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Towards an ontology of HTTP interactions

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Abstract. Enterprise information systems have adopted Web-based foundations for exchanges between heterogeneous programmes. These programs provide and consume via Web APIs some resources identified by URIs, whose representations are transmitted via HTTP. Furthermore HTTP remains at the heart of all Web developments (Semantic Web, linked data, IoT...). Thus, situations where a program must be able to reason about HTTP interactions (request-response) are multiplying. This requires an explicit formal specification of a shared conceptualization of those interactions. A proposal for an RDF vocabulary exists, developed with a view to carrying out web application conformity tests and record the tests outputs. This vocabulary has already been reused. In this report we propose to adapt and extend it for making it more reusable.

The content of this report has been published in French [16]³ at IC 2020.

Keywords: HTTP interaction, Description Logic, Ontology, RDF, OWL, SPARQL, Competency Questions

1 Introduction

The Hypertext Transfer Protocol (HTTP) is, together with the logical addressing (URI) and HTML, the basic building block of the Web. While HTTP remains at the heart of Web development, current enterprise information systems use it routinely for exchanges between heterogeneous programs: to this aim, all is needed is an HTTP server on the one side and an HTTP client on the other. Despite its apparent simplicity the HTTP protocol is quite large, it covers all aspects of client-server communications, while keeping it open for potential evolutions. The size of the HTTP 1.1 specification which consists currently in 8 IETF RFCs, refined and extended by other RFCs, demonstrates that fact. This specification defines constraints that impact not only the implementers of Web Servers but also application developers that are implementing request handlers: they need to ensure that their request handlers conform to the semantics of HTTP. Our goal is to formalize the

³ <https://hal.archives-ouvertes.fr/hal-02888065>

HTTP specification to be able to describe *Web interactions* in a sufficiently precise way for enabling a mechanized verification of protocol conformance. Since the beginning of the Web various proposals have been made to describe interactions between Web clients and a Web server, with different means and objectives. Many of them are "machine-readable" but are limited to the syntactic level and do not rely on an ontological description of HTTP interactions. The main difficulty when describing Web interactions consists in taking into account the presence of hypermedia links in the representation of the Web resources. The point is that HTTP mixes the data and the control over that data. This makes things easy for humans (developers) to interact with. However it is hard to describe it formally, and it is still difficult for machines to interact robustly when using it. In this paper we propose an ontology specified in Description Logic for describing Web interactions, with the following contributions:

- We use the $SR\mathcal{OIQ}^{(D)}$ Description Logic to describe the proposed ontology, which refines the initial W3C draft RDF Vocabulary for HTTP [12]. In this way we characterize more precisely the properties between already identified elements and we properly introduce the new ones.
- HTTP message headers represent an associative array with heterogeneous value types: we provide a way to describe headers in a generic manner while enabling to express more precisions for specific ones such as the `Location` header whose value is linked to a new resource (Section 4.5).
- HTTP allows the usage of various representation formats in the body payload by making use of Media Type declarations. This variability is required for HTTP genericity, but it makes it difficult to formalize the interaction aspect of the protocol regarding the exchanged content: we propose a way to describe uniformly both the data and meta-data of messages for a subset of the allowed content types (Section 4.6).
- URIs primary goal is to identify a resource, however in the context of Web APIs the optional query part of the URI is extensively used to parameterize the behavior of the server request handler. We define a set of properties that can be used to represent the various parts of an URI and show how query parameters can be accessed (Section 4.3).
- Our ontology is implemented⁴ with Protégé using OWL 2 DL, which corresponds to the $SR\mathcal{OIQ}^{(D)}$ Description Logic with the specificity of using URIs as identifiers for both classes and individuals. This facilitates the description of the hypermedia links present in both the message data and meta-data. We use the HermiT reasoner to validate its satisfiability and consistency. We also added some representative sets of individuals, representing real Web interactions, to verify that the SPARQL queries implementing our Competency Questions (representing our knowledge representation needs) can be performed.

We first provide some background on the HTTP protocol with an overview of the W3C RDF vocabulary for HTTP in Section 2, we precise our problem requirements in Section 3, and we present our ontology in Section 4. Before concluding in

⁴ <https://labs.nereide.fr/mthl/http>

Section 7 we situate our proposal with respect to existing solutions that tackled the issue of describing HTTP interactions in Section 6.

2 Background

HTTP is a standard managed by the Internet Engineering Task Force (IETF). Starting from the first proposal of Tim Berners-Lee, a way to describe the transmitted data formats (MIME headers) was early integrated, then came many other efficiency-related features (persistent connection, caching) together with transmission security considerations (HTTPS, encryption), which result in the power of expressing rich and diverse information about client-server interactions. The last HTTP 1.1 specification, produced in 2014, is declined in a serie of 8 RFCs where the principal ones are RFC 7230 which defines the message syntax and routing aspect of the protocol and RFC 7231 which defines the semantics and content aspects. Despite the clarifications contained in these RFC, and the proposed optimisations in HTTP 2⁵, this standard on which a vast majority of current applications are based today stays voluntarily open to make room for new inventions.

While the consultation of the IETF RFCs is always useful and necessary for developers, programs also regularly have to deal with elements of this protocol and would benefit from being able to interpret it, at least partly. An RDF vocabulary for HTTP was developed to support Web accessibility evaluation tools [12]. It is used in EARL⁶, a format for expressing the evaluation results, and describes essentially the HTTP headers exchanged between a client and a server. Although complete for their requirements, the authors left it at the stage of a proposal (W3C Working Group Note, 2017).

This proposal can be considered as an application ontology [8], whose purpose is to represent specificities of HTTP interactions on which Web APIs rely, while a related domain ontology would allow, for instance, to declare and describe any specific problem, function, or algorithm, whether executed using Web APIs or not. Figure 1 gives a visual representation of main classes and properties contained in the HTTP RDF Vocabulary [12]. This vocabulary defines 14 classes and 25 properties in the `http` namespace, plus 11 classes and many properties (including those of DCterm vocabulary) in four other namespaces, dedicated to content, headers, methods and status codes descriptions.

Basically HTTP is a request/response message protocol where a client sends a request message to a server which then replies with a response message. Architecturally things are more complex because there are intermediaries (proxy/gateway) which intercept messages to provide for example the possibility to forward messages or to implement some caching mechanism. However from the point of view of a client agent those details do not impact the simple request/response model. As illustrated in Figure 1, a message has a header part and a body part and there is two kinds of messages, the requests and the responses. A request is further characterized by a URI and a method, and a response comes with a status code. Let

⁵ <https://tools.ietf.org/html/rfc7540>

⁶ <https://www.w3.org/WAI/standards-guidelines/earl/>

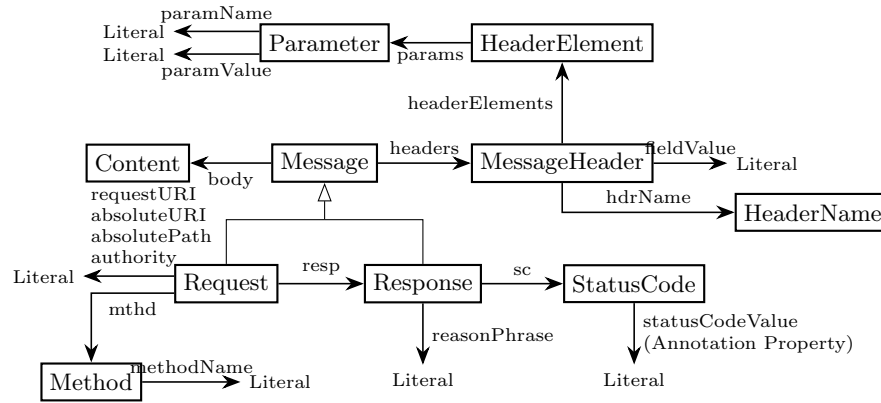


Fig. 1. Main elements of W3C HTTP RDF Vocabulary.

us use a simple example to explain how to represent a Web API interaction with this vocabulary. This example represented in Figure 2 consists in an interaction between a broker client agent sending a request to a registrar server for registering a number of identifiers. The request contains the wanted number of identifiers to register and the server replies with a 201 status code to denote the creation of a new resource corresponding to that registered collection of identifiers. We provide in Figure 3 the RDF representation of this interaction, following W3C HTTP RDF Vocabulary. The used RDF serialisation is Turtle with namespace prefixes reported in Table 1. The RDF graph consists in a pair of instances of `http:Request` and `http:Response` classes which are linked by a `http:resp` property, which defines one interaction. An instance of `http:Request` must have a method and a target URI. In our example the property used for the target URI is `http:absolutePath`, a sub-property of `http:requestURI`. Notice that for the header content we use the `hdrName / fieldValue` representation because in this example header names are predefined ones, while it is also possible to describe any list of key-value pairs by using class `Parameter`.

