Creating Restful APIs over SPARQL endpoints with RAMOSE

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Abstract. Semantic Web technologies are widely used for storing RDF data and making them available on the Web through SPARQL endpoints, queryable using the SPARQL query language. While the use of SPARQL endpoints is strongly supported by Semantic Web experts, it hinders broader use of these data by common Web users, engineers and developers unfamiliar with Semantic Web technologies, who normally rely on Web RESTful APIs for querying Web-available data and creating applications with them. To solve this problem, we have developed RAMOSE, a generic tool developed in Python to create REST APIs over SPARQL endpoints, through the creation of textual configuration files which enable the querying of SPARQL endpoints via simple Web RESTful API calls that return either JSON or CSV-formatted data, thus hiding all the intrinsic complexities of SPARQL from common Web users. We provide evidence for the use of RAMOSE to provide REST API access to RDF data within OpenCitations triplestores, and we show the benefits of RAMOSE in terms of the number of queries made by external users to such RDF data compared with the direct access via the SPARQL endpoint. Our findings prove the importance for suppliers of RDF data of having an alternative API access service, which enables its use by users with no (or little) experience in Semantic Web technologies and the SPARQL query language. Because RAMOSE is generic and can be used with any SPARQL endpoint, it represents an easy technical solution for service providers who wish to create an API service to access Linked Data stored as RDF in a conventional triplestore.

Keywords: REST API, OpenCitations, citation data, SPARQL endpoint, RDF, Linked Data, triplestore, RAMOSE, data access, query language

1. Introduction

Application Programming Interfaces (APIs) are powerful means of automating communication between application programs and data services. The aim of an API is to expose service functions and data so as to facilitate the interaction with users or (particularly) machines. In particular, Representational State Transfer (REST) APIs expose on the Web a set of stateless operations which enhance performance, reliability, and extensive reuse of the Web data resources [1].

Within the Semantic Web domain, the SPARQL 1.1 specifications include a Recommendation for "an application protocol for the distributed updating and fetching of RDF graph content in a Graph Store via the mechanics of the Hypertext Transfer Protocol (HTTP)" [2]. Such REST-based access to SPARQL endpoints has been a common ground used by several Semantic Web developers to query RDF data available on the Web [3]. Indeed, several institutions that have adopted

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Semantic Web technologies to manage their data – such as the British Library (http://bnb.data.bl.uk/), US government (https://www.data.gov/developers/semantic-web), and Wikidata (https://www.wikidata.org/) – usually employ such a REST-based approach to serve their RDF data to users (e.g. Web developers) and application programs via bespoke specialised Web interfaces that mediate the interaction with their SPARQL endpoints.

While SPARQL has widespread adoption among Semantic Web practitioners [4], it is not popular within the community of ordinary Web developers and scholars due to its complexity. The use of SPARQL is characterised by a very steep learning curve that prevents its widespread adoption in common Web projects, which usually leverage Web REST APIs to access and query data. Thus, the exclusive use of SPARQL endpoints to expose RDF data prevents easy access to such data by a large number of stakeholders with legacy technologies. Indeed, several projects (including those of the institutions mentioned above) accompany their SPARQL endpoints with ad-hoc Web REST APIs. Such Web REST APIs are usually hard-coded, and are difficult to maintain since they require expertise in both Web and Semantic Web technologies.

There is, thus, an increasing implicit demand for a generic mechanism that:

1. enables a broader Web audience (Web developers and scholars) to query RDF data available in triplestores behind SPARQL endpoint interfaces without having to use the SPARQL query language; and
2. allows Semantic Web developers easily and quickly to provide REST API access to their RDF data, a situation that we directly experienced in the context of OpenCitations [5] (https://opencitations.net/).

OpenCitations is an independent infrastructure organization for open scholarship dedicated to the publication of open bibliographic and citation data by the use of Semantic Web technologies, and engaged in advocacy for open citations. Initially, the data within the OpenCitations Corpus [6] were queryable only by using our SPARQL endpoint. However, we received several suggestions from people working in different scholarly disciplines for a more holistic approach for data querying, to enable users with no skills in Semantic Web technologies to access these data and to reuse them for building Web applications. In addition to providing a standard Web REST API for access to our Corpus data, we also needed a method whereby we could quickly and easily create new Web REST APIs to extend such access to new RDF datasets that we ourselves might publish, while at the same time providing a generic tool for adoption by the Semantic Web community as a whole.

To address such needs, we developed RAMOSE, the Restful API Manager Over SPARQL Endpoints (https://github.com/opencitations/ramose), which was explicitly created to foster reusability of RDF data across common Web applications. While developed to solve the specific problem of providing REST APIs for OpenCitations data, RAMOSE has been developed in a way which permits it to interact with *any* SPARQL endpoint, following the rationale we adopt for all our software development (available at https://github.com/opencitations), namely: while addressing the problem at hand, do this in a manner that provides a generic, open and public tool which can be reused by others with similar requirements.

RAMOSE is an open source Python software tool released under an ISC license. It allows one to create a Web REST API, with the related documentation, which acts as an interface to one or more SPARQL endpoints, regardless of the kinds of data hosted in a RDF triplestore. The creation of an API only requires the creation of a configuration file in a specific textual Markdown-like format which includes the SPARQL queries used by the API to retrieve RDF data. At OpenCitations, we now use RAMOSE to implement all the REST APIs introduced at http://opencitations.net/querying.

In this article, we provide a quick introduction to the context in which we have made this development (Section 2), followed in Section 3 by a description of RAMOSE, its architectural model, and how to configure and deploy it. In Section 4, we document how Web users engaged with OpenCitations data both before RAMOSE was developed and after we started using it to provide Web REST API access to OpenCitations datasets. After a discussion on past works concerning other software that addresses similar scenarios (Section 5), we conclude the article (Section 6) by sketching out some planned future developments.

