": "basic"},
        "nosec sc": {"scheme": "nosec"}
    "security": ["basic_sc"],
    "properties": {
        "status": {
            "forms": [{
                 "href": "https://mylamp.example.com/status"
            }]
        }
    },
    "actions": {
        "toggle": {
            "forms": [{
                 "href": "https://mylamp.example.com/toggle"
            }]
        }
    },
    "events": {
        "overheating": {
            "forms": [{
                 "href": "https://mylamp.example.com/oh",
                 "security": ["nosec_sc"]
            }]
        }
    }
}
```

Security configurations can also can be specified for different forms within the same <u>Interaction</u>

<u>Affordance</u>. This may be required for devices that support multiple protocols, for example HTTP and CoAP [<u>RFC7252</u>], which support different security mechanisms. This is also useful when alternative authentication mechanisms are allowed. Here is a TD snippet demonstrating three possible ways to

activate a Property affordance: via HTTPS with basic authentication, with digest authentication, with bearer token authentication. In other words, the use of different security configurations within multiple forms provides a way to combine security mechanisms in an "OR" fashion. In contrast, putting multiple security configurations in the same security member combines them in an "AND" fashion, since in that case they would all need to be satisfied to allow activation of the Interaction Affordance. Note that activating one (default) configuration at the Thing level is still mandatory.

```
EXAMPLE 14
{
    "securityDefinitions": {
        "basic_sc": { "scheme": "basic" },
        "digest_sc": { "scheme": "digest" },
        "bearer_sc": { "scheme": "bearer" }
    },
    "security": ["basic_sc"],
    "properties": {
        "status": {
            "forms": [{
                "href": "https://mylamp.example.com/status"
            }, {
                "href": "https://mylamp.example.com/status",
                "security": ["digest sc"]
                "href": "https://mylamp.example.com/status",
                "security": ["bearer_sc"]
            }]
        }
    },
}
```

As another more complex example, OAuth2 makes use of scopes. These are identifiers that may appear in tokens and must match with corresponding identifiers in a resource to allow access to that resource (or <u>Interaction Affordance</u> in the case of <u>W3C</u> WoT). For example, in the following, the status Property can be read by <u>Consumers</u> using bearer tokens containing the scope limited, but the configure Action can only be invoked with a token containing the special scope. Scopes are not

identical to roles, but are often associated with them; for example, perhaps only those in an administrative role are authorized to perform "special" interactions. Tokens can have more than one scope. In this example, an administrator would probably be issued tokens with both the limited and special scopes, while ordinary users would only be issued tokens with the limited scope.

```
EXAMPLE 15
{
    "securityDefinitions": {
        "oauth2_sc": {
            "scheme": "oauth2",
            "flow": "hljs-string">"implicit",
                               ① flow: implicit -> code
$"hljs-string">"code"$,
            "authorization": "https://example.com/authorization",
            "token": "hljs-string">"https://example.com/token",
                                              ① token is necessary
            "scopes": ["limited", "special"]
                                              for code flow
       }
    },
    "security": ["oauth2_sc"],
    "properties": {
        "status": {
            "forms": [{
                "href": "https://scopes.example.com/status",
                "scopes": ["limited"]
           }]
        }
    },
    "actions": {
        "configure": {
            "forms": [{
                "href": "https://scopes.example.com/configure",
                "scopes": ["special"]
           }]
       }
    },
}
```

6.3.5 properties

The value assigned to properties in a Thing instance is a $\underline{\text{Map}}$ of instances of PropertyAffordance . All name-value pairs of a $\underline{\text{Map}}$ of PropertyAffordance instances MUST be serialized as members of the JSON object that results from serializing the $\underline{\text{Map}}$; the name of a pair MUST be serialized as a JSON string and the value of the pair, an instance of PropertyAffordance , MUST be serialized as a JSON object.

All name-value pairs of an instance of PropertyAffordance , where the name is a $\frac{\text{Vocabulary Term}}{\text{Included in (one of) the Signatures of PropertyAffordance , InteractionAffordance , or DataSchema , <math>MUST$ be serialized as members of the JSON object that results from serializing the PropertyAffordance instance, with the $\frac{\text{Vocabulary Term}}{\text{Vocabulary Term}}$ as name. See § 6.3.10 Data Schemas for details on serializing DataSchema instances.

The value assigned to forms in an instance of PropertyAffordance MUST be serialized as a JSON array containing one or more JSON object serializations as defined in § 6.3.9 forms .

A snippet for two Property affordances is given below:

EXAMPLE 16: SAMPLE OF PROPERTY SERIALIZATIONS

```
"properties": {
    "on": {
        "type": "boolean",
        "forms": [...]
    },
    "status": {
        "type": "object",
        "properties": {
            "brightness": {
                 "type": "number",
                 "minimum": 0.0,
                 "maximum": 100.0
                          indent
$
              "rgb": {
<u>‡</u>
                 "type": "array",
                 "items" : {
                     "type" : "number",
                     "minimum": 0,
                     "maximum": 255
                 },
                 "minItems": 3,
                 "maxItems": 3
            }
        },
        "required": ["brightness", "rgb"],
        "forms": [...]
    }
},
```

6.3.6 actions

In a Thing instance, the value assigned to actions is a $\underline{\text{Map}}$ of instances of ActionAffordance . All name-value pairs of a $\underline{\text{Map}}$ of ActionAffordance instances MUST be serialized as members of the

JSON object that results from serializing the $\underline{\text{Map}}$; the name of a pair MUST be serialized as a JSON string and the value of the pair, an instance of ActionAffordance, MUST be serialized as a JSON object.

All name-value pairs of an instance of ActionAffordance , where the name is a <u>Vocabulary Term</u> included in (one of) the <u>Signatures</u> of ActionAffordance or InteractionAffordance , *MUST* be serialized as members of the JSON object that results from serializing the ActionAffordance instance, with the <u>Vocabulary Term</u> as name.

The values assigned to input and output in an instance of ActionAffordance MUST be serialized as JSON objects. They rely on the <u>Class DataSchema</u>, whose serialization is defined in § 6.3.10 Data Schemas.

The value assigned to forms in an instance of ActionAffordance MUST be serialized as a JSON array containing one or more JSON object serializations as defined in § 6.3.9 forms .

A TD snippet of an Action affordance is given below:

EXAMPLE 17: SAMPLE OF AN ACTION SERIALIZATION

```
"actions": {
    "fade" : {
        "title": "Fade in/out",
        "description": "Smooth fade in and out animation.",
        "input": {
            "type": "object",
            "properties": {
                 "from": {
                     "type": "integer",
                     "minimum": 0,
                     "maximum": 100
                 },
                 "to": {
                     "type": "integer",
                     "minimum": 0,
                     "maximum": 100
                 },
                 "duration": {"type": "number"}
            "required": ["to","duration"],
        },
        "output": {"type": "string"},
        "forms": [...]
    }
},
```

6.3.7 events

In a Thing instance, the value assigned to events is a map of instances of EventAffordance . All name-value pairs of a $\underline{\text{Map}}$ of EventAffordance instances MUST be serialized as members of the JSON object that results from serializing the $\underline{\text{Map}}$; the name of a pair MUST be serialized as a JSON string and the value of the pair, an instance of EventAffordance , MUST be serialized as a JSON object.

All name-value pairs of an instance of EventAffordance , where the name is a $\underline{\text{Vocabulary Term}}$ included in (one of) the Signatures of EventAffordance or InteractionAffordance , MUST be

serialized as members of the JSON object that results from serializing the EventAffordance instance, with the Vocabulary Term as name.

The values assigned to subscription , data , and cancellation in an instance of EventAffordance MUST be serialized as JSON objects. They rely on the Class DataSchema , whose serialization is defined in § 6.3.10 Data Schemas .

The value assigned to forms in an instance of EventAffordance MUST be serialized as a JSON array containing one or more JSON object serializations as defined in § 6.3.9 forms .

A TD snippet of an Event object is given below:

```
EXAMPLE 18: SAMPLE OF AN EVENT SERIALIZATION

...

"events": {
      "overheated": {
            "type": "string"
            },
            "forms": [...]
      }
},
...
```

Event affordances have been defined in a flexible manner, in order to adopt existing (e.g., WebSub [websub]) or customer-oriented event mechanisms (e.g., Webhooks). For this reason, subscription and cancellation can be defined according to the desired mechanism. Please find further details in [WOT-BINDING-TEMPLATES]. Example § A.3 Webhook Event Example illustrates how Events can use subscription and cancellation to describe Webhooks.

6.3.8 links

All name-value pairs of an instance of Link , where the name is a <u>Vocabulary Term</u> included in the <u>Signature</u> of Link , *MUST* be serialized as members of the JSON object that results from serializing the Link instance, with the Vocabulary Term as name.

A TD snippet of a link object in the links array is given below:

EXAMPLE 19: SAMPLE OF A LINK SERIALIZATION

```
"links": [{
    "rel": "controlledBy",
    "href": "https://servient.example.com/things/lampController",
    "type": "application/td+json"
}]
...
```

6.3.9 forms

All name-value pairs of an instance of Form, where the name is a <u>Vocabulary Term</u> included in the <u>Signature</u> of Form, *MUST* be serialized as members of the JSON object that results from serializing the Form instance, with the Vocabulary Term as name.

If required, form objects MAY be supplemented with protocol-specific <u>Vocabulary Terms</u> identified with a prefix. See also § 8.3 Protocol Bindings.

A TD snippet of a form object in the forms array is given below:

```
EXAMPLE 20: SAMPLE OF A FORM SERIALIZATION

...

"forms": [{
      "op": "writeproperty",
      "href": "http://mytemp.example.com:5683/temp",
      "contentType": "application/json",
      "htv:methodName": "POST"
}]
...
```

href may also carry a URI that contains dynamic variables such as p and d in http://192.168.1.25 /left?p=2&d=1. In that case the URI can be defined as template as defined in [<u>RFC6570</u>]: http://192.168.1.25/left{?p,d} .

In such a case, the URI Template variables *MUST* be collected in the JSON-object based uriVariables member with the associated (unique) variable names as JSON names.

The serialization of each value in the map assigned to uriVariables in an instance of Form MUST rely on the Class DataSchema , whose serialization is defined in § 6.3.10 Data Schemas .

A TD snippet using a URI Template and uriVariables is given below:

```
EXAMPLE 21
{
    "@context": [
        "https://www.w3.org/2019/wot/td/v1",
        { "eg": "http://www.example.org/iot#" }
    ],
    . . .
    "actions": {
        "LeftDown": {
            "uriVariables": {
                "p" : { "type": "integer", "minimum": 0, "maximum": 16, "@type":
                "d" : { "type": "integer", "minimum": 0, "maximum": 1, "@type": "
            },
            "forms": [{
              "href": "http://192.168.1.25/left{?p,d}",
              "htv:methodName": "GET"
            }]
        },
    },
}
```

The contentType member is used to assign a media type [<u>RFC2046</u>] including media type parameters as attribute-value pairs separated by a; character. Example:

```
EXAMPLE 22
...
"contentType" : "text/plain; charset=utf-8",
...
```

In some use cases, the form metadata of the Interaction Affordance not only describes the request, but

also provides metadata for the expected response. For instance, an Action takePhoto defines an input schema to submit parameter settings of a camera (aperture priority, timer, etc.) using JSON for the request payload (i.e., "contentType": "application/json"). The output of this action is the photo taken, which is available in JPEG format, for example. In such cases, the response member is used to indicate the representation format of the response payload (e.g., "contentType": "image/jpeg"). Here no output schema is required, as the content type fully specifies the representation format.

If present, the value assigned to response in an instance of Form MUST be a JSON object. If present, the response object MUST contain a contentType member as defined in the <u>Class</u> definition of <u>ExpectedResponse</u>.

A form snippet with the response member is shown below based on the takePhoto Action described above:

When forms is present at the top level, it can be used to describe meta interactions offered by a Thing. For example, the operation types "readallproperties" and "writeallproperties" are for meta interactions with a Thing by which Consumers can read and write all properties at once. In the example below, a forms member is included in the TD root object and the Consumer can use the submission target https://mylamp.example.com/allproperties both to read or write all Properties (i.e., on ,

brightness, and timer) of the Thing in a single protocol transaction.