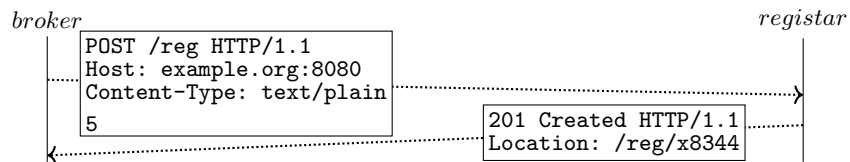


Fig. 2. Interaction between a broker client and a registrar server

An important aspect of the W3C HTTP RDF Vocabulary is that it reifies the methods, headers and status codes whose semantics is precisely defined in RFCs, while also representing them by a string literal which enables to deal with ad-hoc

```

_:req a http:Request ;
  http:mthd mthd:POST ;
  http:absolutePath "/reg" ;
  http:headers [
    http:hdrName hdr:Host ;
    http:fieldValue "example.org:8080"
  ] , [
    http:hdrName hdr:ContentType ;
    http:fieldValue "text/plain"
  ] ;
  http:resp _:resp ;
  http:body [
    a cnt:ContentAsBase64 ;
    dct:isFormatOf [
      a cnt:ContentAsText ;
      cnt:chars "5"
    ]
  ] .

_:resp a http:Response ;
  http:sc sc:Created ;
  http:headers [
    http:hdrName hdr:Location ;
    http:fieldValue "/reg/x8344"
  ] .

```

Fig. 3. Turtle representation of the registrar interaction example

Table 1. Namespace prefixes used in the registrar examples

Prefix	Namespace
http:	http://www.w3.org/2011/http#
mthd:	https://www.w3.org/2011/http-methods#
hdr:	http://www.w3.org/2011/http-headers#
sc:	http://www.w3.org/2011/http-statusCodes#
cnt:	http://www.w3.org/2011/content#
dct:	http://purl.org/dc/terms/

headers or status codes. This matches the extensibility requirement of the HTTP protocol. In the registrar example of Figure 2, we are only using standard methods, headers and status code. As a consequence they are identified by a URI instead of a literal. An interaction is an instance of property `http:resp`. It is characterized by the status code number associated to the response and the proposed vocabulary allows user to determine it by identifying the class associated with this status code number. The status code number must have 3 digits and its class is defined by the first digit where:

Class				
Informational	Successful	Redirection	Client Error	Server Error
Status codes [[100, 199]]	[[200, 299]]	[[300, 399]]	[[400, 499]]	[[500, 599]]

Those classes are defined in the namespace associated with the prefix `sc:` which is part of the HTTP vocabulary. Each reified status code is an instance of its corresponding class. In our example, the status code is 201 and we represent it by the individual `sc:Created`, instance of class `sc:Successful`.

Another aspect which is important to consider is the body part of the message, which is its content payload. The HTTP protocol supports the usage of multiple formats for the same resource, which are identified by Media-Type defined by the `Content-Type` header. In our example the request contains the literal "5" with Media-Type `text/plain`. The `cnt:Content` class provides a way to associate multiple representation views of the same body payload. The `http:body` property is always associated with a `cnt:ContentAsBase64` but we can associate it with the `dct:hasFormat` property to a textual representation using a `cnt:ContentAsText` resource.

3 Problem Statement

Other works use this RDF vocabulary, for example [24] uses it to define `RESTdesc`, a hypermedia API definition framework for automatic composition of hypermedia APIs. "Hypermedia API" refers to those Web APIs that effectively follow the four constraints of the Representational State Transfer (REST) architectural style [7], in particular the fourth: *hypermedia as the engine of application state*. We are also interested in hypermedia APIs, with a goal of automatic verification of the conformance of a client requirement with respect to a server supply: we aim at representing both the requirement and the supply specifications as RDF graphs. This brings us to the need to formally represent the interaction between an HTTP client and an HTTP server, both of them using hypermedia with RDF linked content. But we found limitations to simply use the proposition from [12] as [24] does.

To illustrate why, we notice that the example we used to present the W3C HTTP Vocabulary in RDF is not realistic because, very often, parameters in Web APIs are passed in the query string. Moreover the link associated with the Location header is a Literal where we would want to have it as a URI. We would like to express the conversation shown in Figure 4.

This conversation is composed of two interactions. The first one is similar to the example of Figure 2 but with the difference that the number of requested identifiers takes the form of a `count` query parameter. This difference is meaningful given the wide adoption of this convention which is compatible with browser form handling. The second interaction consists in dereferencing the link provided by the `Location` header of the response of the first interaction. The dereferenced link has a response that contains a body content in the JSON format, which has its own structure which is more complex than the plain string used in the request in Figure 2. This is not possible to attach meaningful semantics to this conversation by simply using the HTTP RDF vocabulary.

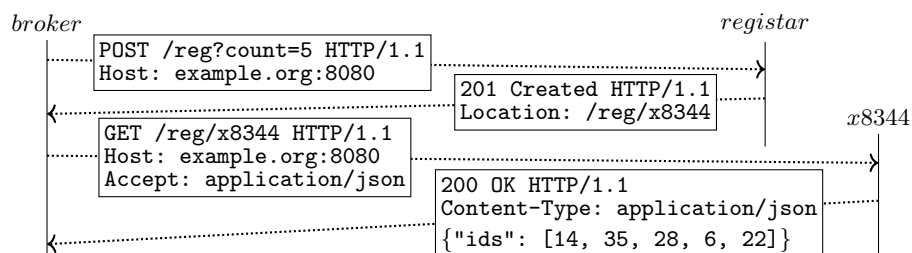


Fig. 4. Hypermedia conversation between a broker and a registrar

Another aspect is that the HTTP RDF vocabulary is based on the RFC 2616 which has been superseded by other RFC documents and in particular by the RFC 7231. This topic of this updated specification is dedicated to the semantics of HTTP 1.1. Those semantics have been mostly preserved by newer versions of the protocols. Those upgrades are mainly concerned by performance aspect in the transport layer meaning either by optimizing TCP connections in the case of HTTP 2 or replacing it with UDP in the case of HTTP 3.

Our proposals presented in next section aim at overcoming the previously mentioned limitations, but in order to precisely evaluate their usefulness we also devise a set of Competency Questions that we would like to answer more easily with our proposed ontology. Competency Questions reflect functional requirements representing ontological commitments [19,3,9].

CQ 1 (Media type) *What is the media-type associated with a message body?*

CQ 2 (Interaction result) *What is the status code number of an interaction?*

CQ 3 (Header values, e.g. location header) *What is the target URI provided in the location header of a response?*

Being able to answer to the previous questions enable to answer to the following one:

CQ 4 (Conversation result) *What is the status code of the combinaison of two interactions, the second query targeting the URI provided in the `location` header of the first response?*

CQ 5 (Content negotiation) *Does the media-type of a response body match one of those declared in the `Accept` header of its corresponding request?*

We should be able to also query the body content when it is expressed in RDF:

CQ 6 (Body content) *What are the values associated with a given property p inside the body of an HTTP message?*

We should be able to ask for parameters in the URI query string:

CQ 7 (Query parameters) *What is the value of a specific parameter, e.g. named "age", passed in the query string of the target resource?*

4 Extending the HTTP ontology

We are using the $\mathcal{SROLQ}^{(\mathcal{D})}$ Description Logic, which is associated with OWL2 DL, to describe our ontology. This formalisation is grounded in the former HTTP RDF vocabulary by the EARL W3C Working Group [12]. We use the RDF property/class terminology instead of the classical role/concept terminology. We denote by \top the class of all individuals and by \mathcal{D} the class of data literals meaning the class of things that cannot be the subject of any of properties and that can have only one interpretation. \top and \mathcal{D} classes are disjoint.