2. Background: OpenCitations and its data

OpenCitations formally started in 2010 as a one-year project funded by JISC (with a subsequent extension). The project was global in scope, and was designed to change the face of scientific publishing and scholarly communication, since it aimed to publish open bibliographic citation information in RDF [3] and to make citation links as easy to traverse as Web links. The main deliverable of the project, among several outcomes, was the release of an open repository of scholarly citation data described using the SPAR (Semantic Publishing and Referencing) Ontologies [7], and named the OpenCitations Corpus (OCC, http://opencitations.net/corpus), which was initially populated with the citations from journal articles within the Open Access Subset of PubMed Central (https://www.ncbi.nlm.nih.gov/pmc/tools/openftlist/).

At the end of 2015, we set up a new instantiation of the OpenCitations Corpus [6] based on a new metadata schema and employing several new technologies to automate the ingestion of fresh citation metadata from authoritative sources. From the beginning of July 2016, OCC started ingesting, processing and publishing reference lists of scholarly papers available in Europe PubMed Central. Additional metadata for these citations were obtained from Crossref (https://crossref.org) [8] and (for authors) from ORCID (https://orcid.org) [9]. Routine ingestion of new data into OCC from Europe PubMed Central ceased in December 2017, when it contained 12,652,601 citation links. Since then OCC has been used as a publication platform for citations derived from the ExCITE Project (http://excite.west.uni-koblenz.de/website/), the Venice Scholar Project (https://venicescholar.dhlab.epfl.ch/about) and other sources, and now contains 13,964,148 bibliographic citations to 7,565,367 cited publications.

Following our development in 2018 of Open Citation Identifiers (globally unique PIDs for citations treated as first-class data entities in their own right [10]), and using open references supplied by Crossref, we switched OpenCitations' bulk publication of citation links from OCC to COCI, the OpenCitations Index of Crossref open DOI-to-DOI citations [11], which was first released in July 2018 and currently contains 721,655,392 bibliographic citations between 58,876,621 DOI-identified publications. Also in July 2018, as a consequence of the development of COCI, we released the first version of RAMOSE and started to expose all OpenCitations data via Web REST APIs.

3. RAMOSE: a technical introduction

RAMOSE, the Restful API Manager Over SPARQL Endpoints, is an open-source application written in Python which allows the agile development and publication of documented REST APIs for querying against any SPARQL endpoint. In particular, it is possible to customize RAMOSE to generate a Web REST API for the URL of a given SPARQL endpoint simply by creating an appropriate textual configuration file.

The modularity of RAMOSE allows a complete definition and customization of API operations and their input parameters. In addition, it enables one to apply pre-processing and post-processing steps by using external Python libraries that can be easily imported, and automatically generates HTML documentation of the API.

RAMOSE has been designed to be consistent with the following principles:

1. It must work with any legacy RDF triplestore providing a public SPARQL endpoint.
2. A Semantic Web expert should only be required initially, to define the SPARQL queries hidden behind the API operations, while all the other aspects of the REST API configuration and use should not require Semantic Web skills.
3. API operations and their input parameters must be fully customizable according to the particular needs of the infrastructure exposing the data.
4. The configuration file of a RAMOSE-based API must be easy to write and must avoid technicalities as much as possible.
5. Pre-processing and post-processing steps, developed as pure Python functions, must be specified in any operation, so as to better customise the interpretation of the input parameters and call outputs.
6. Basic built-in filters and refinement mechanisms must be provided by default.
7. It must be possible to use the REST API within another Python application, to run it as a command line application, and to make it available as a proper service within a web server.

The source code of RAMOSE, its documentation, and examples of its use are all available on GitHub at https://github.com/opencitations/ramose. RAMOSE is licensed under the ISC License.

3.1. Architecture overview

RAMOSE is a middleware interface between the data consumer and one or more SPARQL endpoints. Figure 1 shows an overview of the application. It consists of the application file (i.e. the file `ramose.py`)

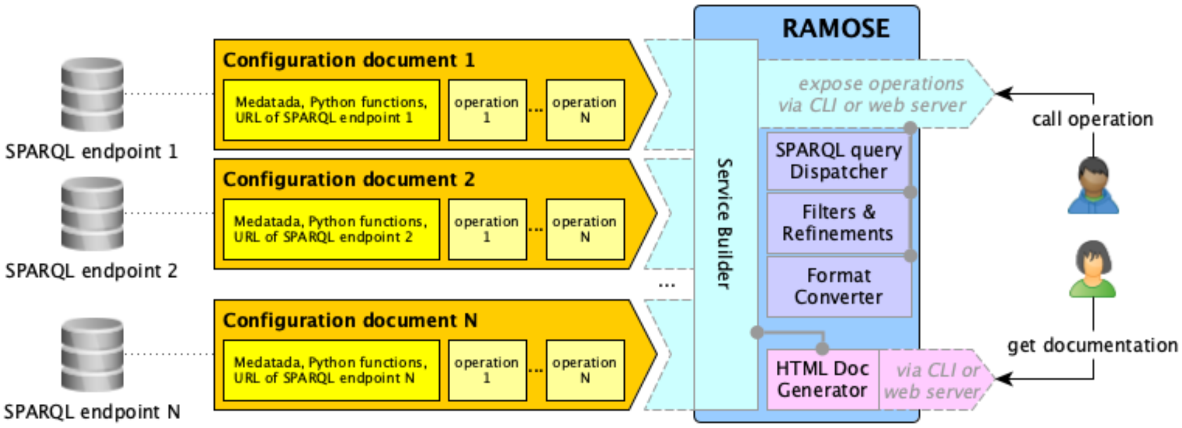


Figure 1. An overview of the main components of RAMOSE.

and one or more configuration documents (one for each Web REST API service that is created by means of RAMOSE).