```
EXAMPLE 24
{
    "properties": {
        "on": {
            "type": "boolean",
            "forms": [...]
        },
        "brightness": {
            "type": "number",
            "forms": [...]
        },
        "timer": {
            "type": "integer",
            "forms": [...]
        }
    },
    "forms": [{
        "op": "readallproperties",
        "href": "https://mylamp.example.com/allproperties",
        "contentType": "application/json",
        "htv:methodName": "GET"
    }, {
        "op": "writeallproperties",
        "href": "https://mylamp.example.com/allproperties",
        "contentType": "application/json",
        "htv:methodName": "PUT"
    }]
}
```

3

6.3.10 Data Schemas

The data schemas of the WoT Thing Description defined through the <u>DataSchema Class</u> are based on a subset of the JSON Schema terms [<u>JSON-SCHEMA</u>]. Thus, serializations of the TD data schemas can be fed directly into JSON Schema validator implementations to validate the data exchanged with <u>Things</u>.

Data schema serialization applies to PropertyAffordance instances, the values assigned to input and output in ActionAffordance instances, the values assigned to subscription , data , and cancellation in EventAffordance instances, and the value assigned to uriVariables in instances of Subclasses of InteractionAffordance (when a form object uses a URI Template).

All name-value pairs of an instance of one of the <u>Subclasses</u> of DataSchema , where the name is a <u>Vocabulary Term</u> included in the <u>Signature</u> of that <u>Subclass</u> or in the <u>Signature</u> of DataSchema , <u>MUST</u> be serialized as members of the JSON object that results from serializing the DataSchema <u>Subclass</u>'s instance, with the <u>Vocabulary Term</u> as name.

The value assigned to properties in an instance of ObjectSchema *MUST* be serialized as a JSON object.

The values assigned to enum , required , and oneOf in an instance of DataSchema MUST be serialized as a JSON array.

The value assigned to items in an instance of ArraySchema *MUST* be serialized as a JSON object or a JSON array containing JSON objects.

A TD snippet data schema members is given below. Note that the surrounding object may be a data schema object (e.g., for input and output) or a Property object, which would contain additional members.

EXAMPLE 25: SAMPLE OF A DATASCHEMA SERIALIZATION

```
"type": "object",
"properties": {
    "status": {
        "title": "Status",
        "type": "string",
        "enum": ["On", "Off", "Error"]
    },
    "brightness": {
        "title": "Brightness value",
        "type": "number",
        "minimum": 0.0,
        "maximum": 100.0
    },
    "rgb": {
        "title": "RGB color value",
        "type": "array",
        "items" : {
            "type" : "number",
            "minimum": 0,
            "maximum": 255
        },
        "minItems": 3,
        "maxItems": 3
    }
},
```

The terms readOnly and writeOnly can be used signal which data items are exchanged in read interactions (i.e., when reading a Property) and which in write interactions (i.e., when writing a Property). This can be used as workaround when Properties of an unconventional Thing exhibit different data for reading and writing, which can be the case when augmenting an existing device or service with a Thing Description.

A TD snippet with the usage of readOnly and writeOnly is given below:

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```
EXAMPLE 26
"properties": {
    "status": {
        "description": "Read or write On/Off status.",
        "type": "object",
        "properties": {
            "latestStatus": {
                "type": "string",
                 "enum": ["On", "Off"],
                 "readOnly": true
            },
            "newStatusValue": {
                 "type": "string",
                 "enum": ["On", "Off"],
                 "writeOnly": true
            }
        },
        forms: [...]
}
```

When the status Property is read, the status data is returned using a latestStatus member in the payload. To update the status Property, the new value must be provided through a newStatusValue member in the payload.

As an additional feature, a Thing Description instance allows the usage of a unit member within data schemas. This can be used to associate a unit of measure to a data item. Its string value can be selected freely. However, it is recommended to select units defined in well-known <u>Vocabularies</u>. See § 7. TD <u>Context Extensions</u> for an example.

6.4 Identification

The JSON-based serialization of Thing Descriptions is identified by the media type application/td+json or the CoAP Content-Format ID T.B.D. (see § 10. IANA Considerations).

NOTE: COAP CONTENT-FORMAT

CoAP-based WoT implementations can use the experimental Content-Format 65100 until the final Content-Format ID has been assigned.

7. TD Context Extensions

This section is non-normative.

In addition to the standard <u>Vocabulary</u> definitions in § 5. <u>TD Information Model</u>, the WoT Thing Description offers the possibility to add context knowledge from additional namespaces. This mechanism can be used to enrich the Thing Description instances with additional (e.g., domain-specific) semantics. It can also be used to import additional <u>Protocol Bindings</u> or new security schemes in the future.

For such <u>TD Context Extensions</u>, the Thing Descriptions use the @context mechanism known from JSON-LD [<u>json-ld11</u>]. When using <u>TD Context Extensions</u>, the value of @context of the <u>Class</u>
Thing is an Array with additional elements of type anyURI identifying JSON-LD context files or <u>Map</u> containing namespace IRIs as defined in § 5.3.1.1 Thing.

The serialization rules for complex types in § 6.1 Mapping to JSON Types define the serialization of an extended @context name-value pair. A snippet with <u>TD Context Extensions</u> is given below:

```
EXAMPLE 27

{
    "@context": [
        "https://www.w3.org/2019/wot/td/v1",
        {
            "eg": "http://example.org/iot#",
            "cov": "http://www.example.org/coap-binding#"
        },
        "https://schema.org/"
    ],
    ....
}
```

7.1 Semantic Annotations

TD Context Extensions allow for additional <u>Vocabulary Terms</u> to a Thing Description instance. If the included namespaces are based on <u>Class</u> definitions such as those provided by the RDF Schema or OWL, they can be used to annotate any <u>Class</u> instance of a Thing Description semantically by associating the instance to a such an external <u>Class</u> definition. This is done by assigning a <u>Class</u> name to the <code>@type</code> name-value pair or including <u>Class</u> name in its <u>Array</u> value for multiple associations/annotations. Following the serialization rules in § <u>6.1 Mapping to JSON Types</u>, <code>@type</code> is either serialized as JSON string or as JSON array. <code>@type</code> is the JSON-LD keyword [<code>json-ld11</code>] used to set the type of a node.

TD Context Extensions also allow the inclusion of additional name-value pairs and well-defined values within any <u>Class</u> instance of a Thing Description. These pairs and values are defined through the included <u>Vocabulary Terms</u> and are serialized as additional members in the corresponding JSON objects or values of existing members, respectively. Examples are additional version metadata for the Thing or units of measure for data items.

As an example, the TD snippet given below extends the version information container by adding version numbers for the hardware and firmware of the Thing, and uses values from external Vocabularies for the Thing and for the data schema unit: SAREF, also used in Example 2, and OM, the Ontology of Units of Measure [RIJGERSBERG]. These Vocabularies are used as examples —others may exist, in particular in the home automation domain.

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```
EXAMPLE 28
{
    "@context": [
        "https://www.w3.org/2019/wot/td/v1",
        {
            "v": "http://www.example.org/versioningTerms#",
            "saref": "https://w3id.org/saref#",
            "om": "http://www.ontology-of-units-of-measure.org/resource/om-2/"
        }
    ],
    "version": {
        "instance": "1.2.1",
        "v:firmware": "0.9.1",
        "v:hardware": "1.0"
    },
    "@type": "saref:TemperatureSensor",
    "properties": {
        "temperature": {
            "description": "Temperature value of the weather station",
            "type": "number",
            "minimum": -32.5,
            "maximum": 55.2,
            "unit": "om:degree_Celsius",
            "forms": [...]
        },
        . . .
    },
}
```

In many cases, <u>TD Context Extensions</u> may be used to annotate pieces of a data schema, to be able to semantically process the state information of the physical world object, which is represented by the data exchanged during an interaction (e.g., in the payload of a response). For example, a semantic description of this state information in RDF can be embedded in the <u>TD Document</u> and pieces of a data schema can be individually annotated as referring to specific parts of that RDF-modeled state of the physical world object.

The TD snippet below uses SAREF to describe the state of a lamp. The external <u>Vocabulary Term</u> ssn:forProperty , taken from SSN , the Semantic Sensor Network Ontology [*VOCAB-SSN*], is

being used to link the data schema of the status <u>Property</u> with the actual on/off state of the physical world object.

```
EXAMPLE 29
{
    "@context": [
        "https://www.w3.org/2019/wot/td/v1",
            "saref": "https://w3id.org/saref#",
            "ssn": "http://www.w3.org/ns/ssn/"
        }
    ],
    "id": "urn:dev:ops:32473-WoTLamp-1234",
    "@type": "saref:LightSwitch",
    "saref:hasState": {
        "@id": "urn:dev:ops:32473-WoTLamp-1234/state",
        "@type": "saref:OnOffState"
    },
    "properties": {
        "status": {
            "ssn:forProperty": "urn:dev:ops:32473-WoTLamp-1234/state",
            "type": "string",
            "forms": [{"href": "https://mylamp.example.com/status"}]
        },
        "fullStatus": {
            "ssn:forProperty": "urn:dev:ops:32473-WoTLamp-1234/state",
            "type": "object",
            "properties": {
                "statusString": { "type": "string" },
                "statusCode": { "type": "number" },
                "statusDescription": { "type": "string" }
            "forms": [{"href": "https://mylamp.example.com/status?full=true"}]
        },
        . . .
    },
    . . .
}
```

In <u>Example 2</u>, the state of the <u>Thing</u> is given by the status affordance itself and possible state changes are given by the toggle affordance. In other words, the state of the physical world object directly provides the <u>Interaction Affordances</u> of the <u>Thing</u>. This design is satisfactory for simple cases. In more elaborate cases, however, several affordances may be available for the same physical state. In the example above, the fullStatus <u>Property</u> provides an alternative, more verbose representation for the state of the lamp.

7.2 Adding Protocol Bindings

With the <u>TD Context Extensions</u> in a Thing Description, the communication metadata can be supplemented or new <u>Protocol Bindings</u> added through additional <u>Vocabulary Terms</u> serialized into JSON objects representing a Form instance. (see also § 8.3 Protocol Bindings).

The following TD example uses a fictional CoAP <u>Protocol Binding</u>, as no such <u>Protocol Binding</u> is available at the time of writing this specification. This <u>TD Context Extension</u> assumes that there is a *CoAP in RDF vocabulary* similar to *HTTP Vocabulary in RDF 1.0* [<u>HTTP-in-RDF10</u>] that is accessible via an example namespace http://www.example.org/coap-binding#. The supplemented cov:methodName member instructs the <u>Consumer</u> which CoAP method has to be applied (e.g., GET for the CoAP Method Code 0.01, POST for the CoAP Method Code 0.02, or iPATCH for CoAP Method Code 0.07).

EXAMPLE 30: SPECIALIZATION OF FORMS THROUGH TD CONTEXT EXTENSION

```
{
    "@context": [
        "https://www.w3.org/2019/wot/td/v1",
        { "cov": "http://www.example.org/coap-binding#" }
    ],
    "properties": {
        "brightness": {
            "description": "The current brightness setting",
            "type": "integer",
            "minimum": -64,
            "maximum": 64,
            "forms": [{
                 "op": "readproperty",
                 "href": "coap://example.org:61616/api/brightness",
                 "cov:methodName": "GET"
            }, {
                 "op": "writeproperty",
                 "href": "coap://example.org:61616/api/brightness",
                 "cov:methodName": "POST"
            }]
        },
    },
}
```

7.3 Adding Security Schemes

Finally, new security schemes that are not included in § 5.3.3 Security Vocabulary Definitions can be imported using the <u>TD Context Extension</u> mechanism. This example uses a fictional ACE security scheme based on [<u>ACE</u>] that is, for this example, defined by the namespace at http://www.example.org/ace-security#. Note that such additional security schemes must be Subclasses of the Class SecurityScheme.