4.1 Message

Communications over the HTTP protocol are based on request/response messages exchanged between a client sending a request and a server providing the response. A message is defined by a collection of headers which represent the metadata and a body which contains the data payload of the message. It is not required for a message to have any header elements or a body content.

$$Message \sqsubseteq \forall headers.Headers \sqcap \forall body.Content \quad \top \sqsubseteq \leq_1 body.\top$$

The property *body* is functional. The details regarding the *Headers* and *Content* classes are provided in Section 4.5 and Section 4.6 respectively. There are only two disjoint kinds of messages which are either requests or responses.

$$Message \equiv Request \sqcup Response \quad Request \sqcap Response \sqsubseteq \perp$$

We relate those two kinds of messages with the property *resp* whose domain is *Request* and range is *Response*.

$$\exists resp.\top \sqsubseteq Request \quad \top \sqsubseteq \forall resp.Response$$

It is possible to have multiple responses for the same request with some restrictions that are explained in Section 4.4.

4.2 Request

A request is a message which must have a method and an effective URI. We define the class *Method* as a superclass of all standardised request methods using *nominals*. We do not use equivalence relationship because request methods can be extended.

$$\begin{aligned} \{\text{GET, HEAD, POST, PUT, DELETE, CONNECT, OPTIONS, TRACE, PATCH}\} &\sqsubseteq \textit{Method} \\ \textit{Request} &\sqsubseteq \textit{Message} \sqcap \exists \textit{mthd}.\textit{Method} \sqcap \exists \textit{uri}.\textit{URI} \\ \top &\sqsubseteq \leq_1 \textit{mthd}.\textit{Method} \quad \top \sqsubseteq \leq_1 \textit{uri}.\textit{URI} \end{aligned}$$

The properties *mthd* and *uri* are functional. The value associated with the property *uri* is a URI following the syntax described in RFC 3986 [2,] which provides the following illustrative example:

$$\underbrace{\text{http}}_{\textit{scheme}} : // \underbrace{\text{example.com:8042}}_{\textit{authority}} / \underbrace{\text{over/there}}_{\textit{path}} ? \underbrace{\text{name=ferret}}_{\textit{query}} \# \underbrace{\text{nose}}_{\textit{fragment}}$$

The property *uri* abstracts the possible concrete syntaxes found in the target URI which can take multiple forms [5, Section 5.3]. Some of them require to combine the value of the `Host` header and the protocol scheme (`http` or `https`) to compute the absolute URI. When the request target has an absolute form, the target URI corresponds to the effective request URI. The various component parts of the URI associated with the property *uri* can be extracted from it with the properties *scheme*, *authority*, *path*, *query*, *fragment*. Those properties have literal values. This choice differs from the W3C HTTP vocabulary which uses the properties `http:requestURI`, `http:absolutePath` and `http:absoluteURI` to provide different views of the target URI but represented as literals. The property *uri* corresponds to the same value as `http:absoluteURI` but lifted to an actual URI. This matters in the context of RDF because only URIs can be the subject of properties. This choice allows us to answer to CQ 7 because we can associate to individuals of class `URI` a property `queryParams` to explicit the query parameters when they are represented by the value associated with the property *query*, as detailed in Section 4.3. The solution in the W3C HTTP vocabulary is to represent the target URI as a string and this is not enough to decompose the parameters.

4.3 Query parameters

One important aspect when describing an HTTP request is to define parameters, which can be passed in multiple ways but one basic way is to use the query part of the URI meaning the characters between the `?` and `#`. In the context of Web applications the format of this part of the URI conforms to the `application/x-www-form-urlencoded`⁷ media type which enables passing key-value pairs as arguments which are denoted *k* and *v* in the following example.

$$\underbrace{\underbrace{\overbrace{\text{age}}^k = \overbrace{54}^v} \& \overbrace{\text{id}}^k = \overbrace{\text{XPZIJ4}}^v}}_{\textit{query}}$$

⁷ <https://url.spec.whatwg.org/#concept-urlencoded>

With the property *query* we can access the string literal corresponding to the encoded version. We want to access those key-value pairs semantically with proper properties and classes. We then define the property *queryParams*.

$$URI \sqsubseteq \forall queryParams.Parameter \quad Parameter \equiv \exists name.\mathcal{D} \sqcap \exists value.\mathcal{D}$$

Our representation of URIs is depicted in Figure 5.

4.4 Response

A response is a message which must have a status instance accessible via the property *sc* which itself has a status code accessible via the property *code* whose value must be a 3 digit number. This number is present in the status line of the concrete response.

$$Response \sqsubseteq Message \sqcap \exists sc.Status \quad Status \sqsubseteq \exists code.[[000, 999]] \\ \top \sqsubseteq \leq_1 sc.\top \quad \mathcal{D} \sqsubseteq \leq_1 code.\mathcal{D}$$

The properties *sc* and *code* are functional. We use the compact notation $[[000, 999]]$ to denote a non-negative integer datatype with a restriction that its value is less or equal than 999. This would take the following form in OWL 2 turtle syntax:

```
:threeDigit a rdfs:Datatype ;
  owl:equivalentClass [
    a rdfs:Datatype ;
    owl:onDatatype xsd:nonNegativeInteger ;
    owl:withRestrictions ([ xsd:maxInclusive 999 ]) ] .
```

There exists a bijection between status instances and status codes which means that the status code is characteristic of its instance. For example we can define the status instance *Created* which means *a new resource has successfully been created* by asserting that this is the unique status instance with a status code of 201.

$$\{Created\} \equiv Status \sqcap \exists code.201$$

Status codes can effectively be thought as the syntactic element that denotes the meaning of the response status. The meaning of the response status is represented by the status instance. While each status has specific meaning they can be classified in *Status* subclasses that characterise the general result of the interaction.

$$Successful \equiv Status \sqcap \exists code.[[200, 299]] \quad ClientError \equiv Status \sqcap \exists code.[[400, 499]] \\ Redirection \equiv Status \sqcap \exists code.[[300, 399]] \quad ServerError \equiv Status \sqcap \exists code.[[500, 599]] \\ Informational \equiv Status \sqcap \exists code.[[100, 199]]$$

All the instances of those classes define *final responses* with the exception of the instance of the *Informational* class which defines *interim responses* meaning temporary responses that will eventually be followed by a *final response*. [6, Section 6.2]. This means that multiple responses can be associated with one request but only one of them can be a *final response*.

$$\exists sc.Informational \sqsubseteq Interim \quad Final \equiv Response \sqcap \neg Interim$$

Definition 1 (Interaction). An interaction is an instance $resp(q, r)$ of the property $resp$ such that q is an instance of *Request* and r is an instance of *Final*.

In Figure 5 we do not represent the sub-classes of *Status*, as we do not represent those of *StatusCode* in Figure 1.

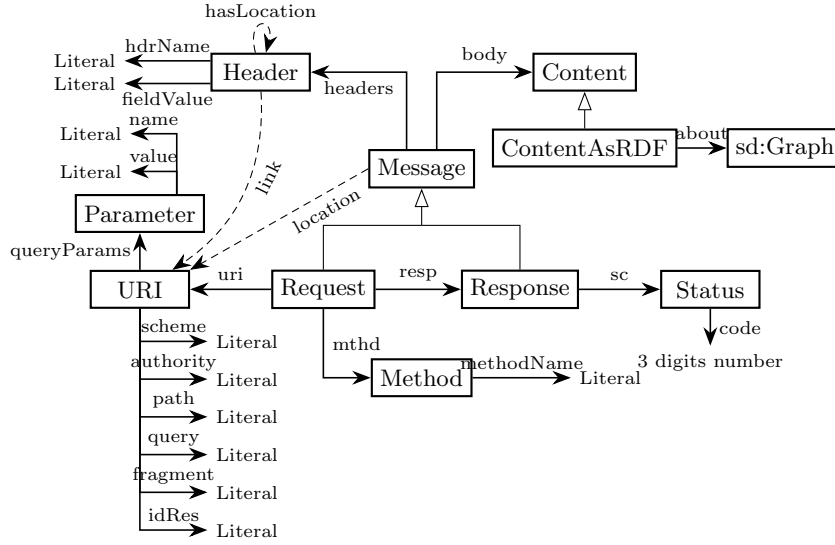


Fig. 5. Main elements of our ontology for HTTP.