The RAMOSE application file handles the following aspects: service builder for running API operations, definition of built-in filters and refinement mechanisms, SPARQL query dispatcher, results format converter (either in CSV or JSON), generation of HTML documentation, setting up of a web server for testing purposes.

Each RAMOSE configuration document contains metadata of the REST API service (name, contacts, license, description, etc.), the URL of the SPARQL endpoint to use, the optional specification of a Python file containing functions that can be used to pre-process the API call input parameters and/or to post-process the result of the execution of the SPARQL query, and the definition of all the operations. Each operation must specify the SPARQL query to run against the SPARQL endpoint, the URL to call the operation which includes also the name and shape of its input parameters, the HTTP method to use for the request, optional pre-processing/post-processing functions to execute before/after the execution of the SPARQL query, the types of all the fields returned by the operation, and additional documentation text (description of the operation, example of use, and an exemplar output in JSON).

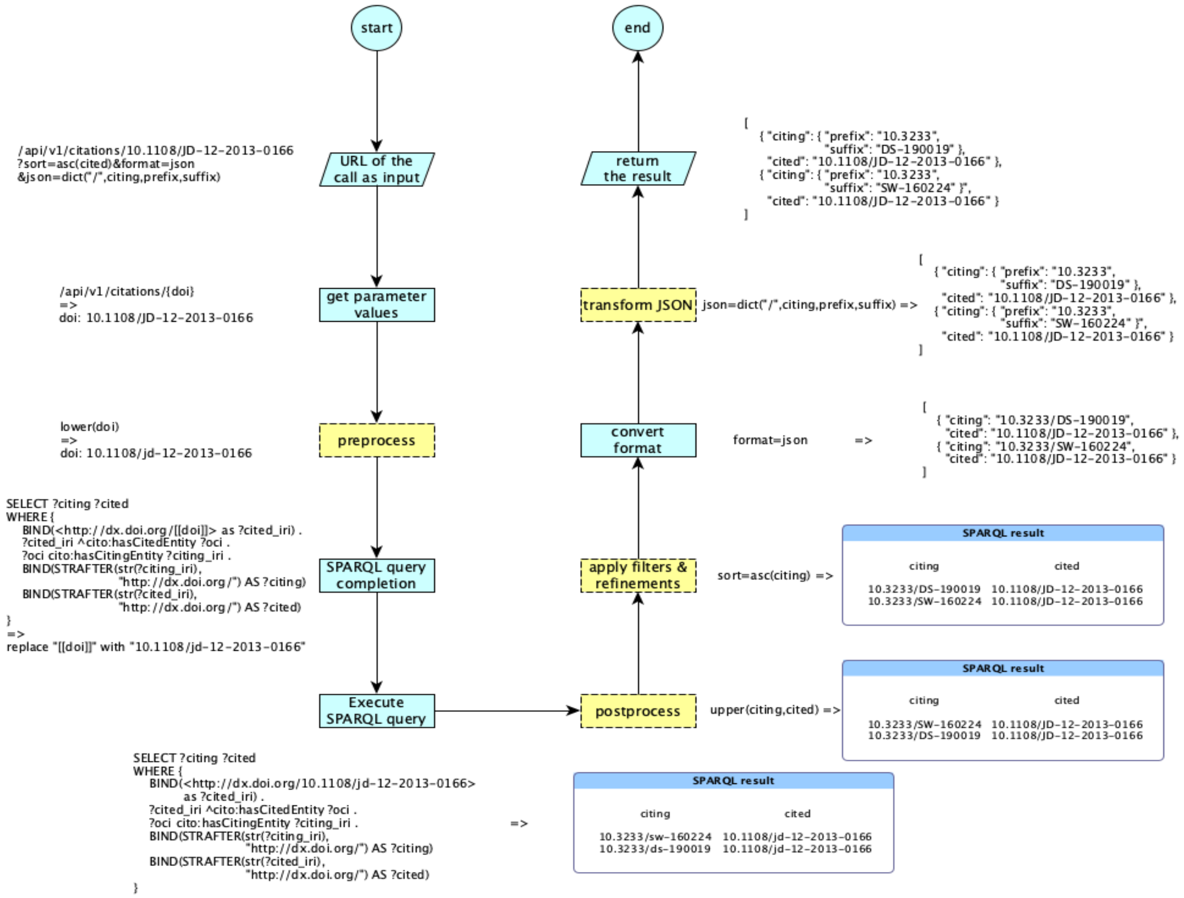
As shown in Figure 2, every time someone executes an operation, the related URL of the call is parsed and the values of the input parameters are retrieved according to the shape (i.e. data type and textual form) specified in the configuration file. The preprocessing functions are executed on the specified input parameters.

Following this preprocessing, any input parameter included in the SPARQL query of the operation between `[[...]]` is replaced with its current value, and finally the SPARQL query is performed against the SPARQL endpoint according to the HTTP method specified. When the SPARQL endpoint returns a result, RAMOSE runs the post-processing functions on it, applies filters and refinements if specified in the call URL, and converts the results either into CSV or into JSON according to what has been specified in the request. Where JSON is chosen as the output format, it is possible to ask RAMOSE, via a particular refinement parameter included in the call URL, to transform the default JSON outcome into a more structured one. An example of the whole process is presented in Figure 2.