```
EXAMPLE 31
{
    @context: [
        "https://www.w3.org/2019/wot/td/v1",
        {
            "cov": "http://www.example.org/coap-binding#",
            "ace": "http://www.example.org/ace-security#"
        }
    ],
    "securityDefinitions": {
        "ace_sc": {
            "scheme": "ace:ACESecurityScheme",
            "ace:as": "coaps://as.example.com/token",
            "ace:audience": "coaps://rs.example.com",
            "ace:scopes": ["limited", "special"],
            "ace:cnonce": true
        }
    },
    "security": ["ace_sc"],
    "properties": {
        "status": {
            "forms": [{
                "op": "readproperty",
                "href": "coaps://rs.example.com/status",
                "contentType": "application/cbor",
                "cov:methodName": "GET",
                "ace:scopes": ["limited"]
            }]
        }
    },
    "actions": {
        "configure": {
            "forms": [{
                "op": "invokeaction",
                "href": "coaps://rs.example.com/configure",
                "contentType": "application/cbor",
                "cov:methodName": "POST",
                "ace:scopes": ["special"]
```

```
}]
},
...
}
```

Note that all security schemes defined in § 5.3.3 Security Vocabulary Definitions are already part of the TD context and need not to be included through a TD Context Extension.

8. Behavioral Assertions

The following assertions relate to the behavior of components of a WoT system, as opposed to the representation or information model of the TD. However, note that TDs are descriptive, and may in particular be used to describe pre-existing network interfaces. In these cases, assertions cannot be made that constrain the behavior of such pre-existing interfaces. Instead, the assertions must be interpreted as constraints on the TD to accurately represent such interfaces.

8.1 Security Configurations

To enable secure interoperation, security configurations must accurately reflect the requirements of the Thing:

- If a <u>Thing</u> requires a specific access mechanism for an interaction, that mechanism *MUST* be specified in the security configuration of the Thing Description.
- If a <u>Thing</u> does not require a specific access mechanism for an interaction, that mechanism *MUST NOT* be specified in the security configuration of the Thing Description.

8.2 Data Schemas

The data schemas provided in the TD should accurately represent the data payloads returned and accepted by the described <u>Thing</u> in the interactions specified in the TD. In general, <u>Consumers</u> should follow the data schemas strictly, not generating anything not given in the WoT Thing Description, but should accept additional data from the <u>Thing</u> not given explicitly in the WoT Thing Description. In general, <u>Things</u> are *described* by WoT Thing Descriptions, but <u>Consumers</u> are *constrained* to follow WoT Thing Descriptions when interacting with <u>Things</u>.

- A <u>Thing</u> acting as a <u>Consumer</u> when interacting with another target <u>Thing</u> described in a WoT Thing Description *MUST* generate data organized according to the data schemas given in the corresponding interactions.
- A WoT Thing Description *MUST* accurately describe the data returned and accepted by each interaction.
- A <u>Thing MAY</u> return additional data from an interaction even when such data is not described in the data schemas given in its WoT Thing Description. This applies to ObjectSchema and ArraySchema (when items is an Array of DataSchema) where there can be additional properties or items in the data returned. This behaves as if "additionalProperties":true or "additionalItems":true as defined in [JSON-SCHEMA].
- A <u>Thing</u> acting as a <u>Consumer</u> when interacting with another <u>Thing</u> <u>MUST</u> accept without error any additional data not described in the data schemas given in the Thing Description of the target <u>Thing</u>. This applies to ObjectSchema and ArraySchema (when items is an Array of DataSchema) where there can be additional properties or items in the data returned. This behaves as if "additionalProperties":true or "additionalItems":true as defined in [<u>JSON-SCHEMA</u>].
- A <u>Thing</u> acting as a <u>Consumer</u> when interacting with another <u>Thing</u> <u>MUST NOT</u> generate data not described in the data schemas given in the Thing Description of that <u>Thing</u>.
- A <u>Thing</u> acting as a <u>Consumer</u> when interacting with another <u>Thing</u> <u>MUST</u> generate URIs according to the URI Templates, base URIs, and form href parameters given in the Thing Description of the target <u>Thing</u>.
- URI Templates, base URIs, and href members in a WoT Thing Description *MUST* accurately describe the WoT Interface of the Thing.

8.3 Protocol Bindings

A <u>Protocol Binding</u> is the mapping from an <u>Interaction Affordance</u> to concrete messages of a specific protocol such as HTTP [<u>RFC7231</u>], CoAP [<u>RFC7252</u>], or MQTT [<u>MQTT</u>]. <u>Protocol Bindings of Interaction Affordances are serialized as forms as defined in § 6.3.9 forms .</u>

Every form in a WoT Thing Description must have a submission target, given by the href member. The URI scheme of this submission target indicates what <u>Protocol Binding</u> the <u>Thing</u> implements [<u>WOT-ARCHITECTURE</u>]. For instance, if the target starts with http or https , a <u>Consumer</u> can then infer the <u>Thing</u> implements the <u>Protocol Binding</u> based on HTTP and it should expect HTTP-specific terms in the form instance (see next section, § 8.3.1 Protocol Binding based on HTTP).

• Every form in a WoT Thing Description MUST follow the requirements of the Protocol Binding

indicated by the URI scheme of its href member.

• Every form in a WoT Thing Description *MUST* accurately describe requests (including request headers, if present) accepted by the Thing in an interaction.

8.3.1 Protocol Binding based on HTTP

Per default the Thing Description supports the <u>Protocol Binding</u> based on HTTP by including the HTTP RDF vocabulary definitions from *HTTP Vocabulary in RDF 1.0* [<u>HTTP-in-RDF10</u>]. This vocabulary can be directly used within TD instances by the usage of the prefix htv , which points to http://www.w3.org/2011/http# . Further details of <u>Protocol Binding</u> based on HTTP can be found in [<u>WOT-BINDING-TEMPLATES</u>].

To interact with a Thing that implements the Protocol Binding based on HTTP, a Consumer needs to

know what HTTP method to use when submitting a form. In the general case, a Thing Description can explicitly include a term indicating the method, i.e., htv:methodName. For the sake of conciseness, the Protocol Binding based on HTTP defines Default Values for teach the the type, type, type, type, the type, the type, the type, the, the) the, the) the</a

4)

| Vocabulary term | Default value | Context |
|-----------------|---------------|--|
| htv:methodName | GET | Form with operation type readproperty , <u>↑readallproperties ↑,↑</u> <u>readmultipleproperties ↑</u> |
| htv:methodName | PUT | Form with operation type writeproperty , <u>^twriteallproperties _^,</u> <u>writemultipleproperties _^</u> |
| htv:methodName | POST | Form with operation type invokeaction |

For example, the <u>Example 1</u> in § 1. <u>Introduction</u> does not contain operation types and HTTP methods in the forms. The following Default Values should be assumed for the forms in the Example 1:

EXAMPLE 32

```
□ with default values for Protocol Binding based on HTTP
{
    "@context": "https://www.w3.org/2019/wot/td/v1",
    "id": "urn:dev:ops:32473-WoTLamp-1234",
    "title": "MyLampThing",
    "securityDefinitions": {
        "basic_sc": {
            "scheme": "basic",
            "in": "header"
        }
    },
    "security": [
        "basic_sc"
    ],
    "properties": {
        "status": {
            "type": "string",
            "forms": [
                 {
                     "href": "https://mylamp.example.com/status"
                 }
            ]
        }
    },
    "actions": {
        "toggle": {
            "forms": [
                 {
                     "href": "https://mylamp.example.com/toggle"
                 }
            ]
        }
    },
    "events": {
        "overheating": {
            "data": {
                 "type": "string"
            },
            "forms": [
                 {
                     "href": "https://mylamp.example.com/oh",
```

```
"subprotocol": "longpoll"
                }
            ]
        }
    }
}
{
    "@context": "https://www.w3.org/2019/wot/td/v1",
    "id": "urn:dev:ops:32473-WoTLamp-1234",
    "title": "MyLampThing",
    "securityDefinitions": {
        "basic_sc": {
            "scheme": "basic",
            "in": "header"
        }
    },
    "security": [
        "basic_sc"
    ],
    "properties": {
        "status": {
            "type": "string",
            "forms": [
                {
                     "op": "readproperty",
                     "href": "https://mylamp.example.com/status",
                     "htv:methodName": "GET"
                },
                {
                     "op": "writeproperty",
                     "href": "https://mylamp.example.com/status",
                     "htv:methodName": "PUT"
                }
            ]
        }
    },
    "actions": {
        "toggle": {
            "forms": [
                {
                     "op": "invokeaction",
                     "href": "https://mylamp.example.com/toggle",
```