4.5 Header fields

A *Message* can contain multiple headers. A header is composed of a field name and a field value which are both literals.

$$Header \sqsubseteq \exists \text{hdrName}.\mathcal{D} \sqcap \exists \text{fieldValue}.\mathcal{D}$$

Such semantic view is still not that descriptive because of the usage of literals which are just strings. To refine the semantic of standard headers such as *Location* and *Content-Type*, we can use a property chain in order to directly refer to their values with properties reflecting their names. This is motivated by our Competency Questions CQ 1 and CQ 3. It is common to have a location header such as in the following example:

Location: <http://example.org/new/resource>

We want to access simply to the associated link. We can then refine the corresponding header instances by stating that if its header field name is "Location" then it has a *link* property. The value of that property corresponds to the URI

literal contained in the property *fieldValue*, but lifted to an URI. This enables the definition of properties on that value.

$$Header \sqcap \exists \text{hdrName}.\{\text{"Location"}\} \sqsubseteq \exists \text{link}.\top$$

In order to describe the associative nature of message headers we can use property chain axioms to associate request to the lifted semantic value associated with standards headers. For example for the `Location` header we can define the property *location*. To achieve that we introduce a reflexive property *hasLocation* for only those instances that have a `Location` field name.

$$\begin{aligned} \exists \text{hdrName}.\{\text{"Location"}\} &\equiv \exists \text{hasLocation}.\text{Self} \\ \text{headers} \circ \text{hasLocation} \circ \text{link} &\sqsubseteq \text{location} \end{aligned}$$

This mechanism is illustrated in Figure 5 for the `Location` header. We propose to do that for all predefined headers, and in particular the `Content-Type` header.

The W3C HTTP vocabulary approach is different in that regard because it tries to augment a literal view of headers with the property `http:headerElements` whose values can be decomposed with `http:elementName`, `http:elementValue` and `http:params` in a generic way. The representation of heterogeneous associative data structures like message headers by a conjunction of well characterized property constraints like the `Location` header is more precise despite requiring a wider TBox.

4.6 Body Content

While the header fields are the representation metadata, the payload body is the representation data. As defined in Section 4.1, this data is accessible from a message via the property *body* which value is always of class *Content*. The W3C HTTP vocabulary delegates the representation of the body values to an external Content Vocabulary [11] which takes into account the fact that a resource can be associated with multiple representations in various formats. Unfortunately the HTTP W3C vocabulary restricts the range of the property *body* to *ContentAsBase64* which does not seem to match the semantics of HTTP where the actual format of the body is advertised by the `Content-Type` and `Content-Encoding` headers. The first one is mandatory when having a body and its value is a media type \mathcal{M} . Those headers allow the recipient of a message to know how to interpret the body content. For example when a `Content-Type` of `text/plain` and no `Content-Encoding` is present the *body* value should directly be an instance of the *ContentAsText* class.

$$\exists \text{body}.\text{Content} \sqsubseteq \exists \text{content-type}.\mathcal{M}$$

In CQ 2 we want to access the links provided in a message. Some of those links are provided in the header field values but others are provided in the body. This is true when the `Content-Type` corresponds to an hypermedia format. Since RDF provides a native way to represent those links which are plain URIs, our proposal is to require the body content to be available as RDF. To do that, we must clearly encapsulate the content graph in order to distinguish it from the graph of the

interaction. With that restriction we can have both the graph of the body and the graph of its message container in a single formalism. We implement that requirement by introducing the *ContentAsRDF* class as a sub-class of *Content*. Property *about* serves as the bridge between the message and the content's graph, and this latter is a named graph as defined in the SPARQL 1.1 Service Description⁸.

$$\text{ContentAsRDF} \sqsubseteq \text{Content} \sqcap \exists \text{about} . \top \quad \top \sqsubseteq \forall \text{about} . \text{Graph} \quad \top \sqsubseteq \leq_1 \text{about} . \top$$

The property *about* is functional. For example a body message describing Resource `:foo` can be represented with the following TriG syntax:

```
:B {
  :foo :ids (1 2 3) ;
      :date "2003-02-10"^^xsd:date .
}
```

Then it can be associated with the body content in the following way:

```
:m a http:Message ;
  http:body :b .
:b a cnt:ContentAsRDF ;
  cnt:about :B .
:B a sd:Graph .
```

For having the body payload in RDF, the basic option is to require representations to be in RDF serialisation formats like RDF/XML, JSON-LD and Turtle. A more advanced option is to adopt the notion of *RDF presentation* [15], which provides a way to *lift* a non-RDF format into an RDF graph and a reverse way to *lower* an RDF graph representation into the same non-RDF format.

5 Evaluation

One important step to enable evaluation is to populate the ontology with representative individuals. We can now represent the two interactions described in Section 3 and illustrated in Figure 4. A visual representation of the associate RDF graph is provided in Figure 6.

The question of ontology evaluation has received a lot of attention and can be divided in several related categories [22], logical, structural, and functional. The *logical* category groups quality dimensions that can be performed using a reasoner, e.g. the satisfiability. Our implementation in OWL 2 DL allows us to verify inference capabilities with the Hermit reasoner, in particular capability of detecting logical inconsistencies through *error provocations* during the population of the ontology with some representative sets of individuals. The *structural* category is composed of context-free dimensions which can be measured by quantitative metrics, for instance using OntoMetrics⁹, but also the popularity or the coupling degree with other linked data resources. To us, some important dimensions in this category are the following ones:

⁸ <https://www.w3.org/TR/2013/REC-sparql11-service-description-20130321/>

⁹ <https://ontometrics.informatik.uni-rostock.de/ontologymetrics>

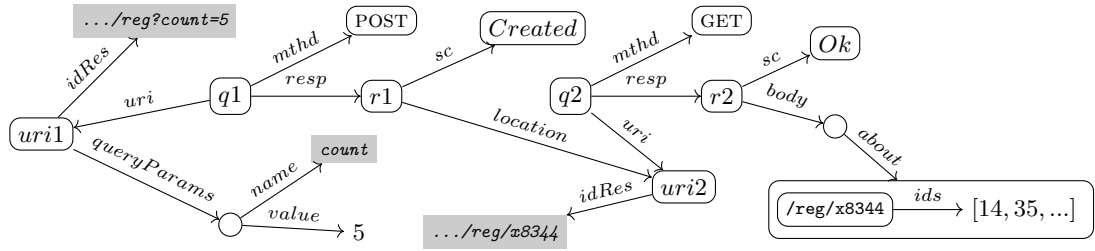


Fig. 6. Graph representation of registrar conversation

- flexibility: is the ontology easily adaptable to multiple uses? We address this question with our proposals for headers, body content and query parameters which enhance the reusability potential of the ontology with respect to the original W3C HTTP RDF Vocabulary.
- transparency: is the ontology easily analysable? We address this question by our formalisation in Description Logic, implemented with OWL2 DL, explicating our choices and motivations.
- cognitive ergonomics: is the ontology easily understandable and exploitable by users? We address this question by writing this article, documenting the ontology, and publicly publishing it.
- compliance to expertise: is the ontology compliant with the knowledge it represents. In our case, we better represent the semantics of RFCs by introducing classes and properties in place of just string literals, for instance for URIs. This dimension is also related to functional properties which, for an application ontology such as the one presented in this paper, are of course of utmost importance.

The *functional* category groups ontology quality dimensions which address intended uses and functions in contexts. We address this by writing SPARQL queries on our ontology in order to answer to the Competency Questions we expressed in Section 3.