3.2. Configuration document

The configuration of the REST API is specified using a *hash-format* file (extension: `.hf`). The hash-format syntax, shown in Listing 1, is based on Markdown. An hash-format document includes several key-values introduced by an hashtag, where the token attached to the hashtag defines the name of a field and the rest of the text after the hashtag is a Markdown content acting as a value associated with that field.

A RAMOSE configuration document includes two main conceptual sections, as shown in Listing 2. The first one contains general metadata and mandatory information about the REST API, and the other one includes a description of all the operations exposed by



```
/api/v1/citations/10.1108/JD-12-2013-0166
?sort=asc(cited)&format=json
&json=dict("/",citing,prefix,suffix)
```

```
/api/v1/citations/{doi}
=>
doi: 10.1108/JD-12-2013-0166
```

```
lower(doi)
=>
doi: 10.1108/jd-12-2013-0166
```

```
SELECT ?citing ?cited
WHERE {
   BIND(<http://dx.doi.org/[[doi]]> as ?cited_iri) .
   ?cited_iri ^cito:hasCitedEntity ?oci .
   ?oci cito:hasCitingEntity ?citing_iri .
   BIND(STRAFTER(str(?citing_iri),
                 "http://dx.doi.org/") AS ?citing)
   BIND(STRAFTER(str(?cited_iri),
                 "http://dx.doi.org/") AS ?cited)
}
=>
replace "[[doi]]" with "10.1108/jd-12-2013-0166"
```

```
SELECT ?citing ?cited
WHERE {
   BIND(<http://dx.doi.org/10.1108/jd-12-2013-0166>
        as ?cited_iri) .
   ?cited_iri ^cito:hasCitedEntity ?oci .
   ?oci cito:hasCitingEntity ?citing_iri .
   BIND(STRAFTER(str(?citing_iri),
                 "http://dx.doi.org/") AS ?citing)
   BIND(STRAFTER(str(?cited_iri),
                 "http://dx.doi.org/") AS ?cited)
}                                                    =>
```

```
SPARQL result
citing              cited
10.3233/sw-160224   10.1108/jd-12-2013-0166
10.3233/ds-190019   10.1108/jd-12-2013-0166
```

```
upper(citing,cited) =>

SPARQL result
citing              cited
10.3233/SW-160224   10.1108/JD-12-2013-0166
10.3233/DS-190019   10.1108/JD-12-2013-0166
```

```
sort=asc(citing) =>

SPARQL result
citing              cited
10.3233/DS-190019   10.1108/JD-12-2013-0166
10.3233/SW-160224   10.1108/JD-12-2013-0166
```

```
format=json        =>
[
  { "citing": "10.3233/DS-190019",
    "cited": "10.1108/JD-12-2013-0166" },
  { "citing": "10.3233/SW-160224",
    "cited": "10.1108/JD-12-2013-0166" }
]
```

```
json=dict("/",citing,prefix,suffix) =>
[
  { "citing": { "prefix": "10.3233",
                "suffix": "DS-190019" },
    "cited": "10.1108/JD-12-2013-0166" },
  { "citing": { "prefix": "10.3233",
                "suffix": "SW-160224" }",
    "cited": "10.1108/JD-12-2013-0166" }
]
```

```
[
  { "citing": { "prefix": "10.3233",
                "suffix": "DS-190019" },
    "cited": "10.1108/JD-12-2013-0166" },
  { "citing": { "prefix": "10.3233",
                "suffix": "SW-160224" }",
    "cited": "10.1108/JD-12-2013-0166" }
]
```

Figure 2. The workflow implemented by RAMOSE to handle an API call specified via a URL, accompanied by a running example. The yellow dotted rectangles are optionally executed since they depend on the call URL (apply filters & refinements, transform JSON) and on the specification of the executed operations (preprocess, postprocess) contained in the configuration document.

the REST API. As examples, the RAMOSE configuration documents we use in OpenCitations are available at https://github.com/opencitations/api.

Table 1 lists all the fields used in the first section of the configuration document to describe the REST API, while Table 2 lists all the fields used to define all the operations included in the second section of the configuration file. In both sections, `#url` must be always the first field of each block.

3.3. Filters and refinements

RAMOSE implements optional filters and refinement mechanisms that can be used to control the results returned by the API. These can be specified as HTTP parameters (i.e. "`?<param1>=<value1>&<param2>=<value2>&...`") in the API call URL.

These filters and refinement mechanisms work independently from the configuration file, the SPARQL endpoint specified in it, and the scope of the RDF data available. They provide common and advanced filtering, sorting, and manipulative functionalities that can be used with any result set returned by the API. The operations that can be used are described as follows.

3.3.1. Excluding rows with empty data

Parameter: `exclude=<field>`. All the rows that have an empty value in the field `<field>` specified as the value of the parameter are removed from the result set. E.g. `exclude=creation` removes all the rows that do not have a value specified in the field `creation`.

```
#<field_name_1> <field_value_1>
#<field_name_1> <field_value_2>
#<field_name_3> <field_value_3>
...
#<field_name_n> <field_value_n>
```

Listing 1. The hash-format syntax.

```
#url <api_base>
#type api
#title <api_title>
#description <api_description>
#version <version_number>
#endpoint <sparql_endpoint_url>
...

#url <operation_url_1>
#type operation
#sparql <sparql_query_1>
...

#url <operation_url_2>
#type operation
#sparql <sparql_query_2>
...
```

Listing 2. An excerpt of the structure of a RAMOSE configuration document, organised in two conceptual sections: the one with information about the API (in italic in the listing), and the other describing all the operations that the API exposes.

Table 1. The key-value pairs containing general information about the API.

