



Table Access Protocol

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Latest version

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Previous versions

[TAP-1.0](#)

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Abstract

The table access protocol (TAP) defines a service protocol for accessing general table data, including astronomical catalogs as well as general database tables. Access is provided for both database and table metadata as well as for actual table data. This version of the protocol includes support for multiple query languages, including queries specified using the Astronomical Data Query Language ([std:ADQL]) within an integrated interface. It also includes support for both synchronous and asynchronous queries. Special support is provided for spatially indexed queries using the spatial extensions in ADQL. A multi-position query capability permits queries against an arbitrarily large list of astronomical targets, providing a simple spatial cross-matching capability. More sophisticated distributed cross-matching capabilities are possible by orchestrating a distributed query across multiple TAP services.

Status of This Document

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Contents

1 Introduction	4
1.1 Role within the VO Architecture	5
1.2 Motivating Use Cases	6
1.2.1 Discover Metadata	6
1.2.2 Query Custom Tables	6
1.2.3 Query Standard Tables	6
1.2.4 Query Standard Data Models	6
1.2.5 ADQL Queries	6
1.2.6 Other Query Languages	7
1.2.7 Asynchronous Queries	7
1.2.8 Synchronous Queries	7

1.3	Interface Overview – move to examples section?	7
2	Resources	9
2.1	{sync}	10
2.2	{async}	10
2.3	/availability	12
2.4	/capabilities	12
2.5	/tables	14
2.6	/examples	15
2.7	Parameters	15
2.7.1	REQUEST - remove?	16
2.7.2	LANG	16
2.7.3	QUERY	17
2.7.4	FORMAT and RESPONSEFORMAT	18
2.7.5	MAXREC	18
2.7.6	RUNID	18
2.7.7	VERSION	19
2.7.8	UPLOAD	19
3	Use of VOTable	20
3.1	INFO elements	20
3.2	Successful Queries	22
3.3	Errors	23
3.4	Overflows	23
3.5	VOTable vs RDBMS Tables and Columns	24
4	Metadata: TAP_SCHEMA	25
4.1	Schemas	26
4.2	Tables	26
4.3	Columns	27
4.4	Foreign Keys	28
5	Examples	28
5.1	Example: Asynchronous Query	28
5.1.1	Creating a Query	29
5.1.2	Running a Query	30
5.1.3	Example: Synchronous Query	32
5.1.4	Example: DALI-examples Document	32

6	Use of STC-S in TAP - deprecated	32
7	VOSpace Integration - deprecated	32
8	Use of HTTP - deprecated	32
A	Changes from Previous Versions	33
	A.1 Changes from TAP-1.0	33

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Conformance-related definitions

The words “MUST”, “SHALL”, “SHOULD”, “MAY”, “RECOMMENDED”, and “OPTIONAL” (in upper or lower case) used in this document are to be interpreted as described in IETF standard, [Bradner \(1997\)](#).

The *Virtual Observatory (VO)* is general term for a collection of federated resources that can be used to conduct astronomical research, education, and outreach. The [International Virtual Observatory Alliance \(IVOA\)](#) is a global collaboration of separately funded projects to develop standards and infrastructure that enable VO applications.

1 Introduction

The Table Access Protocol (TAP) is a web-service protocol that gives access to collections of tabular data referred to collectively as a tableset. TAP services accept queries posed against the tableset available via the service and return the query response as another table, in accord with the relational model. Queries may be submitted using various query languages and may execute synchronously or asynchronously. Support for the Astronomical Data Query Language ([std:ADQL]) is mandatory; support for other query languages is supported but optional.