CQ 1 What is the media-type associated with a message body?

```
SELECT ?m ?mt
WHERE {
  ?m a http:Message .
  ?m http:content-type ?mt .
}
```

CQ 2 What is the status code number of an interaction?

```
SELECT ?status
WHERE {
  ?q http:resp ?r .
  ?r http:sc/http:code ?status .
}
```

CQ 3 What is the URI link provided in the `location` header of a response?

```
SELECT ?next
WHERE {
  ?q0 http:resp/http:location ?next .
}
```

CQ 4 What is the status code of the combination of two interactions, the second query targeting the URI provided in the `location` header of the first response?

```
SELECT ?status
WHERE {
  ?q0 http:resp/http:location ?next .
  ?q1 http:uri ?next .
  ?q1 http:resp/http:sc ?status .
}
```

CQ 5 Does the media-type of a response body match one of those declared in the `Accept` header of its corresponding request?

```
ASK {
  ?q http:resp ?r .
  ?q http:accept/http:media-type ?mt1 .
  ?r http:content-type ?mt2 .
  FILTER (CONTAINS(STR(?mt1), STR(?mt2))
    || CONTAINS(STR(?mt2), STR(?mt1)))
}
```

Here we rely on string comparison which is a simplistic form of content negotiation because in practice media types have derivatives with syntactic variations. A semantic description of media types would solve that limitation.

CQ 6 What are the values associated with a given property p , for instance `ex:ids`, inside the body of an HTTP message?

```
SELECT ?ids
WHERE {
  ?m http:body/cnt:about ?G .
  GRAPH ?G { ?x ex:ids/rdf:rest*/rdf:first ?ids } .
}
```

Here Property `ex:ids` associates the root of the content representation with an RDF list of identifiers. Each element present in that list is extracted by using the `rdf:rest*/rdf:first` pattern.

CQ 7 What is the value of a specific parameter, e.g. named "age", passed in the query string of the target resource?

```
SELECT ?age
WHERE {
  ?q http:uri/http:queryParams ?p .
  ?p http:name "age" .
  ?p http:value ?age
}
```


6 Related Work

As explained in Section 3 our aim is to validate a Web API with respect to a specification, in order to support the work of developers, producers and consumers of Web APIs. Web developers know well HTTP and are less interested in more abstracted representations: for explaining them their potential mistakes, we think that it is better for the validator to manipulate HTTP items. This is why we choose to rely on an ontology of HTTP. It allows us to represent a Web API as a *conversation* graph, composed of linked interactions, an *interaction* being an instance of Property *resp* relating an instance of class *Request* to an instance of class *Response*. The HTTP ontology provides the framework for building the conversation graph from the Web API code. It is also a guide for the automatic validation that we intend to perform on the conversation graph, through the verification of the constraints expressed in the specification.

In this related works section we consider the Web API specification problem which motivates our work, from several points of view, reflected by the past and current uses of the various proposals. Historically, at the beginning were the so-called Web services, defined with SOAP, WSDL and UDDI [26], with several proposals aimed at specifying semantic Web services, such as OWL-S [17] or SAWSDL [13]. These Web services follow a remote procedure call (RPC) form of inter-process communication popularised by the rise of object oriented programming, ignoring the principle of hypermedia at the heart of the Web, and defining and exposing their own arbitrary sets of operations rather than the defined HTTP methods. They have been widely studied and developed, and big enterprise information systems still use it (e.g. Amazon). From a developer point of view WSDL specifications really provide a good support for using such kind of services, but no attempt to automate their use by programs has definitely proved successful. Yet WSDL provides a machine-readable description of how the service can be called, what parameters it expects, and what data structures it returns [26]. It describes services as collections of network endpoints (ports), which are associations of a URL with a binding describing a concrete protocol and message format specifications, namely the supported operations with descriptions of the data being exchanged. SAWSDL [13] is a set of extension attributes for defining how to add semantic annotations to the various parts of a WSDL document. It allows designers to relate WSDL and XML Schema specifications to ontologies.

The subsequent history of Web services is dominated by the so-called REST services or RESTful services [20], or hypermedia APIs [24], together with the emergence of Linked Data and the growing popularity of JSON and JSON-LD. Before considering these other kinds of Web services, it is important to notice the universality of the requirement of a way to provide information on a service general functionalities as well as on the form and meaning of its inputs and outputs. This is the aim of SAWSDL for SOAP-based services, or OWL-S [17] intended for any kind of service. Interestingly, this one can be compared to the recent proposal of another universal description of functions [4], which is also motivated to complement Web services specifications that are very coupled with the technology stack¹⁰, allowing

¹⁰ <https://w3id.org/function/spec>

to declare and describe any specific problem, function, or algorithm, whether executed using Web APIs or not. Both OWL-S and the Function Ontology address the need to automatic discovery, invocation, composition and interoperation of services. OWL-S is an old W3C Member Submission (2004) while the Function Ontology is at a stage of first non official draft, intended for applications built on top of the Semantic Web. Both of them include a binding mechanism to relate the upper level functional descriptions to more concrete Web APIs descriptions, these latter being expressed using WSDL, or the HTTP ontology, or Hydra [14].

Hydra's purpose is to describe and use the so-called Web APIs that are based on the REST architectural style and are simpler to deploy and interact with than SOAP-based services [23,20]. Those Web APIs are now the most developed and used Web services. OpenAPI [10] is a widely used initiative to associate to Web APIs a machine-readable documentation, that can be compiled into a Web page, and thus findable with a Web browser using standard Web search engines. With such a syntax-level description, OpenAPI offers what WSDL enables for SOAP Web services, or WADL for REST Web services (JSON replacing XML). In contrast, Hydra offers a semantic-level description and aims to go further in simplifying the development of truly RESTful services by leveraging the power of Linked Data [14], which is mostly ignored by the OpenAPI initiative. To this end, Hydra consists in a lightweight RDFS vocabulary to both describe Web APIs and to augment Linked Data with hypermedia controls (allowing to specify which IRIs in an RDF graph are intended to be dereferenced or not). Notice that W3C also supports the Linked Data Platform (LDP) standard [21] whose aim is to allow Linked Data (LD) providers exposing LD in a RESTful manner, including an interaction model to interact (read-write) with them. This is in line with Hydra's intention of describing RESTful Web APIs that can consume LD. Hydra is the most similar proposal to the HTTP ontology. But it is different though, as it introduces more abstract classes and properties to represent HTTP and IRI components, together with purely RDF-based notions which requires Web API developers to master (JSON-LD serialised) RDF.

Hydra is used in several applications, for instance for automating the discovery and consumption of Web services by software agents via SPARQL micro-services [18], which allow programs to query any Web API using SPARQL. The Web API is wrapped by such a micro-service, which uses an internally stored description of the Web API and the incoming SPARQL query to (i) query the Web API, (ii) transform its output into an RDF graph and (iii) perform the query on this dynamically built graph. The Web API functional description is based on Hydra and schema.org, plus SHACL [18] for guiding the dynamic graph building.

RESTdesc [25,24] is also a semantic description format for hypermedia APIs, which relies on the HTTP ontology rather than Hydra, and on Notation3 Logic [1] rather than RDFS or OWL. It is devised for automatic discovery and composition of hypermedia APIs. For its authors, the intended benefit of using Linked Data is to provide the ground to enable intelligent agents to navigate APIs and perform choices at runtime, like humans do on Website. While this goal is highly interesting, it is far from what is done in practice in current enterprise information systems where the service composition is manually programmed from a fixed set

of endpoints. In our experience this careful manual composition process is already making things difficult to manage and maintain when services evolve, to not want to rely on automatic compositions as proposed in RESTdesc to fulfil our requirements. In order to support the daily work of producers and consumers of Web APIs, we basically want to validate a Web API with respect to a specification, and explain the possibly occurring errors to the developer. To this end we focus on representing the common knowledge shared by all these developers: HTTP interactions.