#<field> <value>	**Description**
`#url <api_base>`	The base URL of the API (e.g. "`/api/v1`")
`#type api`	The section type – only "`api`" is allowed
`#base <base_url>`	The base URL of the webpage from which the API is available (e.g. "`https://w3id.org/oc/index`")
`#method <get|post>`	The HTTP methods supported, that can be "`get`", "`post`", or both
`#title <api_title>`	The title or name of the API
`#description <api_description>`	A textual description of the API
`#version <version_number>`	The textual string defining the version of the API
`#license <license>`	The textual string defining information about the licenses associated to the API, the data it returns, etc.
`#contacts <contact_url>`	The contact information for the API.
`#endpoint <endpoint_url>`	The SPARQL endpoint URL to query
`#addon <addon_file_name>`	The path of a Python file implementing functions that can be called in the preprocessing and postprocessing steps of each operation

3.3.2. Filtering rows

Parameter: `filter=<field>:<operator><value>`. Only the rows compliant with the filter specified (i.e. `<field>:<operator><value>`) are considered in the result returned by the API call. The term `<operator>` is not mandatory.

If `<operator>` is not specified, `<value>` is interpreted as a regular expression – e.g. `filter=creation:^20.+` returns the row in which the value specified in the field creation starts with "20" and it is followed by one or more characters. Otherwise, if `<operator>` is specified, the value of `<field>` of each row is compared with `<value>` by means of the specified `<operator>`, that may assume the following values: "=", "<", and ">". The comparison will be done according to the particular type associated to the field in consideration, as specified in `#field_type` (see Table 2). For instance, supposing that `filter=creation:>2016-05` returns all the rows that have a date greater than 1 May 2016.

3.3.3. Sorting rows

Parameter: `sort=<order>(<field>)`. Sort in ascending (`<order>` set to "asc") or descending (`<order>` set to "desc") order the rows in the result set according to the values in `<field>`. For instance, `sort=asc(citing)` sorts all the rows according to the value specified in the field `citing` in ascending order.

3.3.4. Formatting results

Parameter: `format=<type>`. The final table is returned in the format specified in `<type>` that can be either "csv" (see Listing 3) or "json" (see Listing 4). For instance, `format=csv` returns the final table in CSV format. It is worth noting that this parameter takes priority over the format type specified in the "Accept" header of the HTTP request. Thus, if the header of a request to the API specifies `Accept: text/csv` and the URL of such request includes `format=json`, the final table is returned in JSON.

Table 2. The key-value pairs defining each operation of the API. All the fields accompanied with an "[O]" are optional in the configuration file.

#<field> <value>	Description
#url <operation_url>	The URL of the operation. It may contain zero or more parameters name between {...} (e.g. "/citations/{doi}")
#type operation	The section type – only "operation" is allowed
#<param> <type>(<regex>) [O]	The shape (type and textual form) an input parameter of the operation must have (e.g. "str(10\..+)"). Possible types are strings ("str", which is the default value), integers ("int"), floating numbers ("float"), durations ("duration"), and date times ("datetime"). The regular expression is used to catch the value of the parameter from the URL.
#preprocess <functions> [O]	The Python functions used to preprocess the input parameters. One can specify one or more functions separated by "-->" which must take in input the name of one or more parameters (separated by a comma) between curly brackets, (e.g. "lower(doi) --> encode(doi)")
#postprocess <functions> [O]	The Python functions used to postprocess the results returned after the execution of the SPARQL query. One can specify one or more functions separated by "-->" which must take in input the name of zero or more variables (separated by a comma) returned by the SPARQL query between curly brackets (e.g. "decode_doi(citing, cited)")
#method <get|post>	The HTTP method used to send the request to the SPARQL endpoint for this operation, that can be either "get" or "post"
#description <op_description>	A textual description of the operation
#field_type <var_type_list>	A list of types of the variables that will be returned by executing the operation, split by a space ("<type1>(<var1>) <type2>(<var2>) ...") accompanied by their type – e.g. "str(oci) datetime(creation) duration(timespan)". Possible types are strings ("str", which is the default value), integers ("int"), floating numbers ("float"), durations ("duration"), and date times ("datetime")
#call <ex_request_call>	The URL of an example of an API call (e.g. "/citations/10.1108/jd-12-2013-0166")
#output_json <ex_response>	An example in JSON format of the results expected by the execution of the example call
#sparql <sparql_query>	The SPARQL query to perform on the specified SPARQL endpoint. The query may include any input parameter of the operation between "[[...]]" (e.g. "[[doi]]") which is replaced with its current value before calling the SPARQL endpoint

3.3.5. Transforming JSON results

Parameter: **json=<op>("<sep>",<field>, <new_field_1>,<new_field_2>,...).** When the JSON format is requested in the data return (see previous subsection), it is possible to transform each row of the final JSON table according to the rule specified. Two possible operations <op> can be specified: "array" and "dict".

If <op> is set to "array", the string value associated with the field <field> is converted into an array by splitting the various textual parts at locations identified by means of the separator <sep>. For instance, considering the JSON shown in Listing 4, the execution of array("/",cited) returns the JSON shown in Listing 5.

Instead, if <op> is set to "dict", the value associated with <field> is converted into a JSON object by splitting the various textual parts using the separator <sep> by associating each of these split strings according to the new fields specified <new_field_1>, <new_field_2>, etc. For instance, considering the JSON shown in Listing 5, the execution of dict("/",citing,prefix,suffix) returns the JSON shown in Listing 6.

It is worth mentioning that, in cases where the value of the field has already been converted to a list of strings, the "dict" operation still works, and will be applied to all the strings contained in such a list. For instance, considering the JSON shown in Listing 6, the execution of dict("0",cited,one,two) returns the JSON shown in Listing 7.