```
"htv:methodName": "POST"
                 }
            ]
        }
    },
    "events": {
        "overheating": {
             "data": {
                 "type": "string"
            },
             "forms": [
                 {
                     "op": "subscribeevent",
                     "href": "https://mylamp.example.com/oh",
                     "subprotocol": "longpoll"
                 }
            ]
        }
    }
}
```

8.3.2 Other Protocol Bindings

The number of <u>Protocol Bindings</u> a <u>Thing</u> can implement is not restricted. Other <u>Protocol Bindings</u> (e.g., for CoAP, MQTT, or OPC UA) are intended to be standardized in separate documents such as a protocol <u>Vocabulary</u> similar to *HTTP Vocabulary in RDF 1.0* [<u>HTTP-in-RDF10</u>] or specifications including <u>Default Value</u> definitions. Such protocols can be simply integrated into the TD by the usage of the TD Context Extension mechanism (see § 7. TD Context Extensions).

Please refer to [<u>WOT-BINDING-TEMPLATES</u>] for information on how to describe IoT platforms and ecosystems.

9. Security and Privacy Considerations

This section is non-normative.

In general the security measures taken to protect a WoT system will depend on the threats and attackers that system may face and the value of the assets needs to protect. In addition privacy risks will depend

on the association of Things with identifiable people and both the direct information and the inferred information available from such an association. A detailed discussion of security and privacy considerations for the Web of Things, including a threat model that can be adapted to various circumstances, is presented in the informative document [<u>WOT-SECURITY-GUIDELINES</u>]. This section discusses only security and privacy risks and possible mitigations directly relevant to the WoT Thing Description.

A WoT Thing Description can describe both secure and insecure network interfaces. When a Thing Description is retro-fitted to an existing network interface, no change in the security status of the network interface is to be expected.

The use of a WoT Thing Description introduces the security and privacy risks given in the following sections. After each risk, we suggest some possible mitigations.

9.1 Context \December Dereferencing \December \Text{Fetching \December Privacy Risk} are about English

Mitigation:

Avoid actual \$\frac{\dereferencing}\$ \$\frac{\fra

9.2 Immutable Identifiers Privacy Risk

A Thing Description containing an identifier (id) may describe a Thing that is associated with an identifiable person. Such identifiers pose various risks including tracking. However, if the identifier is also immutable, then the tracking risk is amplified, since a device may be sold or given to another person and the known ID used to track that person.

Mitigation:

All identifiers should be mutable, and there should be a mechanism to update the id of a Thing. Specifically, the id of a Thing should not be fixed in hardware. This does, however, conflict with the Linked Data ideal that identifiers are fixed URIs. In many circumstances it will be acceptable to only allow updates to identifiers if a Thing is reinitialized. In this case as a software entity the old Thing ceases to exist and a new Thing is created. This can be sufficient to break a tracking chain when, for example, a device is sold to a new owner. Alternatively, if more frequent changes are desired during the operational phase of a device, a mechanism can be put into place to notify only authorized users of the change in identifier when a change is made. Note however that some classes of devices, e.g., medical devices, may require immutable IDs by law in some jurisdictions. In this case extra attention should be paid to secure access to files, such as Thing Descriptions, containing such immutable identifiers. It may also be desirable to not share the "true" immutable identifier in such a case in the TD whenever possible.

9.3 Fingerprinting Privacy Risk

As noted above, the id member in a TD can pose a privacy risk. However, even if the id is updated as described to mitigate its tracking risk, it may still be possible to associate a TD with a particular physical device, and from there to an identifiable person, through fingerprinting.

Even if a specific device instance cannot be identified through fingerprinting, it may be possible to infer the type of a device from the information in the TD, such as the set of interactions, and use this type to infer private information about an identifiable person, such as a medical condition.

Mitigation:

Only authorized users should be provided access to the Thing Description for a Thing, and only the amount of information needed for the level of authorization and the use case should be provided. If the TD is only distributed to authorized users through secure and confidential channels, for example through a directory service that requires authentication, then external unauthorized parties will not have access to the TD to fingerprint it. To further mitigate this risk, information not necessary for a particular use case of a TD should be omitted whenever possible. For example, for an ad-hoc connection to a device where the Consumer does not store state about the Thing, the id can be omitted. If the Consumer does not need certain interactions for its use case, they can be omitted. If the Consumer is not authorized to use certain interactions, they can likewise be omitted. If the Consumer does not have any capability to display human-readable information such as titles or descriptions, they can be omitted or replaced with zero-length strings.

9.4 Globally Unique Identifier Privacy Risk

Globally unique identifiers pose a privacy risk if a centralized authority is needed to create and distribute them, since then a third party has knowledge of the identifiers.

Mitigation:

Typo

The id field in TDs are intentionally not required to be globally unique. There are several cryptographic mechanisms available to generate suitable IDs in a distributed fashion that do not require a central registry. These mechanisms typically have a \pma \pma \pma very low probability of generating duplicate identifiers, and this needs to be taken into account in the system design; for example, by detecting duplicates and regenerating IDs when necessary. The scope of IDs also does not need to be global: it is acceptable to use identifiers that only distinguish Things in a certain context, such as within a home or factory.

9.5 TD Interception and Tampering Security Risk

Intercepting and tampering with TDs can be used to launch man-in-the-middle attacks, for example by rewriting URLs in TDs to redirect accesses to a malicious intermediary that can capture or manipulate data.

Mitigation:

Obtain Thing Descriptions only through mutually authenticated channels. This ensures that the <u>Consumer</u> and the server are both sure of the identity of the other party to the communication. This is also necessary in order to deliver TDs only to authorized users.

9.6 Context Interception and Tampering Security Risk

Intercepting and tampering with context files can be used to facilitate attacks by modifying the interpretation of vocabulary.

Mitigation:

Ideally context files would only be obtained through authenticated channels but it is notable (and unfortunate) that many contexts are indicated using HTTP URLs, which are vulnerable to interception and modification if dereferenced. However, if context files are immutable and cached, and dereferencing is avoided whenever possible, then this risk can be reduced.

9.7 Inferencing of Personally Identifiable Information Privacy Risk

In many locales, in order to protect the privacy of users, there are legal requirements for the handling of personally identifiable information, that is, information that can be associated with a particular

person. Such information can of course be generated by IoT devices directly. However, the existence and metadata of IoT devices (the kind of data stored in a Thing Description) can also contain or be used to infer personally identifiable information. This information can be as simple as the fact that a certain person owns a certain type of device, which can lead to additional inferences about that person.

Mitigation:

Treat a Thing Description associated with a personal device as if it contained personally identifiable information. As an example application of this principle, consider how to obtain user consent. Consent for usage of personally identifiable data generated by a <u>Thing</u> is often obtained when a <u>Thing</u> is paired with system consuming the data, which is frequently also when the Thing Description is registered with a local directory or the system consuming the Thing Description in order to access the device. In this case, consent for using data from a <u>Thing</u> can be combined with consent for accessing the Thing Description of the <u>Thing</u>. As a second example, if we consider a TD to contain personally identifiable information, then it should not be retained indefinitely or used for purposes other than those for which consent was given.

10. IANA Considerations

10.1 application/td+json Media Type Registration

Type name:

application

Subtype name:

td+json

Required parameters:

None

Optional parameters:

None

Encoding considerations:

See RFC 6839, section 3.1.

Security considerations:

See $\downarrow RFC 8259 \downarrow \uparrow RFC 8259$, section 12 \uparrow .

Links made more specific, per request by IANA.

Since WoT Thing Description is intended to be a pure data exchange format for <u>Thing</u> metadata, the serialization *SHOULD NOT* be passed through a code execution mechanism such as JavaScript's eval() function to be parsed. An (invalid) document may contain code that, when executed, could lead to unexpected side effects compromising the security of a system.

Links made more specific, per

WoT Thing Descriptions can be evaluated with a JSON-LD 1.1 processor, which typically follows links to remote contexts (i.e., TD context extensions, see $\frac{18}{7}$. TD Context Extensions $\frac{1}{2}$ \frac the explicit request of the Consumer for each one. If remote contexts are served by third parties, it may allow them to gather usage patterns or similar information leading to privacy concerns. While implementations on resource-constrained devices are expected to perform raw JSON processing (as opposed to JSON-LD processing), implementations in general SHOULD statically cache vetted versions of their supported context extensions and not to follow links to remote contexts. Supported context extensions can be managed through a secure software update mechanism instead.

specific, per

Links made more Context Extensions (see ↓§ 7. TD Context Extensions ↓ <u>↑W3C ↑↑ WoT Thing Description</u>, request by IANA. section 7 \(\) that are loaded from the Web over non-secure connections, such as HTTP, run the risk of being altered by an attacker such that they may modify the TD Information Model in a way that could compromise security. For this reason, Consumer again SHOULD vet and cache remote contexts before allowing the system to use it.

> Given that JSON-LD processing usually includes the substitution of long IRIs [RFC3987] with short terms, WoT Thing Descriptions may expand considerably when processed using a JSON-LD 1.1 processor and, in the worst case, the resulting data might consume all of the recipient's resources. Consumers SHOULD treat any TD metadata with due skepticism.

Interoperability considerations:

See RFC 8259.

Rules for processing both conforming and non-conforming content are defined in this specification.

Published specification:

https://w3c.github.io/wot-thing-description

Applications that use this media type:

All participating entities in the W3C Web of Things, that is, Things, Consumers, and Intermediaries as defined in the Web of Things (WoT) Architecture.

Fragment identifier considerations:

See RFC 6839, section 3.1.

Additional information:

Magic number(s):

Not Applicable

File extension(s):

.jsontd

Macintosh file type code(s):

TEXT

Person & email address to contact for further information:

Matthias Kovatsch <w3c@kovatsch.net>

Intended usage:

COMMON

Restrictions on usage:

None

Author(s):

The WoT Thing Description specification is a product of the Web of Things Working Group.

Change controller:

W₃C

10.2 CoAP Content-Format Registration

IANA assigns compact CoAP Content-Format IDs for media types in the <u>CoAP Content-Formats</u> subregistry within the <u>Constrained RESTful Environments (CoRE) Parameters</u> registry [<u>RFC7252</u>]. The Content-Format ID for WoT Thing Description is (t.b.d.) in the 256-9999 range (IETF Review or IESG Approval).

Media Type:

application/td+json

Encoding:

ID:

T.B.D.

Reference:

["Web of Things (WoT) Thing Description", May 2019]

A. Example Thing Description Instances

This section is non-normative.

A.1 MyLampThing Example with CoAP Protocol Binding

Feature list of the Thing:

• Title: MyLampThing

• Context Extensions: none

• Offered affordances: 1 Property, 1 Action, 1 Event

• Security: PSKSecurityScheme

• Protocol Binding: CoAP [RFC7252] over TLS

• Comment: Also see § 7.2 Adding Protocol Bindings.

EXAMPLE 33: MYLAMPTHING WITH COAP PROTOCOL BINDING

```
{
   "@context": [
      "https://www.w3.org/2019/wot/td/v1",
      {
      "cov": "http://www.example.org/coap-binding#"
      }
    ],
    "id": "urn:dev:ops:32473-WoTLamp-1234",
    "title": "MyLampThing",
    "description": "MyLampThing uses JSON serialization",
    "securityDefinitions": {"psk_sc":{"scheme": "psk"}},
    "security": ["psk_sc"],
    "properties": {
        "status": {
            "description" : "Shows the current status of the lamp",
            "type": "string",
            "forms": [{
                "op": "readproperty",
                "href": "coaps://mylamp.example.com/status",
                "cov:methodName" : "GET"
            }]
        }
    },
    "actions": {
        "toggle": {
            "description" : "Turn on or off the lamp",
            "forms": [{
                "href": "coaps://mylamp.example.com/toggle",
                "cov:methodName" : "POST"
            }]
        }
    },
    "events": {
        "overheating": {
            "description" : "Lamp reaches a critical temperature (overheating)",
            "data": {"type": "string"},
            "forms": [{
                "href": "coaps://mylamp.example.com/oh",
                "cov:methodName" : "GET",
                "subprotocol" : "cov:observe"
            }]
```