7 Conclusion

We present in this article an ontological description of HTTP interactions, based on a deep study of the HTTP RFC 7231 specification. We started from the HTTP RDF Vocabulary proposed as a W3C Note, used and reused by several works. Besides that, it relies on a limited interpretation (more attached to the HTTP syntax than semantics) of RFCs, it does not allow us to formulate simply the queries which correspond to the Competency Questions reflecting our requirements. We conducted a formal analysis, using both Description Logics and Protégé OWL 2 DL, to introduce our proposed ontology, which answers to our needs as shown by our evaluation efforts. Regarding the related works, to the best of our knowledge only the W3C HTTP RDF Vocabulary is directly related to our aim of semantically representing the HTTP protocol, while the more general aim of describing web services is addressed in many works. This more general problem is not directly usable to validate a Web API with respect to a HTTP specification, for simply explaining to developers their potential errors.

The HTTP RFC 7231 specification being quite large, our effort to formalise it still incomplete and multiple aspect remains to be studied. Moreover we observed in the case of query parameters that common practices are in fact ad-hoc extensions of the URI specification, but they still need to be taken into account because of their massive adoption. We are aware of several limitations of our approach. For instance when representing an HTTP conversation that involves multiple interactions on the same resource, we still are unable to describe the evolution of those representations. Neither do we define how to represent the time dependency relation between messages. Another limitation comes from the Open World Assumption (OWA) which means that it is not possible to check for the absence of things, which is useful in a context of validation. For example we could want to check that responses associated with the `HEAD` method do not have a body. Combining OWL and SHACL could be the solution. Indeed, our immediate future work is the exploitation of that ontology by instrumenting HTTP interactions either on the client or on the server side. The logical inference performed by OWL 2 reasoner will check the conformance of those interactions towards the protocol specification. For example it could check for every message that `Content-Type` are properly declared in the presence of a body. To achieve this, we are working to implement a program that converts HTTP messages into RDF graphs following our ontology.

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A Appendix: HTTP Interaction Ontology in Turtle

```

@prefix : <http://w3id.org/http#> .
@prefix mthd: <http://w3id.org/http/mthd#> .
@prefix sc: <http://w3id.org/http/sc#> .
@prefix hds: <http://w3id.org/http/headers#> .
@prefix cnt: <http://w3id.org/http/content#> .

@prefix owl: <http://www.w3.org/2002/07/owl#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix sd: <http://www.w3.org/ns/sparql-service-description#> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .

: a owl:Ontology ;
  rdfs:label "HTTP Ontology"@en ;
  rdfs:comment "A namespace for describing HTTP interactions"@en .

## ----- ##
## Messages. ##
## ----- ##

:Message a owl:Class, owl:AllDisjointClasses ;
  rdfs:label "Message"@en ;
  rdfs:comment "An HTTP message."@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  owl:members (:Request :Response) ;
  rdfs:subClassOf [
    owl:intersectionOf ([
      a owl:Restriction ;
      owl:onProperty :body ;
      owl:allValuesFrom cnt:Content ;

```

```

    ] [
      a owl:Restriction ;
      owl:onProperty :hdr ;
      owl:allValuesFrom :Header;
    ])] .

:Request a owl:Class ;
  rdfs:label "Request"@en ;
  rdfs:comment "An HTTP request."@en ;
  rdfs:subClassOf [
    owl:intersectionOf (:Message [
      a owl:Restriction ;
      owl:onProperty :mthd ;
      owl:someValuesFrom :Method ;
    ] [
      a owl:Restriction ;
      owl:onProperty :uri ;
      owl:someValuesFrom :URI;
    ]) ] ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> .

:Response a owl:Class, owl:AllDisjointClasses ;
  rdfs:label "Response"@en ;
  rdfs:comment "An HTTP response."@en ;
  owl:members (:InterimResponse :FinalResponse) ;
  rdfs:subClassOf [
    owl:intersectionOf (:Message [
      a owl:Restriction ;
      owl:onProperty :sc ;
      owl:someValuesFrom :StatusCode ;
    ]) ] .

:InterimResponse a owl:Class ;
  rdfs:label "Interim"@en ;
  rdfs:subClassOf :Response, [
    a owl:Restriction ;
    owl:onProperty :sc ;
    owl:someValuesFrom sc:Informational ;
  ] ;
  rdfs:comment "An interim response."@en .

:FinalResponse a owl:Class ;
  rdfs:label "Final"@en ;
  rdfs:subClassOf :Response, [ owl:complementOf :InterimResponse ] ;
  rdfs:comment "A final response."@en .

:resp a owl:ObjectProperty ;
  rdfs:label "response"@en ;
  rdfs:comment "The HTTP response sent in answer to an HTTP request."@en ;
  rdfs:domain :Request ;

```

```

    rdfs:range :Response .

## ----- ##
## Method. ##
## ----- ##

:Method a owl:Class ;
    rdfs:label "Method"@en ;
    rdfs:comment "The HTTP method used for the request."@en ;
    owl:equivalentClass [
        a owl:Restriction ;
        owl:onProperty :methodName ;
        owl:someValuesFrom :notEmptyToken ] .

:mthd a owl:ObjectProperty, owl:FunctionalProperty ;
    rdfs:label "method"@en ;
    rdfs:comment "The HTTP method used for the HTTP request."@en ;
    rdfs:domain :Request ;
    rdfs:range :Method .

:methodName a owl:DatatypeProperty, owl:FunctionalProperty ;
    rdfs:label "method name"@en ;
    rdfs:comment "The HTTP method name used for the HTTP request."@en ;
    rdfs:domain :Method ;
    rdfs:range :notEmptyToken .

:notEmptyToken a rdfs:Datatype ;
    rdfs:label "Non-empty token"@en ;
    rdfs:comment "A token with at least one character" ;
    owl:equivalentClass [
        a rdfs:Datatype ;
        owl:onDatatype xsd:token ;
        owl:withRestrictions ([ xsd:minLength 1])] .

mthd:GET a :Method ;
    rdfs:label "GET" ;
    rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231#section-4.3.1> ;
    :methodName "GET" .

mthd:HEAD a :Method ;
    rdfs:label "HEAD" ;
    rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231#section-4.3.2> ;
    :methodName "HEAD" .

mthd:POST a :Method ;
    rdfs:label "POST" ;
    rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231#section-4.3.3> ;
    :methodName "POST" .

mthd:PUT a :Method ;

```

```

    rdfs:label "PUT" ;
    rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231#section-4.3.4> ;
    :methodName "PUT" .

mthd:DELETE a :Method ;
    rdfs:label "DELETE" ;
    rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231#section-4.3.5> ;
    :methodName "DELETE" .

mthd:CONNECT a :Method ;
    rdfs:label "CONNECT" ;
    rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231#section-4.3.6> ;
    :methodName "CONNECT" .

mthd:OPTIONS a :Method ;
    rdfs:label "OPTIONS" ;
    rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231#section-4.3.7> ;
    :methodName "OPTIONS" .

mthd:TRACE a :Method ;
    rdfs:label "TRACE" ;
    rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231#section-4.3.8> ;
    :methodName "TRACE" .

mthd:PATCH a :Method ;
    rdfs:label "PATCH" ;
    rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc5789> ;
    :methodName "PATCH" .

## ---- ##
## URI. ##
## ---- ##

:uri a owl:ObjectProperty, owl:FunctionalProperty ;
    rdfs:label "uri" ;
    rdfs:comment "Effective request URI" ;
    rdfs:domain :Request ;
    rdfs:range :URI .

:URI a owl:Class ;
    rdfs:label "URI description" ;
    rdfs:comment
        "A semantic description of the syntactic parts composing a URI."@en .

:scheme a owl:DatatypeProperty, owl:FunctionalProperty ;
    rdfs:label "scheme"@en ;
    rdfs:domain :URI ;
    rdfs:comment "The scheme part of an URI."@en .

:authority a owl:DatatypeProperty, owl:FunctionalProperty ;