3.3.6. Application of the filters and refinement mechanisms

In an API call, it is possible to specify one or more parameters of the same kind if you want to run the same filter and/or refinement multiple times. For instance, exclude=citing&exclude=cited excludes from the result all the rows that have unspecified the value of either the field citing or the field cited.

```
citing,cited
10.3233/ds-190019,10.1108/jd-12-2013-0166
10.3233/sw-160224,10.1108/jd-12-2013-0166
…
```

Listing 3. A result set returned by RAMOSE in CSV format.

```
[
  {
    "citing":"10.3233/ds-190019",
    "cited":"10.1108/jd-12-2013-0166"
  },
  {
    "citing":"10.3233/sw-160224",
    "cited":"10.1108/jd-12-2013-0166"
  },
  …
]
```

Listing 4. The same result set returned by RAMOSE shown in Listing 3, but in JSON format.

```
[
  {
    "citing":"10.3233/ds-190019",
    "cited":["10.1108","jd-12-2013-0166"]
  },
  {
    "citing":"10.3233/sw-160224",
    "cited":["10.1108","jd-12-2013-0166"]
  },
  …
]
```

Listing 5. The same result in JSON shown in Listing 4, transformed according to the rule `array("/",cited)`, which splits the string value of the field `cited` according to the separator `/` and organises the resulting strings into a list.

```
[
  {
    "citing":{"prefix":"10.3233",
              "suffix":"ds-190019"},
    "cited":["10.1108","jd-12-2013-0166"]
  },
  {
    "citing":{"prefix":"10.3233",
              "suffix": "sw-160224"},
    "cited":["10.1108","jd-12-2013-0166"]
  },
  …
]
```

Listing 6. The same result in JSON shown in Listing 5, transformed according to the rule `dict("/",citing,prefix,suffix)`, which splits the string value of the field `citing` according to the separator `/` and organises the resulting strings into a JSON object with the new field labels `prefix` and `suffix`.

```
[
  {
    "citing":{"prefix":"10.3233",
              "suffix": "ds-190019"},
    "cited":[
      {"one":"1","two":".1108"},
      {"one":"jd-12-2","two": "13-0166"}
    ]
  },
  {
    "citing":{"prefix":"10.3233",
              "suffix": "sw-160224"},
    "cited":[
      {"one":"1","two":".1108"},
      {"one":"jd-12-2","two": "13-0166"}
    ],
  },
  …
]
```

Listing 7. The same result in JSON shown in Listing 6, transformed according to the rule `dict("0",cited,one,two)`, which splits each string value of the list in the field `cited` according to the separator `0` and organises the resulting strings into a JSON object according to the new fields `one` and `two`.

The order in which each parameter of the *same type* of a filter/refinement is run by RAMOSE depends on the order in which it is specified in the URL. However, the order of execution of the particular types of filter/refinement do not follow the actual order in the URL of the API call. Rather, RAMOSE first processes `exclude`, then `filter`, which is followed by `sort`. Then it applies `format` and, if the requested format is JSON, it finally executes `json`.

3.4. Run and deploy RAMOSE

There are three ways to run RAMOSE. First, one can use its command line interface (CLI) to execute it. Second, it can be executed directly within a web server. Finally, it can be used directly within a Python code by using its main class, i.e. `APIManager`. These possibilities are described in the following subsections.

3.4.1. Command line interface (CLI)

RAMOSE can be run via CLI by specifying one or more configuration documents (parameter `-s`) and the operation to call (parameter `-c`), composed by concatenation of the API base URL with the operation URL, plus the wanted parameters for filtering and refining if needed. Also, it can take as input additional optional parameters (a) to specify the format of the output (parameter `-f`, JSON being the default), (b) to specify the name of the file in which to store the output (parameter -o, (the output is printed in the shell output stream if a filename is not specified), and (c) to specify the method to use for the API request (parameter -m, GET being the default). The template of a CLI call of RAMOSE is shown as follows:

```
python ramose.py
    -s <conf_files>
    -c <api_base><operation_url>?<params>
    -f <csv|json>
    -o <output_name>
    -m <get|post>
```

RAMOSE can also create an HTML documentation of the API described in a configuration file. Specifically, the HTML documentation is requested by using the -d parameter, the HTML document returned by RAMOSE can be stored in a file (parameter -o, as shown before) and, if needed, an additional CSS file can be specified to customise the layout of the document (parameter -css). The template of a CLI call of RAMOSE to generate the documentation is shown as follows:

```
python ramose.py
    -s <conf_file>
    -d
    -o <output_name>
    -css <css_file_path>
```

3.4.2. Web server

RAMOSE can also be used within a web server which is instantiated by using the parameter -w specifying the IP address of the host and the related port separated by ":" (e.g. 127.0.0.1:8080). RAMOSE uses Flask to run the web server on the specified host machine. To deploy the REST API in *localhost* (i.e. 127.0.0.1), one can use the following command:

```
python ramose.py
    -s <conf_files>
    -w <host:port>
    -css <css_file_path>
```

The web API application raised by the web server can be open by using a browser at the host and port specified (e.g. http://127.0.0.1:8080) and includes a basic dashboard for tracking API calls (available at http://<host>:<port>), and a documentation of the REST API (available at http://<host>:<port>/<api_base>).

3.4.3. Python class

RAMOSE The Python class APIManager implements all the functionalities made available by RAMOSE. The signature of the class is as follows:

```
APIManager(conf_files)
```

The constructor of the class takes as input a list of API configuration files defined according to the hash format, and makes all the operations they define available to call using the following method:

```
exec_op(op_complete_url,method,content_type)
```

This method takes as input a string containing the complete URL of the operation to execute, i.e. <api_base> plus <operation_url> such as "/api/v1/citations/10.1108/JD-12-2013-0166", the string describing the method to use to call the SPARQL endpoint (either "get" or "post"), and the content type (i.e. the format) of the result returned by the call (either "csv" or "json"). The method returns a tuple of two items. The first item contains the status code of the HTTP response, while the second item contains the string of the results in the requested format.