```
}
}
}
```

A.2 \pmyLightSensor \pmyIlluminanceSensor \pm Example with MQTT Protocol Binding

Name change in

Example

Feature list of the Thing:

• Title: \psi MyIlluminanceSensor \psi MyIlluminanceSensor \psi

• Context Extensions: none

• Offered affordances: 1 Event

• Security: none

• Protocol Binding: MQTT [<u>MQTT</u>]

Name change in Example

• Comment: An MQTT client frequently publishes the ↓light sensor ↓ \$\frac{1}\liminity \frac{1}\liminity \liminity \limin

```
EXAMPLE 34 : <del>↓MYLIGHTSENSOR ↓</del> ↑MYILLUMINANCESENSOR ↑ WITH MQTT
PROTOCOL BINDING
{
    "@context": "https://www.w3.org/2019/wot/td/v1",
    "title": "hljs-string">"MyLightSensor",
                                           Name change in
                                           Example
$"hljs-string">"MyIlluminanceSensor"$,
    "id": "hljs-string">"urn:dev:ops:32473-WoTLightSensor-1234",
*"hljs-string">"urn:dev:ops:32473-WoTIlluminanceSensor-1234"♣, Name change in
                                                          Example
   "securityDefinitions": {"nosec sc": {"scheme": "nosec"}},
    "security": ["nosec_sc"],
    "events": {
      -:-{

       "illuminance": {
           "data":{"type": "integer"},
           "forms": [
              {
                  "href": "hljs-string">"mqtt://192.168.1.187:1883/lightSensor"
                                                          Name change in
$"hljs-string">"mqtt://192.168.1.187:1883/illuminance"$.
                                                          Example
                  "contentType" : "hljs-string">"text/plain"
$"hljs-string">"text/plain"$,
                                   Explicit "op" makes
"hljs-attr">"op" : "subscribeevent"
                                   for a better example
              }
           ]
       }
   }
}
```

A.3 Webhook Event Example

Feature list of the Thing:

• Title: WebhookThing

Context Extensions: use HTTP <u>Protocol Binding</u> supplements (htv prefix already included in TD context)

Offered affordances: 1 Event

• Security: none

Protocol Binding: HTTP

• Comment: WebhookThing provides an Event affordance temperature which periodically pushes the latest temperature value to the Consumer using a Webhook mechanism, where the Thing sends POST requests to a callback URI provided by the Consumer. To describe this, the subscription member defines a write-only parameter callbackURL, which must be submitted through the subscribeevent form. The read-only parameter subscriptionID is returned by the subscription. The WebhookThing will then periodically POST to this callback URI with a payload defined by data. To unsubscribe, the Consumer has to submit the unsubscribeevent form, which makes use of a URI Template. The uriVariables member informs the Consumer to include the subscriptionID string. This can be further automated by using a TD Context Extension to include proper semantic annotations. Alternatively, one can imagine unsubscribing using the cancellation member similarly to subscription and combine this with a unsubscribeevent form that describes a POST request with payload to unsubscribe.

EXAMPLE 35: TEMPERATURE EVENT WITH SUBSCRIPTION AND CANCELLATION

```
{
    "@context": "https://www.w3.org/2019/wot/td/v1",
    "id": "urn:dev:ops:32473-Thing-1234",
    "title": "WebhookThing",
    "description": "Webhook-based Event with subscription and unsubscribe form.",
    "securityDefinitions": {"nosec_sc": {"scheme": "nosec"}},
    "security": ["nosec sc"],
    "events": {
        "temperature": {
            "description": "Provides periodic temperature value updates.",
            "subscription": {
                "type": "object",
                "properties": {
                    "callbackURL": {
                         "type": "string",
                         "format": "uri",
                         "description": "Callback URL provided by subscriber for W
                         "writeOnly": true
                    },
                    "subscriptionID": {
                         "type": "string",
                         "description": "Unique subscription ID for cancellation p
                         "readOnly": true
                    }
                }
            },
            "data": {
                "type": "number",
                "description": "Latest temperature value that is sent to the call
            },
            "cancellation": {
                "type": "object",
                "properties": {
                     "subscriptionID": {
                         "type": "integer",
                         "description": "Required subscription ID to cancel subscr
                         "writeOnly": true
                    }
                }
            },
            "uriVariables": {
```

```
"subscriptionID": { "type": "string" }
            },
            "forms": [
                {
                     "op": "subscribeevent",
                     "href": "http://192.168.0.124:8080/events/temp/subscribe",
                     "contentType": "application/json",
                     "htv:methodName": "POST"
                },
                {
                     "op": "unsubscribeevent",
                     "href": "http://192.168.0.124:8080/events/temp/{subscriptionI
                     "htv:methodName": "DELETE"
                }
            ]
        }
    }
}
```

B. JSON Schema for TD Instance Validation

This section is non-normative.

Below is a JSON Schema [<u>JSON-SCHEMA</u>] document for syntactically validating Thing Description instances serialized in JSON based format.

NOTE

The Thing Description defined by this document allows for adding external vocabularies by using <code>@context</code> mechanism known from JSON-LD [<code>json-ld11</code>], and the terms in those external vocabularies can be used in addition to the terms defined in § 5. TD Information Model. For this reason, the below JSON schema is intentionally non-strict in that regard. You can replace the value of additionalProperties schema property true with false in different scopes/levels in order to perform a stricter validation in case no external vocabularies are used.

NOTE

Please note that some JSON Schema validation tools do not support the iri string format.

The following JSON Schema for validating TD instances does not require the terms with <u>Default Values</u> to be present. Thus the terms with <u>Default Values</u> are optional. (see also § 5.4 <u>Default Value</u> Definitions)

```
"title": "WoT TD Schema - 16 October 2019",
"description": "JSON Schema for validating TD instances against the TD model.
"$schema ": "http://json-schema.org/draft-07/schema#",
"definitions": {
     "anyUri": {
        "type": "string",
        "format": "iri-reference"
    "description": {
        "type": "string"
                                           What else?
    <u>},</u>
                                           (see Github)
    "descriptions": {
        "type": "object",
        "additionalProperties": {
            "type": "string"
        _}
    <u>},</u>
    "<u>title": {</u>
        "type": "string"
    <u>},</u>
    "titles": {
        "type": "object",
        "additionalProperties": {
            "type": "string"
        _}
    <u>},</u>
    "security": {
        "oneOf": [{
                 "type": "array",
                 "items": {
                     "type": "string"
                 }
            <u>},</u>
                 "type": "string"
    "scopes": {
        "oneOf": [{
                 "type": "array",
                 "items": {
```

```
"type": "string"
                     "type": "string"
        <u>},</u>
        "subProtocol": {
            "type": "string",
            "enum": [
                 "longpoll",
                 "websub",
                 "sse"
        _},
<u>↑</u>
        "thing-context-w3c-uri": {
             "type": "string",
            "enum": [
                 "https://www.w3.org/2019/wot/td/v1"
            ]
        },
        "thing-context": {
             "oneOf": [{
                     "type": "array",
                      "items": {
                      "items": [{
                          "$ref": "#/definitions/thing-context-w3c-uri"
                     }],
                     "additionalItems": {
$
                          "any0f": [{
                                  "$ref": "#/definitions/anyUri"
                              },
                              {
                                  "type": "object"
                              }
                          ]
                     -},
                     "contains": {
                         "$ref": "#/definitions/thing-context-w3c-uri"
```

```
}
                 },
                 {
                      "$ref": "#/definitions/thing-context-w3c-uri"
                 }
             ]
         },
         "type_declaration": {
             "oneOf": [{
                      "type": "string"
                 },
                 {
                      "type": "array",
                      "items": {
                          "type": "string"
                      }
                 }
             ]
         },
          "property_element": {
$
          "dataSchema": {
<u>‡</u>
             "type": "object",
             "properties": {
                  "@type": {
                      "$ref": "#/definitions/type_declaration"
                 },
                 "description": {
                      "$ref": "#/definitions/description"
                 },
                  "descriptions": {
                      "$ref": "#/definitions/descriptions"
                 },
                 "title": {
                      "$ref": "#/definitions/title"
                 },
                  "descriptions": {
                      "$ref": "#/definitions/descriptions"
                 <u>},</u>
<u>↑</u>
```

```
"titles": {
               "$ref": "#/definitions/titles"
           },
           "uriVariables": {
           "type": "object",
            "additionalProperties": {
               "$ref": "#/definitions/dataSchema"
          "forms": {
           "type": "array",
"minItems": 1,
"items": {
              "$ref": "#/definitions/form element property"
          -}-
          "observable": {
           "type": "boolean"
           "writeOnly": {
               "type": "boolean"
           },
           "readOnly": {
               "type": "boolean"
           },
           "oneOf": {
              "type": "array",
               "items": {
                  "$ref": "#/definitions/dataSchema"
              }
           },
           "unit": {
               "type": "string"
           },
           "enum": {
               "type": "array",
               "minItems": 1,
               "uniqueItems": true
           },
           "format": {
               "type": "string"
           },
```

```
"const": {},
"type": {
    "type": "string",
    "enum": [
        "boolean",
        "integer",
        "number",
        "string",
        "object",
        "array",
        "null"
    ]
},
"items": {
    "oneOf": [{
            "$ref": "#/definitions/dataSchema"
        },
        {
            "type": "array",
            "items": {
                "$ref": "#/definitions/dataSchema"
            }
        }
    ]
},
"maxItems": {
    "type": "integer",
    "minimum": 0
},
"minItems": {
    "type": "integer",
    "minimum": 0
},
"minimum": {
    "type": "number"
},
"maximum": {
    "type": "number"
},
"properties": {
    "additionalProperties": {
        "$ref": "#/definitions/dataSchema"
    }
```

```
},
        "required": {
            "type": "array",
            "items": {
                "type": "string"
            }
        }
    "required": [
      "forms"
    "additionalProperties": true
"action_element": {
    "type": "object",
   "properties": {
        "description": {
            "type": "string"
       "descriptions": {
         "$ref": "#/definitions/descriptions"
        "title": {
           "$ref": "#/definitions/title"
        "titles": {
            "$ref": "#/definitions/titles"
        },
        "uriVariables": {
            "type": "object",
            "additionalProperties": {
                "$ref": "#/definitions/dataSchema"
        <del>"@type": {</del>
            "$ref": "#/definitions/type_declaration"
        <del>},</del>
        "forms": {
            "type": "array",
            "minItems": 1,
            "items": {
                "$ref": "#/definitions/form element action"
```

```
"input": {
              "$ref": "#/definitions/dataSchema"
            "output": {
                "$ref": "#/definitions/dataSchema"
            "safe": {
             "type": "boolean"
            "idempotent": {
              "type": "boolean"
        "required": [
          "forms"
        "additionalProperties": true
"event_element": {
 "type": "object",
       "properties": {
            "description": {
             "type": "string"
            "descriptions": {
                "$ref": "#/definitions/descriptions"
            },
            "title": {
                "$ref": "#/definitions/title"
            "titles": {
                "$ref": "#/definitions/titles"
            "uriVariables": {
                "type": "object",
                "additionalProperties": {
                    "$ref": "#/definitions/dataSchema"
            <del>"@type": {</del>
              "$ref": "#/definitions/type_declaration"
```

```
"forms": {
                "type": "array",
          "minItems": 1,
          <u>"items":</u>
                   "$ref": "#/definitions/form_element_event"
              },
               "subscription": {
               "$ref": "#/definitions/dataSchema"
               "data": {
                 "$ref": "#/definitions/dataSchema"
               "cancellation": {
                  "$ref": "#/definitions/dataSchema"
               "type": {
               "not": {}
             <del>"enum": {</del>
              <u>"not": {}</u>
      "const": {
             "not": {}
          -},
          "required": [
             "forms"
           "additionalProperties": true