```



```

    rdfs:label "authority"@en ;
    rdfs:domain :URI ;
    rdfs:comment "The authority part of an URI."@en .

:path a owl:DatatypeProperty, owl:FunctionalProperty ;
    rdfs:label "path"@en ;
    rdfs:domain :URI ;
    rdfs:comment "The path part of an URI."@en .

:query a owl:DatatypeProperty, owl:FunctionalProperty ;
    rdfs:label "query"@en ;
    rdfs:domain :URI ;
    rdfs:comment "The query part of an URI."@en .

:fragment a owl:DatatypeProperty, owl:FunctionalProperty ;
    rdfs:label "fragment"@en ;
    rdfs:domain :URI ;
    rdfs:comment "The fragment part of an URI."@en .

:idRes a owl:DatatypeProperty, owl:FunctionalProperty ;
    rdfs:label "resource"@en ;
    rdfs:comment "Everything except the query part"@en ;
    rdfs:domain :URI .

## ----- ##
## Headers. ##
## ----- ##

:Header a owl:Class ;
    rdfs:label "Header"@en ;
    rdfs:comment "A header in an HTTP message."@en ;
    rdfs:subClassOf [
        a owl:Restriction ;
        owl:onProperty :hdrName ;
        owl:someValuesFrom rdfs:Literal
    ] , [
        a owl:Restriction ;
        owl:onProperty :hdrValue ;
        owl:someValuesFrom rdfs:Literal
    ] .

:hdrName a owl:DatatypeProperty, owl:FunctionalProperty ;
    rdfs:label "header name"@en ;
    rdfs:comment "The name of an HTTP message header."@en ;
    rdfs:domain :Header ;
    rdfs:range rdfs:Literal .

:hdrValue a owl:DatatypeProperty, owl:FunctionalProperty ;
    rdfs:label "header value"@en ;
    rdfs:comment "The value of an HTTP message header."@en ;

```

```

    rdfs:domain :Header ;
    rdfs:range rdfs:Literal .

:hdr a owl:ObjectProperty ;
    rdfs:label "header"@en ;
    rdfs:comment "The headers in an HTTP message."@en ;
    rdfs:domain :Message ;
    rdfs:range :Header .

### Location Header property

hds:isLocationHeader a owl:ObjectProperty, owl:ReflexiveProperty ;
    rdfs:label "location header?" ;
    rdfs:domain :Header ;
    rdfs:range :Header .

:link a owl:ObjectProperty, owl:FunctionalProperty .

hds:LocationHeader a owl:Class ;
    rdfs:subClassOf [
        a owl:Restriction ;
        owl:onProperty hds:isLocationHeader ;
        owl:hasSelf true
    ] , [
        a owl:Restriction ;
        owl:onProperty :link ;
        owl:someValuesFrom :URI ;
    ] ;
    owl:equivalentClass [
        owl:intersectionOf (:Header [
            a owl:Restriction ;
            owl:onProperty :hdrName ;
            owl:hasValue "Location" ;
        ])] .

hds:location a owl:ObjectProperty ;
    rdfs:label "location" ;
    rdfs:domain :Response ;
    rdfs:range :URI ;
    owl:propertyChainAxiom (:hdr hds:isLocationHeader :link) .

## ----- ##
## Query parameters. ##
## ----- ##

:QueryParam a owl:Class ;
    rdfs:comment "A parameter for a part of a header value."@en ;
    rdfs:label "Query Parameter"@en .

:paramName a owl:DatatypeProperty, owl:FunctionalProperty ;

```

```

    rdfs:label "parameter name"@en ;
    rdfs:comment "The name of a query parameter."@en ;
    rdfs:domain :QueryParam ;
    rdfs:range rdfs:Literal .

:paramValue a owl:DatatypeProperty, owl:FunctionalProperty ;
    rdfs:label "parameter value"@en ;
    rdfs:comment "The literal value of a query parameter."@en ;
    rdfs:domain :QueryParam ;
    rdfs:range rdfs:Literal .

:queryParams a owl:ObjectProperty ;
    rdfs:label "query parameters"@en ;
    rdfs:comment "The parameters found in the query string part of a URL."@en ;
    rdfs:domain :URI ;
    rdfs:range :QueryParam .

## ----- ##
## Content. ##
## ----- ##

cnt:Content a owl:Class ;
    rdfs:label "Content"@en ;
    rdfs:comment
        "Representation of a content which can associated to various formats."@en .

sd:Graph a rdfs:Class ;
    rdfs:label "Graph"@en ;
    rdfs:comment
        "An instance of sd:Graph represents the description of an RDF graph."@en .

cnt:about a owl:ObjectProperty ;
    rdfs:label "graph"@en ;
    rdfs:comment "A property associating an RDF content with its RDF graph"@en ;
    rdfs:domain cnt:ContentAsRDF ;
    rdfs:range sd:Graph .

cnt:ContentAsRDF a owl:Class ;
    rdfs:label "RDF Content"@en ;
    rdfs:comment "RDF Content embedded in the body of an HTTP message"@en ;
    rdfs:subClassOf cnt:Content ;
    owl:equivalentClass [
        a owl:Restriction ;
        owl:onProperty cnt:about ;
        owl:cardinality 1 ] .

:body a owl:ObjectProperty, owl:FunctionalProperty ;
    rdfs:label "body"@en ;
    rdfs:comment "The entity body of an HTTP message."@en ;
    rdfs:domain :Message ;

```

```

    rdfs:range cnt:Content .

## ----- ##
## Status codes ##
## ----- ##

:StatusCode a owl:Class ;
    rdfs:label "Status code"@en ;
    owl:equivalentClass [
        a owl:Restriction ;
        owl:onProperty :statusCodeNumber ;
        owl:someValuesFrom :threeDigit ;
    ] ;
    rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231#section-6> ;
    rdfs:comment "The status code of an HTTP response."@en .

:sc a owl:ObjectProperty, owl:FunctionalProperty ;
    rdfs:label "status code"@en ;
    rdfs:domain :Response ;
    rdfs:range :StatusCode ;
    rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231#section-6> ;
    rdfs:comment "The status code of an HTTP response."@en .

:threeDigit a rdfs:Datatype ;
    rdfs:label "3-digit integer"@en ;
    rdfs:comment "A positive integer consisting in three digit" ;
    owl:equivalentClass [
        a rdfs:Datatype ;
        owl:onDatatype xsd:nonNegativeInteger ;
        owl:withRestrictions ([ xsd:maxInclusive 999]) .
    ] ;

:statusCodeNumber a owl:DatatypeProperty, owl:FunctionalProperty ;
    rdfs:label "status code number"@en ;
    rdfs:domain :StatusCode ;
    rdfs:range :threeDigit ;
    rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231#section-6> ;
    rdfs:comment "The status code number."@en .

:sc:Informational a owl:Class ;
    owl:equivalentClass [ owl:intersectionOf (:StatusCode [
        a owl:Restriction ;
        owl:onProperty :statusCodeNumber ;
        owl:someValuesFrom [
            a rdfs:Datatype ;
            owl:onDatatype xsd:integer ;
            owl:withRestrictions ([ xsd:minInclusive 100] [ xsd:maxInclusive 199])])
    ] ;
    rdfs:label "Informational"@en ;
    rdfs:comment "A status code starting with 1, denoting Status an informational response"@en .