4. Use of REST APIs in OpenCitations

In order to understand the effects that the introduction of RAMOSE can bring for access to and reuse of data stored in RDF and usually queryable by a SPARQL endpoint, we analysed the logs of the requests to OpenCitations services between January 2018 and March 2020. This period is particularly meaningful, since the first REST API made available by OpenCitations was released in June 2018, before which our data was available only through SPARQL endpoints. The logs thus allowed us to understand the extent to which introduction of the REST API, implemented with RAMOSE, changed the way users interact with OpenCitations data.

We compared the number of total SPARQL queries made against the OpenCitations SPARQL endpoints – via HTTP calls, the Opencitations SPARQL GUI editor, and the search/browse interfaces available on the website (excluding those coming from RAMOSE) with the number of all the REST API calls received in the same period. The results, split by trimester for the sake of readability, are shown in Figure 3.

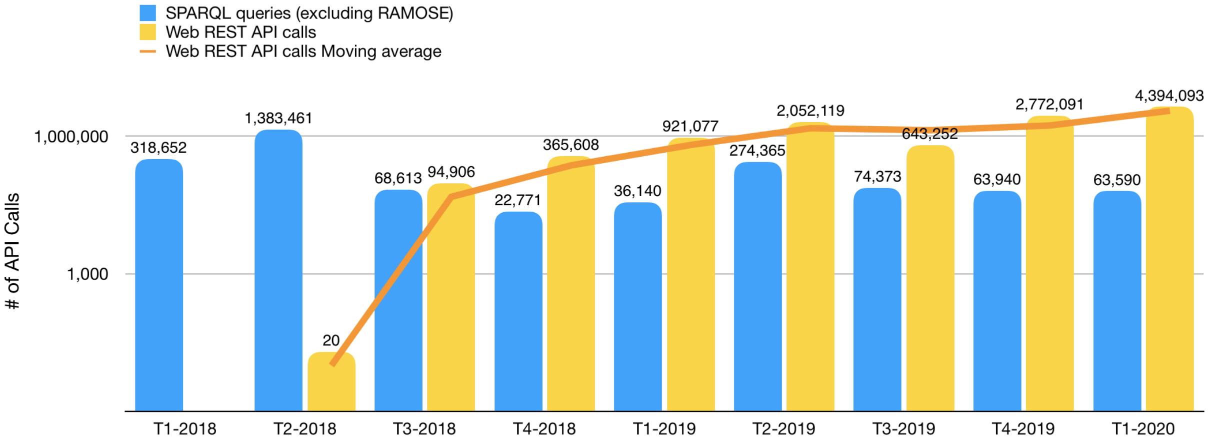


Figure 3. The number of requests received by the OpenCitations SPARQL endpoints vs. the calls to the OpenCitations REST APIs between January 2018 and March 2020 – listed by trimester. The orange line represents the moving average of the number of Web REST API calls. Note that the vertical axis has a logarithmic scale.

In this Figure, the blue bars show usage employing the OpenCitations SPARQL endpoints directly or using the other available non-API services, while the yellow bars show access using the APIs created with RAMOSE. The increase in overall usage of OpenCitations datasets following the introduction of the APIs may be attributed both to the increased ease of access to OpenCitations data that these APIs make possible, thus attracting use by people unfamiliar with SPARQL, and also to the launch in June 2018 of COCI (Heibi et al., 2019a), which for the first time made available through OpenCitations the hundreds of millions of citations derived from open references at Crossref.

While there is some fluctuation in the quarterly figures, there has been a significant increase in the average number of API calls since T3-2018, and a significant declining trend in the interaction with the other SPARQL services. That trimester could be considered the turning point, since at that time several developers with no or limited expertise with Semantic Web technologies started to build prototype applications using the OpenCitations data newly available via the REST API. In that trimester, the total number of accesses to the REST API was 138% of the number of accesses to the other SPARQL services. In subsequent trimesters, the use of the original SPARQL services decreased substantially to become stable at about 30,000 requests per month, while the number of REST API calls increased dramatically, reaching a total number of 4,394,093 calls in T1-2020. These figures point to substantial benefits from the adoption of RAMOSE with regards to increasing user interaction with OpenCitations data. All the data shown in Figure 3 are available on Zenodo [12].

The flexibility of RAMOSE enabled the simple creation of additional REST APIs for each of the new datasets released by OpenCitations. Since the first REST API was released in June 2018, three other REST APIs have been released, as described at http://opencitations.net/querying, with all the configuration documents being available at https://github.com/opencitations/api.

Other REST APIs based on RAMOSE, for services external to OpenCitations, have been developed to address specific tasks. For instance, during the Hack Day of the 2018 Workshop on Open Citations (https://workshop-oc.github.io/2018/), we developed an exemplar REST API service (still available at http://opencitations.net/wikidata/api/v1) to extract scholarly metadata from the Wikidata SPARQL endpoint (https://query.wikidata.org). This REST API has been used by the citation network visualisation tool VOSviewer [13] (https://www.vosviewer.com) to display the citation network within more than 5,000 papers in the Wikidata Zika Corpus (https://twitter.com/ReaderMeter/status/1037349669335126016).