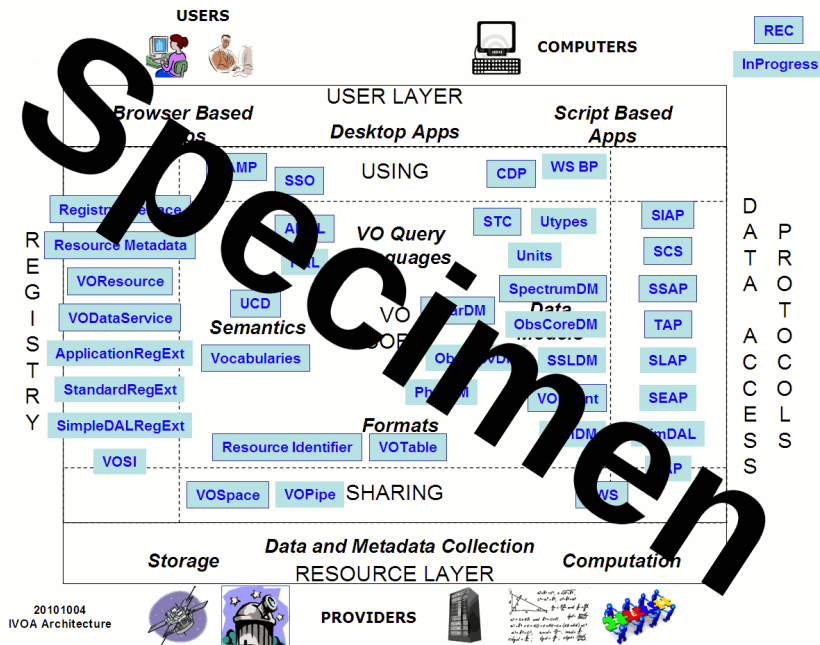


Figure 1: Architecture diagram for this document

The result of a TAP query is another table, normally returned as a VOTable. Support for VOTable output is mandatory; all other formats are optional.

The table collections made accessible via TAP are typically stored in relational database management systems (RDBMS). A TAP service exposes the database schema to client applications so that queries can be posed directly against arbitrary data tables available via the service.

Multi-table operations such as joins or cross matches are possible provided the tables are all managed by the local TAP service, and provided the service supports these capabilities. Larger scale operations such as a distributed cross match are also possible, but require combining the results of multiple TAP services.

1.1 Role within the VO Architecture

NOTE: not in TAP-1.0

Fig. section 1 shows the role this document plays within the IVOA architecture (Arviset et al. 2010).

1.2 Motivating Use Cases

Below are some of the more common use cases that have motivated the development of the TAP specification. While this is not complete, it helps to understand the problem area covered by this specification.

1.2.1 Discover Metadata

Since content in relational databases is often custom and project-specific, users of a TAP service must be able to discover the names of tables and columns, datatypes, units, and other information necessary to construct meaningful correct queries.

1.2.2 Query Custom Tables

A large amount of astronomical data and metadata is stored in tables in relational databases. Historically, users could query these tables through custom user interfaces (usually web page forms), but such approaches could not provide support for truly ad-hoc querying. A TAP service should enable users to discover and query custom tables with a flexible and expressive input that supports ad-hoc querying: selecting output, filtering the result, joining multiple tables, computing aggregate quantities, etc.

1.2.3 Query Standard Tables

A TAP service should enable users to query externally defined standard tables in a uniform way such that the same web service request can be sent to multiple services. Services must be able to declare their support for standard tables in the service metadata.

1.2.4 Query Standard Data Models

A TAP service should enable users to query (parts of) externally defined data models that are (partially or fully) implemented by the service. Services must be able to declare their support for data models as well as the way that model elements are mapped to tables and columns.

1.2.5 ADQL Queries

The Astronomical Data Query Language ([std:ADQL]) is the standard query language for the IVOA. Support for ADQL queries is mandatory. ADQL

can be used to specify queries that access one or more tables provided by the TAP service, including the standard metadata tables. In general, the client must access table metadata in order to discover the names of tables and columns and then formulate queries. ADQL queries provide a direct (low-level) access to the tables; a query will be written for a specific TAP service and will not be usable with other services unless the query refers only to common tables and columns. It is also possible that the service registration (in an IVOA Registry) may include sufficient table metadata to enable queries to be written directly.