```

```

sc:Successful a owl:Class ;
  owl:equivalentClass [ owl:intersectionOf (:StatusCode [
    a owl:Restriction ;
    owl:onProperty :statusCodeNumber ;
    owl:someValuesFrom [
      a rdfs:Datatype ;
      owl:onDatatype xsd:integer ;
      owl:withRestrictions ([ xsd:minInclusive 200] [ xsd:maxInclusive 299])]]
  ] ;
  rdfs:label "Successful"@en ;
  rdfs:comment "A status code starting with 2, denoting a successful interaction"@en .

sc:Redirection a owl:Class ;
  owl:equivalentClass [ owl:intersectionOf (:StatusCode [
    a owl:Restriction ;
    owl:onProperty :statusCodeNumber ;
    owl:someValuesFrom [
      a rdfs:Datatype ;
      owl:onDatatype xsd:integer ;
      owl:withRestrictions ([ xsd:minInclusive 300] [ xsd:maxInclusive 399])]]
  ] ;
  rdfs:label "Redirection"@en ;
  rdfs:comment "A status code starting with 3"@en .

sc:ClientError a owl:Class ;
  owl:equivalentClass [ owl:intersectionOf (:StatusCode [
    a owl:Restriction ;
    owl:onProperty :statusCodeNumber ;
    owl:someValuesFrom [
      a rdfs:Datatype ;
      owl:onDatatype xsd:integer ;
      owl:withRestrictions ([ xsd:minInclusive 400] [ xsd:maxInclusive 499])]]
  ] ;
  rdfs:label "Client Error"@en ;
  rdfs:comment "A status code starting with 4"@en .

sc:ServerError a owl:Class ;
  owl:equivalentClass [ owl:intersectionOf (:StatusCode [
    a owl:Restriction ;
    owl:onProperty :statusCodeNumber ;
    owl:someValuesFrom [
      a rdfs:Datatype ;
      owl:onDatatype xsd:integer ;
      owl:withRestrictions ([ xsd:minInclusive 500] [ xsd:maxInclusive 599])]]
  ] ;
  rdfs:label "Server Error"@en ;
  rdfs:comment "A status code starting with 5"@en .

## Entities

```

```

sc:Accepted a :StatusCode ;
  rdfs:label "Accepted"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 202 .

sc:BadGateway a :StatusCode ;
  rdfs:label "Bad Gateway"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 502 .

sc:BadRequest a :StatusCode ;
  rdfs:label "Bad Request"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 400 .

sc:Conflict a :StatusCode ;
  rdfs:label "Conflict"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 409 .

sc:Continue a :StatusCode ;
  rdfs:label "Continue"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 100 .

sc:Created a :StatusCode ;
  rdfs:label "Created"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 201 .

sc:ExpectationFailed a :StatusCode ;
  rdfs:label "Expectation Failed"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 417 .

sc:FailedDependency a :StatusCode ;
  rdfs:label "Failed Dependency"@en ;
  rdfs:isDefinedBy <http://www.ietf.org/rfc/rfc4918.txt> ;
  :statusCodeNumber 424 .

sc:Forbidden a :StatusCode ;
  rdfs:label "Forbidden"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 403 .

sc:Found a :StatusCode ;
  rdfs:label "Found"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 302 .

```

```
sc:GatewayTimeout a :StatusCode ;
  rdfs:label "Gateway Timeout"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 504 .

sc:Gone a :StatusCode ;
  rdfs:label "Gone"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 410 .

sc:HTTPVersionNotSupported a :StatusCode ;
  rdfs:label "HTTP Version Not Supported"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 505 .

sc:IMUsed a :StatusCode ;
  rdfs:label "IM Used"@en ;
  rdfs:isDefinedBy <http://www.ietf.org/rfc/rfc3229.txt> ;
  :statusCodeNumber 226 .

sc:InsufficientStorage a :StatusCode ;
  rdfs:label "Insufficient Storage"@en ;
  rdfs:isDefinedBy <http://www.ietf.org/rfc/rfc4918.txt> ;
  :statusCodeNumber 507 .

sc:InternalServerError a :StatusCode ;
  rdfs:label "Internal Server Error"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 500 .

sc:LengthRequired a :StatusCode ;
  rdfs:label "Length Required"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 411 .

sc:Locked a :StatusCode ;
  rdfs:label "Locked"@en ;
  rdfs:isDefinedBy <http://www.ietf.org/rfc/rfc4918.txt> ;
  :statusCodeNumber 423 .

sc:MethodNotAllowed a :StatusCode ;
  rdfs:label "Method Not Allowed"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 405 .

sc:MovedPermanently a :StatusCode ;
  rdfs:label "Moved Permanently"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 301 .
```

```
sc:MultiStatus a :StatusCode ;
  rdfs:label "Multi-Status"@en ;
  rdfs:isDefinedBy <http://www.ietf.org/rfc/rfc4918.txt> ;
  :statusCodeNumber 207 .

sc:MultipleChoices a :StatusCode ;
  rdfs:label "Multiple Choices"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 300 .

sc:NoContent a :StatusCode ;
  rdfs:label "No Content"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 204 .

sc:NonAuthoritativeInformation a :StatusCode ;
  rdfs:label "Non-Authoritative Information"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 203 .

sc:NotAcceptable a :StatusCode ;
  rdfs:label "Not Acceptable"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 406 .

sc:NotExtended a :StatusCode ;
  rdfs:label "Not Extended"@en ;
  rdfs:isDefinedBy <http://www.ietf.org/rfc/rfc2774.txt> ;
  :statusCodeNumber 510 .

sc:NotFound a :StatusCode ;
  rdfs:label "Not Found"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 404 .

sc:NotImplemented a :StatusCode ;
  rdfs:label "Not Implemented"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 501 .

sc:NotModified a :StatusCode ;
  rdfs:label "Not Modified"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 304 .

sc:OK a :StatusCode ;
  rdfs:label "OK"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 200 .
```



```
sc:PartialContent a :StatusCode ;
  rdfs:label "Partial Content"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 206 .

sc:PaymentRequired a :StatusCode ;
  rdfs:label "Payment Required"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 402 .

sc:PreconditionFailed a :StatusCode ;
  rdfs:label "Precondition Failed"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 412 .

sc:Processing a :StatusCode ;
  rdfs:label "Processing"@en ;
  rdfs:isDefinedBy <http://www.ietf.org/rfc/rfc2518.txt> ;
  :statusCodeNumber 102 .

sc:ProxyAuthenticationRequired a :StatusCode ;
  rdfs:label "Proxy Authentication Required"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 407 .

sc:RequestEntityTooLarge a :StatusCode ;
  rdfs:label "Request Entity Too Large"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 413 .

sc:RequestTimeout a :StatusCode ;
  rdfs:label "Request Timeout"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 408 .

sc:RequestURITooLong a :StatusCode ;
  rdfs:label "Request-URI Too Long"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 414 .

sc:RequestedRangeNotSatisfiable a :StatusCode ;
  rdfs:label "Requested Range Not Satisfiable"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 416 .

sc:Reserved a :StatusCode ;
  rdfs:label "(Reserved)"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 306 .
```

```
sc:ResetContent a :StatusCode ;
  rdfs:label "Reset Content"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 205 .

sc:SeeOther a :StatusCode ;
  rdfs:label "See Other"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 303 .

sc:ServiceUnavailable a :StatusCode ;
  rdfs:label "Service Unavailable"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 503 .

sc:SwitchingProtocols a :StatusCode ;
  rdfs:label "Switching Protocols"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 101 .

sc:TemporaryRedirect a :StatusCode ;
  rdfs:label "Temporary Redirect"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 307 .

sc:Unauthorized a :StatusCode ;
  rdfs:label "Unauthorized"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 401 .

sc:UnprocessableEntity a :StatusCode ;
  rdfs:label "Unprocessable Entity"@en ;
  rdfs:isDefinedBy <http://www.ietf.org/rfc/rfc4918.txt> ;
  :statusCodeNumber 422 .

sc:UnsupportedMediaType a :StatusCode ;
  rdfs:label "Unsupported Media Type"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 415 .

sc:UpgradeRequired a :StatusCode ;
  rdfs:label "Upgrade Required"@en ;
  rdfs:isDefinedBy <http://www.ietf.org/rfc/rfc2817.txt> ;
  :statusCodeNumber 426 .

sc:UseProxy a :StatusCode ;
  rdfs:label "Use Proxy"@en ;
  rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> ;
  :statusCodeNumber 305 .
```

```
sc:VariantAlsoNegotiates a :StatusCode ;
    rdfs:label "Variant Also Negotiates (Experimental)"@en ;
    rdfs:isDefinedBy <http://www.ietf.org/rfc/rfc2295.txt> ;
    :statusCodeNumber 506 .

## ----- ##
## Misc. ##
## ----- ##

:httpVersion a owl:DatatypeProperty ;
    rdfs:label "http version"@en ;
    rdfs:comment "The HTTP version of an HTTP message."@en ;
    rdfs:domain :Message ;
    rdfs:range rdfs:Literal ;
    rdfs:isDefinedBy <http://tools.ietf.org/rfc/rfc7231> .
```