In addition to VOSviewer, the REST APIs developed by OpenCitations using RAMOSE have been extensively used in several other software and data services. Those of which we are aware are Citation Gecko (https://citationgecko.com), OpenAccess Helper (https://www.oahelper.org), DBLP (https://dblp.uni-trier.de), CiteCorp (https://github.com/ropenscilabs/citecorp), and Zotero (https://github.com/zuphilip/zotero-open-citations). Our interactions with the developers of those services have been instrumental in guiding the development of the facilities that RAMOSE makes available, including the filters and refinement mechanisms that have demonstrated their usefulness is several scenarios, and have led, for example, to the adoption of JSON as the default data format returned by RAMOSE, to meet to the input requirements of VOSviewer.

5. Related works

In the past, several tools, in particular REST APIs on top of SPARQL endpoints, have been developed to leverage RDF data served through SPARQL query interfaces, often employing bespoke solutions tailored to their data, such as the DBpedia REST APIs (https://wiki.dbpedia.org/rest-api) and the Europeana Search API (https://pro.europeana.eu/page/search). Among works that are closer to what RAMOSE provides, the following deserve specific mention.

BASIL [14] is a cloud platform that supports sharing and reusing of SPARQL queries, and automatically generates Web APIs from those, which can be easily embedded into users' applications. Moreover, it allows one to reuse results as HTML snippets, called "views". While pre-processing operations are possible, the only way to undertake post-processing operations is separately to implement ad-hoc procedures on the returned results. BASIL runs using Java and requires the installation and configuration of a MySQL server on the running machine.

Another important tool in this category is grlc (http://grlc.io/) [15], a lightweight server that translates on the fly to Linked Data API calls SPARQL queries stored in a GitHub repository, in a local filesystem, or listed at a URL. The idea behind grlc is to implement an API mapping along with the use of SPARQL decorators which extends the original queries with other generated metadata which add extra functionalities to the APIs. In order to make this happen, the specified archive must contain a collection of SPARQL queries as `.rq` files and include the decorators as comments inside each `.rq` file. With grlc the pre-/post-processing operations are defined as decorators, and each API call can point to a different SPARQL endpoint by specifying the decorator "endpoint" before the SPARQL query.

A useful add-on to integrate with the grlc, suggested by its authors, is SPARQL Transformer [16]. This tool allows one to simplify the JSON outputs of a SPARQL query by re-shaping and simplifying the final JSON schema. SPARQL Transformer relies on a single JSON object to define which data should be extracted from the endpoint and what shape should they assume. Although this approach refines the final output, using it alone does not allow one to perform custom operations on the returned results (e.g. data normalisation or cleansing), which are delegated to separated post-processing operations, e.g. using the grlc features, or ad-hoc functions. SPARQL Transformer is written in JavaScript and can be imported and integrated in an HTML module.

In [17], Schröder *et al.* present a generic approach to convert any given SPARQL endpoint into a path-based JSON REST API. This work focused mostly on simple CRUD (create, retrieve, update, delete) workflows. The idea behind this approach is to build API paths that follow RDF triple patterns, e.g. the call `/class/dbo:Country/dbr:Germany` returns a JSON object for the specified entity (i.e. the DBpedia resource representing Germany). Despite being very intuitive for Semantic Web practitioners, it is not of immediate usage for adopters that are not acquainted both with RDF knowledge organisation and the scope of the dataset at hand.

In [18], Hopkinson *et al.* propose a set of parameterized SPARQL queries to access the RDF data stored in the KnowledgeStore system, along with other calls to the dataset CRUD (create, retrieve, update, delete) endpoint. This work has been tested by means of a user study and revealed positive reactions from users unfamiliar with Semantic Web technologies. However, operations are tailored on legacy data, and customisation requires the development of specific code for each application.

SpectQL (http://docs.thedatatank.com/4.3/spectql) is an ad-hoc query language based on the API calls style, created by datatank for querying its RDF datasets. It is bound to legacy technologies (datatank), only allows one to perform a restricted number of operations, and does not support RDF data query (for which SPARQL queries have to be specified instead).

In addition to the tools mentioned above, other SPARQL editor interfaces have been published in the past, with the aim of assisting users in querying against SPARQL endpoints by means of a user-friendly GUI, e.g. YASGUI [19]. Such tools are meant to allow users to perform exploratory queries, but do not offer means to programmatically access data. Moreover, these are usually hard to use by users with no knowledge of SPARQL.

Another class of tools include WYSIWYG web applications for searching and browsing RDF data by hiding the complexity of SPARQL. Such tools include general-purpose RDF search engines and GUI interfaces, such as Pubby (http://wifo5-03.informatik.uni-mannheim.de/pubby/), LodView [20], our own search interface OSCAR [21], Scholia [22], Elda (http://www.epimorphics.com/web/tools/elda.html), and BioCarian [23].

6. Conclusions

In this article, we have introduced RAMOSE, the Restful API Manager Over SPARQL Endpoints. RAMOSE is an open source Python software development that allows one to create Web REST API interfaces to one or more SPARQL endpoints by editing a configuration file in Markdown-like syntax, automatically generating documentation and a web server for testing and monitoring purposes. This generic software can be used over any SPARQL endpoint simply by creating the appropriate configuration text file. We have illustrated all the features that RAMOSE implements and we have presented the analysis of our motivating scenario, namely the dramatic increase in usage of OpenCitations data demonstrated by our access logs, so as to demonstrate the benefit that such a tool has brought to OpenCitations in terms of user interaction with its data. We commend the use of RAMOSE to others wishing to expose their own RDF data via a REST API.

In the future, we aim at extending RAMOSE with missing CRUD (Create, Read, Update, Delete) operations so as to fully support Semantic Web developers when interacting with the triplestores they own. Secondly, we want to enhance RAMOSE capabilities and support web developers in interacting with other types of data sources, such as JSON, XML, CSV data dumps and relational databases, so that it will be possible to leverage the same software solution over different data sources.

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