       },
       "form_element_property": {
           "type": "object",
           "properties": {
              <u>"href": {</u>
                  "$ref": "#/definitions/anyUri"
               "op": {
                   "oneOf": [{
```

```
"type": "string",
                                "enum": [
                                    "readproperty",
                                    "writeproperty",
                                    "observeproperty",
                                    "unobserveproperty"
                                ]
                           },
                           {
                                "type": "array",
                                "items": {
                                    "type": "string",
                                    "enum": [
                                         "readproperty",
                                         "writeproperty",
                                         "observeproperty",
                                         "unobserveproperty"
                                    ]
                                }
                           }
                       ]
                  },
                   "hre<u>f":</u>{
                       "$ref": "#/definitions/anyUri"
                  <u>},</u>
<u>↑</u>
                  "contentType": {
                       "type": "string"
                  },
                   "contentCoding": {
                      "type": "string"
                  <u>},</u>
                  "subProtocol": {
                       "$ref": "#/definitions/subProtocol"
                  <u>},</u>
<u>↑</u>
                  "security": {
                       "type": "array",
                      "items": {
                           "type": "string"
+
                        "$ref": "#/definitions/security"
```

```
<u>‡</u>
                 },
                 "scopes": {
                   "type": "array",
                     "items": {
                         "type": "string"
                 "subProtocol": {
                   "type": "string",
                    <u>"enum":</u>
                     "longpoll",
                         "websub",
                         "sse"
+
                      "$ref": "#/definitions/scopes"
$
<u>‡</u>
                 },
                 "response": {
                     "type": "object",
                     "properties": {
                          "contentType": {
                              "type": "string"
                         }
                     }
                 }
            },
             "required": [
                 "href"
            ],
             "additionalProperties": true
        },
        "form_element_action": {
             "type": "object",
             "properties": {
                 <u>"href": {</u>
                     "$ref": "#/definitions/anyUri"
                 },
                 "op": {
                     "oneOf": [{
                              "type": "string",
```

```
"enum": [
                                    "invokeaction"
                                1
                           },
                               "type": "array",
                               "items": {
                                    "type": "string",
                                    "enum": [
                                        "invokeaction"
                                    ]
                               }
                           }
                      ]
                  },
                   "href": {
                      "$ref": "#/definitions/anyUri"
                  },
<u>1</u>
                  "contentType": {
                      "type": "string"
                  },
                   "contentCoding": {
                      "type": "string"
                  <u>},</u>
                  "subProtocol": {
                      "$ref": "#/definitions/subProtocol"
                  <u>},</u>
                  "security": {
                       "type": "array",
                      "items": {
                           "type": "string"
+
                       "$ref": "#/definitions/security"
<u>‡</u>
                  },
                  "scopes": {
                      <del>"type": "array",</del>
                      "items": {
                         "type": "string"
```

```
"subProtocol": {
                 "type": "string",
                 <del>"enum": [</del>
                      "longpoll",
                         "websub",
                         "sse"
                      "$ref": "#/definitions/scopes"
$
<u>‡</u>
                 },
                 "response": {
                     "type": "object",
                     "properties": {
                         "contentType": {
                              "type": "string"
                         }
                     }
                 }
            },
            "required": [
                 "href"
            ],
            "additionalProperties": true
        },
        "form_element_event": {
            "type": "object",
            "properties": {
                 "href": {
                     "$ref": "#/definitions/anyUri"
4
                 "op": {
                     "oneOf": [{
                              "type": "string",
                              "enum": [
                                  "subscribeevent",
                                  "unsubscribeevent"
                              ]
                         },
                         {
                              "type": "array",
```

```
"items": {
                                   "type": "string",
                                   "enum": [
                                       "subscribeevent",
                                       "unsubscribeevent"
                                  ]
                              }
                          }
                     ]
                 },
                  "<u>href": {</u>
                     "$ref": "#/definitions/anyUri"
                 <u>},</u>
1
                 "contentType": {
                     "type": "string"
                 },
                  "contentCoding": {
                     "type": "string"
                 <u>},</u>
                 "subProtocol": {
                     "$ref": "#/definitions/subProtocol"
                 <u>},</u>
<u>↑</u>
                 "security": {
                     "type": "array",
                     "items": {
                          "type": "string"
                       "$ref": "#/definitions/security"
$
$
                 },
                 "scopes": {
                     "type": "array",
                     "items": {
                         "type": "string"
                 },
                 "subProtocol": {
                  "type": "string",
              "enum": [
                     "longpoll",
```

```
"websub",
                         "sse"
                      "$ref": "#/definitions/scopes"
},
                 "response": {
                     "type": "object",
                     "properties": {
                         "contentType": {
                             "type": "string"
                         }
                    }
                }
            },
            "required": [
                "href"
            ],
            "additionalProperties": true
        },
        "form_element_root": {
            "type": "object",
            "properties": {
                 "href": {
                     "$ref": "#/definitions/anyUri"
                },
                 "op": {
                     "oneOf": [{
                             "type": "string",
                             "enum": [
                                 "readallproperties",
                                 "writeallproperties",
                                 "readmultipleproperties",
                                 "writemultipleproperties"
                             ]
                         },
                         {
                             "type": "array",
                             "items": {
                                 "type": "string",
                                 "enum": [
```

```
"readallproperties",
                                        "writeallproperties",
                                        "readmultipleproperties",
                                        "writemultipleproperties"
                                   ]
                               }
                          }
                      ]
                  },
                   "<u>href": {</u>
                      "$ref": "#/definitions/anyUri"
                  <u>},</u>
<u>↑</u>
                  "contentType": {
                      "type": "string"
                  },
                   "contentCoding": {
                      "type": "string"
                  },
                  "subProtocol": {
                      "$ref": "#/definitions/subProtocol"
                  <u>},</u>
<u>↑</u>
                  "security": {
                      "type": "array",
                      "items": {
                          "type": "string"
+
"$ref": "#/definitions/security"
$
                  },
                  "scopes": {
                      "type": "array",
                      "items": {
                          "type": "string"
                  "subProtocol": {
                     "type": "string",
                     <u>"enum":</u>
                          "longpoll",
                          "websub",
```

```
<u>"sse"</u>
                      "$ref": "#/definitions/scopes"
$
},
                 "response": {
                     "type": "object",
                     "properties": {
                         "contentType": {
                             "type": "string"
                         }
                     }
                 }
            },
            "required": [
                 "href"
            ],
            "additionalProperties": true
        },
        "description": {
           "type": "string"
        "title": {
            "type": "string"
        →,
        "descriptions": {
           "type": "object"
        "titles": {
        "type": "object"
        "dataSchema": {
+
$
         "property element": {
<u>‡</u>
             "type": "object",
             "properties": {
                 "@type": {
                     "$ref": "#/definitions/type_declaration"
                 },
                 "description": {
                     "$ref": "#/definitions/description"
```

```
},
                  <del>"title": {</del>
                     "$ref": "#/definitions/title"
                  "descriptions": {
                      "$ref": "#/definitions/descriptions"
                  },
                   "title": {
                      "$ref": "#/definitions/title"
<u>↑</u>
                  "titles": {
                      "$ref": "#/definitions/titles"
                  },
                   "forms": {
                      "type": "array",
                      "minItems": 1,
                      "items": {
                          "$ref": "#/definitions/form element property"
                  <u>},</u>
                  "uriVariables": {
                      <u>"type": "object",</u>
                      "additionalProperties": {
                          "$ref": "#/definitions/dataSchema"
                      _}
                  <u>},</u>
                  "observable": {
                      "type": "boolean"
                  },
<u>1</u>
                  "writeOnly": {
                      "type": "boolean"
                  },
                  "readOnly": {
                      "type": "boolean"
                  },
                  "oneOf": {
                      "type": "array",
                      "items": {
                           "$ref": "#/definitions/dataSchema"
                      }
```

```
},
"unit": {
    "type": "string"
},
"enum": {
    "type": "array",
    "minItems": 1,
    "uniqueItems": true
},
"format": {
    "type": "string"
},
"const": {},
"type": {
    "type": "string",
    "enum": [
        "boolean",
        "integer",
        "number",
        "string",
        "object",
        "array",
        "null"
    ]
},
"items": {
    "oneOf": [{
            "$ref": "#/definitions/dataSchema"
        },
        {
            "type": "array",
            "items": {
                 "$ref": "#/definitions/dataSchema"
             }
        }
    ]
},
"maxItems": {
    "type": "integer",
    "minimum": 0
},
"minItems": {
    "type": "integer",
```

```
"minimum": 0
                 },
                 "minimum": {
                      "type": "number"
                 },
                 "maximum": {
                      "type": "number"
                 },
                  "properties": {
                      "additionalProperties": {
                          "$ref": "#/definitions/dataSchema"
                      }
                 },
                 "required": {
                      "type": "array",
                      "items": {
                          "type": "string"
                      }
                 }
             "required": [
                 "forms"
             "additionalProperties": true
<u>‡</u>
         },
          "link_element": {
$
          "action_element": {
$
             "type": "object",
             "properties": {
                   "anchor": {
                      "$ref": "#/definitions/anyUri"
                   <u>"@type":</u> {
                      "$ref": "#/definitions/type_declaration"
                 <u>},</u>
                 "description": {
                      "$ref": "#/definitions/description"
                 <u>},</u>
```

```
"descriptions": {
             "$ref": "#/definitions/descriptions"
         <u>},</u>
         "title": {
             "$ref": "#/definitions/title"
         <u>},</u>
         "titles": {
             "$ref": "#/definitions/titles"
         <u>},</u>
         "forms": {
             "type": "array",
             "minItems": 1,
             "items": {
                  "$ref": "#/definitions/form element action"
             <u>}</u>
         <u>},</u>
         "uriVariables": {
             "type": "object",
             "additionalProperties": {
                  "$ref": "#/definitions/dataSchema"
         <u>},</u>
         "input": {
             "$ref": "#/definitions/dataSchema"
         <u>},</u>
         "output": {
             "$ref": "#/definitions/dataSchema"
         },
         "safe": {
             "type": "boolean"
         },
         "idempotent": {
             "type": "boolean"
         }
    <u>},</u>
    "required": [
         "forms"
    "additionalProperties": true
<u>},</u>
"event_element": {
    "type": "object",
    "properties": {
```

```
<u>"@type":</u> {
                      "$ref": "#/definitions/type declaration"
                 },
                  "description": {
                      "$ref": "#/definitions/description"
                 <u>},</u>
                  "descriptions": {
                      "$ref": "#/definitions/descriptions"
                 <u>},</u>
                  "title": {
                      "$ref": "#/definitions/title"
                  "titles": {
                      "$ref": "#/definitions/titles"
                 <u>},</u>
                  "forms": {
                      "type": "array",
                      "minItems": 1,
                      "items": {
                          "$ref": "#/definitions/form element event"
                 <u>},</u>
                  "uriVariables": {
                      "type": "object",
                      "additionalProperties": {
                          "$ref": "#/definitions/dataSchema"
                      _}
                 <u>},</u>
                 "subscription": {
                      "$ref": "#/definitions/dataSchema"
$
                 },
                   "data": {
                      "$ref": "#/definitions/dataSchema"
                 <u>},</u>
                  "cancellation": {
                      "$ref": "#/definitions/dataSchema"
                 }
             <u>},</u>
             "required": [
                 "forms"
             "additionalProperties": true
```