1.2.6 Other Query Languages

A TAP service must be able to support use of other query languages, such as pass-through of native SQL directly to an underlying DBMS or simple key-value (parameter-based) constraints. The service interface must allow for this and the service capabilities must be able to describe it. This mechanism also allows future developments within and outside the IVOA to be used without revising the TAP specification.

1.2.7 Asynchronous Queries

Asynchronous queries allow for long running queries to complete without the client maintaining a connection to the service. Results are stored by the service for later retrieval by the client. Asynchronous query execution is generally more robust and not susceptible to time-outs or other transient failures. They are especially suited to queries that run for a long time before producing output (e.g. queries that compute or aggregate values).

1.2.8 Synchronous Queries

Synchronous queries execute immediately and the client must wait for the query to finish. Synchronous query execution is generally simpler and provides a faster (low latency) response and should be adequate when the query will execute and start returning results quickly. Even with large query results, synchronous queries are a good approach as long as the service can stream the output and consume modest internal resources.

1.3 Interface Overview – move to examples section?

Table Access Protocol (TAP) is implemented over the HTTP protocol using standard HTTP GET and POST requests and conventions. A TAP request

specifies one or more parameter key/value pairs; both keys and values are strings. The keys used are discussed in this specification and in the specifications for query languages supported by a service. The values may need to be encoded, using standard URL-encoding. For the following examples, `http://example.com/tap/` is the base URL for a TAP service.

This is an example of a synchronous ADQL query on `r` magnitude:

```
HTTP POST http://example.com/tap/sync
REQUEST=doQuery
LANG=ADQL
QUERY=SELECT * FROM magnitudes as m where m.r>=10 and m.r<=16
```

Synchronous queries return the table of results in the HTTP response to the initial request. In the examples above, the output format defaults to `VOTable`; the `FORMAT` parameter could be added to select a different format.

Asynchronous queries are created in the same way as the synchronous kind, using the `/async` endpoint:

```
HTTP POST http://example.com/tap/async
REQUEST=doQuery
LANG=ADQL
QUERY=SELECT * FROM magnitudes AS m WHERE m.r>=10 AND m.r<=16
```

The service's response to these requests is a URL representing the query's state and progress and where the state may be monitored and controlled. The query result or an error document can then be retrieved from a URL associated with the job. This is an application of the UWS pattern. The query is then executed with a separate request to run the job URL:

```
HTTP POST http://example.com/tap/async/<jobid>/phase
PHASE=RUN
```

The state of the job can be retrieved from the phase resource:

```
HTTP GET http://example.com/tap/async/<jobid>/phase
```

The client may have to check the phase multiple times until the job finishes. Once the returned value is `COMPLETED`, the results can be obtained from the results resource:

```
HTTP GET http://example.com/tap/async/<jobid>/results/result
```


In addition to the sync and async resources for query execution, a TAP service also has metadata resources defined by the VOSI standard. The availability of a service can be monitored by accessing:

```
HTTP GET http://example.com/tap/availability
```

The complete table metadata can be obtained:

```
HTTP GET http://example.com/tap/tables
```

The capabilities can be obtained by:

```
HTTP GET http://example.com/tap/capabilities
```

The capabilities are also accessible via a service request to the synchronous query resource:

```
HTTP GET http://example.com/tap/sync?REQUEST=getCapabilities
```

This output lists support for optional TAP functionality and additional implemented interfaces.

2 Resources

An implementation of a TAP service provides the following RESTful resources under the base URL.

resource type	resource name	required
sync	/sync	must (anonymous)
async	/async	must (anonymous)
sync	service-specific	may (alternate authentication method)
async	service-specific	may (alternate authentication method)
VOSI-availability	/availability	should
VOSI-capabilities	/capabilities	must
VOSI-tables	/tables	should
DALI-examples	/examples	should

At least one set of sync and async resources must be named /sync and /async respectively for backwards compatibility with TAP-1.0 (which required these names). These resources must be used for anonymous query execution. Other sync and async resources may have service specific names, but all resources listed above must be siblings so that a client with one such

URL can find the VOSI-capabilities URL and thus discover other available resources.