```
<u>},</u>
         "link element": {
              "type": "object",
              "properties": {
<u>↑</u>
                   "href": {
                       "$ref": "#/definitions/anyUri"
                   },
                    <u>"rel": {</u>
\downarrow
                    <u>"type":</u> {
$
<u>‡</u>
                       "type": "string"
                   },
                    "type": {
+
                    "re<u>l":</u> {
$
                       "type": "string"
                   <u>},</u>
                   "anchor": {
                       "$ref": "#/definitions/anyUri"
<u>↑</u>
                   }
              },
              "required": [
                   "href"
              ],
              "additionalProperties": true
         },
         "securityScheme": {
              "oneOf": [{
                       "type": "object",
                        "properties": {
                            "@type": {
                                 "$ref": "#/definitions/type_declaration"
                            },
                            "description": {
                                 "$ref": "#/definitions/description"
                            },
                            "descriptions": {
                                 "$ref": "#/definitions/descriptions"
                            },
```

```
"proxy": {
            "$ref": "#/definitions/anyUri"
        },
        "scheme": {
            "type": "string",
            "enum": [
                "nosec"
            ]
        }
    },
    "required": [
        "scheme"
    ]
},
{
    "type": "object",
    "properties": {
        "@type": {
            "$ref": "#/definitions/type_declaration"
        },
        "description": {
            "$ref": "#/definitions/description"
        },
        "descriptions": {
            "$ref": "#/definitions/descriptions"
        },
        "proxy": {
            "$ref": "#/definitions/anyUri"
        },
        "scheme": {
            "type": "string",
            "enum": [
                "basic"
        },
        "in": {
            "type": "string",
            "enum": [
                "header",
                "query",
                "body",
                "cookie"
            ]
```

```
},
                          "name": {
                              "type": "string"
                     },
                     "required": [
                          "scheme"
                     ]
                 },
                 {
                     "type": "object",
                     "properties": {
                          "@type": {
                              "$ref": "#/definitions/type_declaration"
                          },
                          "description": {
                              "$ref": "#/definitions/description"
                          },
                          "descriptions": {
                              "$ref": "#/definitions/descriptions"
                          },
                          "proxy": {
                              "$ref": "#/definitions/anyUri"
                          },
                          "scheme": {
                              "type": "string",
                              "enum": [
                                   "cert"
+
"digest"
<u>‡</u>
                              ]
                          },
                           "identity": {
+
                           "qop": {
                              "type": "string",
                              "enum": [
                                  "auth",
                                  "auth-int"
                          <u>},</u>
                          "in": {
```

```
"type": "string",
                              "enum": [
                                  "header",
                                  "query",
                                  "body",
                                  "cookie"
                          <u>},</u>
                          "<u>name": {</u>
<u>‡</u>
                              "type": "string"
                          }
                     },
                      "required": [
                          "scheme"
                     ]
                 },
                 {
                      "type": "object",
                      "properties": {
                          "@type": {
                              "$ref": "#/definitions/type_declaration"
                          },
                          "description": {
                              "$ref": "#/definitions/description"
                          },
                          "descriptions": {
                              "$ref": "#/definitions/descriptions"
                          },
                          "proxy": {
                              "$ref": "#/definitions/anyUri"
                          },
                          "scheme": {
                              "type": "string",
                              "enum": [
                                   "digest"
                          <del>"qop": {</del>
                           "type": "string",
                          "enum": [
                              ---"auth",
                               "auth-int"
```

```
"apikey"
<u>‡</u>
                              ]
                         },
                          "in": {
                              "type": "string",
                              "enum": [
                                  "header",
                                  "query",
                                  "body",
                                  "cookie"
                              ]
                          },
                          "name": {
                              "type": "string"
                          }
                     },
                     "required": [
                          "scheme"
                     ]
                 },
                 {
                     "type": "object",
                     "properties": {
                          "@type": {
                              "$ref": "#/definitions/type_declaration"
                          },
                          "description": {
                              "$ref": "#/definitions/description"
                          },
                          "descriptions": {
                              "$ref": "#/definitions/descriptions"
                          },
                          "proxy": {
                              "$ref": "#/definitions/anyUri"
                          },
                          "scheme": {
                              "type": "string",
                              "enum": [
                                  "bearer"
                         },
```

```
"authorization": {
                                "$ref": "#/definitions/anyUri"
                           },
                           "alg": {
                            "type": "string",
                             <del>"enum": [</del>
                                 "MD5",
                                    "ES256",
                                    "ES512-256"
                                 "type": "string"
                           },
                           "format": {
                                "type": "string",
                                "enum": [
                                   <del>"jwt",</del>
                                   <del>"jwe",</del>
                                    <del>"jws"</del>
+
$
                                 "type": "string"
<u>‡</u>
                           },
                           "in": {
                                "type": "string",
                                "enum": [
                                     "header",
                                    "query",
                                     "body",
                                     "cookie"
                                ]
                           },
                           "name": {
                                "type": "string"
                           }
                       },
                       "required": [
                           "scheme"
                       ]
                  },
```

```
"type": "object",
    "properties": {
        "@type": {
            "$ref": "#/definitions/type_declaration"
        },
        "description": {
            "$ref": "#/definitions/description"
        },
        "descriptions": {
            "$ref": "#/definitions/descriptions"
        },
        "proxy": {
            "$ref": "#/definitions/anyUri"
        },
        "scheme": {
            "type": "string",
            "enum": [
                "psk"
            1
        },
        "identity": {
            "type": "string"
        }
    },
    "required": [
        "scheme"
    ]
},
{
    "type": "object",
    "properties": {
        "@type": {
            "$ref": "#/definitions/type_declaration"
        },
        "description": {
            "$ref": "#/definitions/description"
        },
        "descriptions": {
            "$ref": "#/definitions/descriptions"
        },
        "proxy": {
            "$ref": "#/definitions/anyUri"
        },
```

```
"scheme": {
                             "type": "string",
                             "enum": [
                              ---"public"
                        },
                        "identity": {
                         "type": "string"
                    "required": [
                       "scheme"
                    "type": "object",
                    "properties": {
                         <del>"@type": {</del>
                            "$ref": "#/definitions/type_declaration"
                        "description": {
                         "$ref": "#/definitions/description"
                        "descriptions": {
                            "$ref": "#/definitions/descriptions"
                         "proxy": {
                            "$ref": "#/definitions/anyUri"
                         "scheme": {
                         "type": "string",
                           <u>"enum": </u>[
+
                                 "oauth2"
                             ]
                         },
                         "authorization": {
                             "$ref": "#/definitions/anyUri"
                         },
                         "token": {
                             "$ref": "#/definitions/anyUri"
                         },
                         "refresh": {
```

```
"$ref": "#/definitions/anyUri"
                         },
                         "scopes": {
                           "type": "array",
                            "items": {
                                "type": "string"
                              "oneOf": [{
                                     "type": "array",
                                     "items": {
                                         "type": "string"
                                <u>_},</u>
                                     "type": "string"
$
                         },
                         "flow": {
                             "type": "string",
                             "enum": [
                              "implicit",
                                 "password",
                                 "client",
+
                                 "code"
                             ]
                         }
                    },
                    "required": [
                         "scheme",
                         "flow"
                    "type": "object",
                    "properties": {
                      <del>"@type": {</del>
                          "$ref": "#/definitions/type_declaration"
                       "description": {
```

```
"$ref": "#/definitions/description"
    "descriptions": {
    "$ref": "#/definitions/descriptions"
    "proxy": {
       "$ref": "#/definitions/anyUri"
    "scheme": {
      "type": "string",
       <u>"enum":</u>
       "apikey"
    "in": {
       "type": "string",
        <del>"enum": [</del>
          "header",
           "query",
          <del>"body",</del>
          <u>"cookie"</u>
    -},
   <u>"name": {</u>
     "type": "string"
→,
"required": [
    "scheme"
"type": "object",
"properties": {
    <del>"@type": {</del>
        "$ref": "#/definitions/type_declaration"
    },
    "description": {
       "$ref": "#/definitions/description"
   "descriptions": {
       "$ref": "#/definitions/descriptions"
```

```
"proxy": {
             "$ref": "#/definitions/anyUri"
            "scheme": {
            "type": "string",
             <del>"enum": [</del>
                <del>"pop"</del>
            "authorization": {
               "$ref": "#/definitions/anyUri"
            "format": {
            "type": "string",
              <del>"enum": [</del>
                <del>"jwt",</del>
                 <del>"jwe",</del>
                    <del>"jws"</del>
           <del>},</del>
<del>"alg": {</del>
 "type": "string",
     <u>"enum": [</u>
    "MD5",
     "ES256",
               "ES512-256"
           -},
               "type": "string",
          <u>"enum":</u>
         "header",
          "query",
               "body",
               "cookie"
            <del>},</del>
           <u>"name": {</u>
            "type": "string"
 <u>"required": [</u>
```

```
"scheme"
                ]
            }
        ]
    "anyUri": {
       "type": "string",
        "format": "iri-reference"
    }
},
"type": "object",
"properties": {
    "id": {
        "type": "string",
        "format": "uri"
    },
    "title": {
        "$ref": "#/definitions/title"
    },
    "titles": {
        "$ref": "#/definitions/titles"
    },
    "properties": {
        "type": "object",
        "additionalProperties": {
            "$ref": "#/definitions/property_element"
        }
    },
    "actions": {
        "type": "object",
        "additionalProperties": {
            "$ref": "#/definitions/action_element"
        }
    },
    "events": {
        "type": "object",
        "additionalProperties": {
            "$ref": "#/definitions/event_element"
        }
    },
    "description": {
        "$ref": "#/definitions/description"
```

},

```
"descriptions": {
    "$ref": "#/definitions/descriptions"
},
"version": {
    "type": "object",
    "properties": {
        "instance": {
            "type": "string"
        }
    },
    "required": [
        "instance"
    ]
},
"links": {
    "type": "array",
    "items": {
        "$ref": "#/definitions/link_element"
    }
},
"forms": {
    "type": "array",
    "minItems": 1,
    "items": {
        "$ref": "#/definitions/form_element_root"
    }
},
"base": {
    "$ref": "#/definitions/anyUri"
},
"securityDefinitions": {
    "type": "object",
    "minProperties": 1,
    "additionalProperties": {
        "$ref": "#/definitions/securityScheme"
    }
},
"support": {
    "$ref": "#/definitions/anyUri"
},
"created": {
     "type": "string"
```

```
"type": "string",
            "format": "date-time"
},
        "modified": {
             "type": "string"
#
              "type": "string",
            "format": "date-time"
<u>‡</u>
        },
        "security": {
            "type": "array",
            "minItems": 1,
            "items": {
                "type": "string"
              "oneOf": [{
                     "type": "string"
                     <u>"type": "array",</u>
                     "minItems": 1,
                     "items": {
                         "type": "string"
                 }
$
        },
        "@type": {
             "$ref": "#/definitions/type_declaration"
        },
        "@context": {
             "$ref": "#/definitions/thing-context"
        }
    },
    "required": [
        "title",
        "security",
        "securityDefinitions",
```

```
"@context"
],
"additionalProperties": true
}
```

C. Thing Description Templates

This section is non-normative.

A *Thing Description Template* is a description for a *class* of <u>Things</u>. It describes the properties, actions, events and common metadata that are shared for an entire group of <u>Things</u>, to enable the common handling of thousands of devices by a cloud server, which is not practical on a per-<u>Thing</u> basis. The Thing Description Template uses the same core vocabulary and information model from § 5. TD Information Model.

The Thing Description Template enables:

- management of multiple Things by a cloud service.
- simulation of devices/ Things that have not yet been developed.
- common applications across devices from different manufacturers that share a common <u>Thing</u> model.
- combining multiple models into a Thing.

The Thing Description Template is a logical description of the interface and possible interaction with devices (properties, actions and events), however it does not contain device-specific information, such as a serial number, GPS location, security information or concrete protocol endpoints.

Since a Thing Description Template does not contain a <u>Protocol Binding</u> to specific endpoints and does not define a specific security mechanism, the *forms* and *securityDefinitions* and *security* keys must not be present.

The same Thing Description Template can be implemented by <u>Things</u> from multiple vendors, a <u>Thing</u> can implement multiple Thing Description Templates, define additional metadata (vendor, location, security) and define bindings to concrete protocols. To avoid conflicts between properties, actions and events from different Thing Description Templates that are combined into a common <u>Thing</u>, all these identifiers must be unique within a <u>Thing</u>.

A common Thing Description Template for a class of devices enables writing applications across vendors and creates a more attractive market for application developers. A concrete Thing Description

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can implement multiple Thing Description Templates and thus can aggregate function blocks into a combined device.

The business models of cloud vendors are typically built on managing thousands of identical devices. All devices with the same Thing Description Template can be managed in the same way by cloud applications. It is easy to create multiple simulated devices, if the interface and the instance are treated separately.

Since a Thing Description Template is a subset of the Thing Description in which some optional and mandatory <u>Vocabulary Terms</u>

do not exist, however, it can be serialized in the same way and in the same formats as a Thing Description. Note that Thing Template instances cannot be validated in the same way as Thing Description instances due to some missing mandatory terms.

C.1 Thing Description Template Examples

This section shows a Thing Description Template for a lamp and a Thing Description Template for a buzzer.

C.1.1 Thing Description Template: Lamp

EXAMPLE 36: MYLAMPTHINGTEMPLATE SERIALIZED IN JSON { "@context": ["https://www.w3.org/2019/wot/td/v1"], "@type" : "ThingTemplate", "title": "Lamp Thing Description Template", "description" : "Lamp Thing Description Template", "properties": { "status": { "description" : "current status of the lamp (on off)", "type": "string", "readOnly": true } }, "actions": { "toggle": { "description" : "Turn the lamp on or off" } }, "events": { "overheating": { "description": "Lamp reaches a critical temperature (overheating)", "data": {"type": "string"} } } }

C.1.2 Thing Description Template: Buzzer

EXAMPLE 37: MYBUZZERTHINGTEMPLATE SERIALIZED IN JSON { "@context": ["https://www.w3.org/2019/wot/td/v1"], "@type" : "ThingTemplate", "title": "Buzzer Thing Description Template", "description" : "Thing Description Template of a buzzer that makes noise for "actions": { "buzz": { "description" : "buzz for 10 seconds" } } }

D. JSON-LD Context Usage

This section is non-normative.

The present specification introduces the <u>TD Information Model</u> as a set of constraints over different <u>Vocabularies</u>, i.e. sets of <u>Vocabulary Terms</u>. This section briefly explains how a machine-readable definition of these constraints can be integrated into client applications, by making use of the mandatory @context of a TD document.

Accessing the <u>TD Information Model</u> from a TD document is done in two steps. First, clients must retrieve a mapping from JSON strings to IRIs. This mapping is defined as a JSON-LD context, as explained later. Second, clients can access the constraints defined on these IRIs by dereferencing them. Constraints are defined as logical axioms in the RDF format, readily interpretable by client programs.

All <u>Vocabulary Terms</u> referenced in § 5. TD <u>Information Model</u> are serialized as (compact) JSON strings in a TD document. However, each of these terms is unambiguously identified by a full IRI, as per the first Linked Data principle [<u>LINKED-DATA</u>]. The mappings from JSON keys to IRIs is what the @context value of a TD points to. For instance, the file at

```
https://www.w3.org/2019/wot/td/v1

includes the following mappings (among others):

properties → https://www.w3.org/2019/wot/td#hasPropertyAffordance
object → https://www.w3.org/2019/wot/json-schema#ObjectSchema
```

```
basic \rightarrow https://www.w3.org/2019/wot/security#BasicSecurityScheme href \rightarrow https://www.w3.org/2019/wot/hypermedia#hasTarget ...
```

This JSON file follows the JSON-LD 1.1 syntax [<u>JSON-LD11</u>]. Numerous JSON-LD libraries can automatically process the @context of a TD and expand all the JSON strings it includes.

Once every <u>Vocabulary Term</u> of a TD is expanded to a IRI, the second step consists in dereferencing this IRI to get fragments of the <u>TD Information Model</u> that refer to that <u>Vocabulary Term</u>. For instance, dereferencing the IRI

```
https://www.w3.org/2019/wot/json-schema#ObjectSchema
```

results in an RDF document stating that the term ObjectSchema is a <u>Class</u> and more precisely, a sub-class of DataSchema . Such logical axioms are represented in RDF using formalisms of various complexity: here, sub-class relations are expressed as RDF Schema axioms [<u>RDF-SCHEMA</u>]. Moreover, these axioms may be serialized in various formats. Here, they are serialized in the Turtle format [TURTLE]:

```
<https://www.w3.org/2019/wot/json-schema#ObjectSchema>
    a rdfs:Class .
<https://www.w3.org/2019/wot/json-schema#ObjectSchema>
rdfs:subClassOf
<https://www.w3.org/2019/wot/json-schema#DataSchema>
.
```

By default, if a user agent does not perform any content negotiation, a human-readable HTML documentation is returned instead of the RDF document. To negotiate content, clients must include the HTTP header Accept: text/turtle in their request.

E. Recent Specification Changes

↑E.1 ↑↑ Changes from Second Candidate Recommendation ↑

- ↑ At-risk features ↑↑ CertSecurityScheme ↑,↑ PublicSecurityScheme ↑,↑

 PoPSecurityScheme ↑↑ as well as ↑↑ implicit ↑,↑ password ↑↑ and ↑↑ client ↑↑ flows in

 ↑↑ OAuth2SecurityScheme ↑↑ were removed. ↑
- ↑ In section ↑↑ § ↑↑ 5.3.2 ↑↑ Data Schema Vocabulary Definitions ↑,↑ clarified the relationship

between data schemas and content types. ↑

- ↑ In section ↑↑ § ↑↑ 6.3.9 ↑↑ forms ↑,↑ clarified the expectations of ↑↑ Consumers ↑↑ and ↑↑

 Things ↑↑ for operation types ↑↑ writemultipleproperties ↑,↑ readmultipleproperties

 ↑↑ and ↑↑ readallproperties ↑.
- ↑ In section ↑↑ § ↑↑ 8.3.1 ↑↑ Protocol Binding based on HTTP ↑,↑ the contexts in which default values ↑↑ GET ↑↑ or ↑↑ PUT ↑↑ are used for vocabulary term ↑↑ htv:methodName ↑↑ were clarified. ↑
- ↑ The example Thing Description in appendix section ↑↑ § ↑↑ A.2 ↑↑ MyIlluminanceSensor
 Example with MQTT Protocol Binding ↑↑ was improved to make a better example using MQTT.
 ↑

↓E.1 ↓ ↑ E.2 ↑ Changes from First Candidate Recommendation

• General

- Clarified definition of <u>TD Processor</u> and related text that implementations may be TD producer or TD consumer only as correctly assumed by all implementations (no impact on implementations).
- Clarified uniqueness and possible values for Thing id, in particular privacy-preserving values such as URIs with local IP addresses or temporary and mutable URIs.
- Updated references.
- Improved text on semantic annotations.
- Updated Example 2 to fix bugs.
 - name was renamed to title to reflect a previous change of the § 5.3.1.1 Thing Class definition.
 - Otype was removed from the forms.
- Updated Example 33 to fix bug.
 - op was added to the form of the status Property to override the default value.
 - The default value of ["readproperty", "writeproperty"] would have caused both \$\frac{1}{2}\$ forms \$\frac{1}{2}\$ to have the method GET, which was not the intention.
- Minor editorial text improvements and fixes.
- Terminology
 - Section § 3. Terminology is non-normative.
- TD Information Model

- In section § 5.3.1.1 Thing, the <u>vocabulary term</u> id of a <u>Thing</u> was made optional. Also, mentions of uniqueness of id were removed because there is not such a requirement.
- o Adjusted location of a label in Figure 1.
- Fix uppercase *MAY* to lowercase that was not part of an assertion sentence/markup (TD Context Extension for data schema; no impact on implementations).
- o The title of Figure 2 "JSON schema vocabulary" was changed to "Data schema Vocabulary".
- The <u>vocabulary term</u> flow of <u>OAuth2</u> authentication security configuration now does not have a default value. Therefore, it was removed from section § 5.4 <u>Default Value</u>
 Definitions.

• TD Representation Format

In section § 6.3.9 forms, the expectation for <u>Consumers</u> and <u>Things</u> in handling the operation type writeallproperties is clarified.

• TD Context Extensions

- o Improved Example 28 and Example 29
 - Use saref: TemperatureSensor to semantically annotate the Thing with an extension class.
 - Use SAREF to also annotate Property to be consistent across the examples.
 - Use newer version of ontology-of-units-of-measure (om).
- Updated Example 29 to clarify the design difference from that of Example 2.

• Behavioral Assertions

- Section § 8.2 Data Schemas describes the precise conditions as to when Things may return
 additional data and Consumers have to accept additional data even when such data is not
 described in the data schemas.
- Section § 8.3.1 Protocol Binding based on HTTP was so renamed from "HTTP Protocol Binding".

• Security and Privacy Considerations

- Updated section § 9. Security and Privacy Considerations to match the vocabulary term id of a Thing being non-unique and optional.
 - Added mitigations such as "filtering out IDs when not needed for a use case".
 - Added risks such as fingerprinting the type of a device.
 - Added risks for globally unique IDs, and points out that this is not required and that distributed cryptographic mechanisms or locally-scoped ids can be used.

• Appendix

- Appendix section § C. Thing Description Templates was so renamed from "Thing Templates".
- Appendix section § D. JSON-LD Context Usage now explains the two steps to retrieve the TD information model in RDF.
- A reference to the WoT Architecture specification [WOT-ARCHITECTURE] is informative.

\downarrow E.2 \downarrow \uparrow E.3 \uparrow Changes from Third Public Working Draft

Changes from Third Public Working Draft are described in the Candidate Recommendation

F. Acknowledgements

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Finally, special thanks to Joerg Heuer for leading the WoT IG for 2 years from its inception and guiding the group to come up with the concept of WoT building blocks including the Thing Description.

G. References

G.1 Normative references

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```
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↑[html] ↑
```

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