A TAP service must be represented as a set of sibling web resources each addressable via a URL in the http scheme, or the https scheme, or both.

The web resource at the root of the tree must represent the service as a whole. This specification defines no standard representation for this root resource. Implementations may provide a representation, or may return a '404 not found' response to requests for the root web-resource. One possible representation is an HTML page describing the scientific usage and content of the service. TAP clients must not depend on a specific representation of the root web-resource.

2.1 {sync}

A TAP service must provide a web resource with relative URL `/sync` that is a direct child of the root web resource. This web resource represents the results of synchronous requests. The exact form of the query, and hence the representation of the resource, is defined by the query parameters as listed in section 2.7. Representations of results of queries is defined in section 2.7.4 and section 3.

For query languages that produce a single result (e.g. ADQL) executed using the `/sync` endpoint, the result of a successful query is returned in the response or the response includes an HTTP redirect (303: See Other) to a resource from which the result may be retrieved.

An HTTP-GET request to the `/sync` web resource may return a cached copy of the representation. This cached copy might come from an HTTP cache between the client and the service, and the service may also maintain its own cache. Clients which require an up-to-date representation of volatile data or metadata must use HTTP POST.

2.2 {async}

A TAP service must provide a web resource with relative URL `/async` that is a direct child of the root web resource. This web resource represents controls for asynchronous queries. Specifically, the web resource must represent the job-list as specified in the UWS standard [std:UWS].

The child web resources of the `/async` resource are as specified by UWS. These are descendants of the `/async` web-resource, and they include a web resource that represents the eventual result of an asynchronous query, e.g.:

`http://example.com/tap/async/42/results/result`

where the base URL for the TAP service is:

`http://example.com/tap`

the UWS job list is:

`http://example.com/tap/async`

and the job resource is

`http://example.com/tap/async/42`

where 42 is the job identifier. A client making an asynchronous request must use the UWS facilities to monitor or control the job. In addition to the job list and job resource above, UWS specifies the name and semantics of the a small set of child resources used to view and control the job, e.g.:

`http://example.com/tap/async/42/phase`

`http://example.com/tap/async/42/quote`

`http://example.com/tap/async/42/executionduration`

`http://example.com/tap/async/42/destruction`

`http://example.com/tap/async/42/error`

`http://example.com/tap/async/42/parameters`

`http://example.com/tap/async/42/results`

`http://example.com/tap/async/42/owner`

Successful TAP queries produce results which must be accessible as resources under the UWS result list, e.g.:

`http://example.com/tap/async/42/results/`

Failed TAP queries produce an error document (see section 3.3) which must be accessible as the error resource, e.g.:

`http://example.com/tap/async/42/error`

For query languages that produce a single result executed using the /async endpoint, the result of a successful query can be found within the result list specified by UWS [std:UWS]; the result must be named result and thus clients are able to access it directly, e.g.:

`http://example.com/tap/async/42/results/result`

Access of this resource must deliver the result, either directly or as an HTTP redirect (303: See Other) to a resource from which the result may be retrieved.

For query languages that may produce multiple result resources, the names of the results are not specified (they may be specified in the specification for the language). The client can always access the result list resource as specified by UWS [3].

If the query returned no rows, the result resource must exist and contain no data rows. Details on interacting with these resources are specified in the UWS standard; for examples specific to TAP see section 5 below.

2.3 /availability

The VOSI availability metadata should be accessible from a web resource with relative URL /availability that is a direct child of the root web resource. If implemented, the /availability resource must be accessible via the http GET method. The content is described by [std:VOSI].

Services which do not implement the /availability resource must respond with an HTTP response code of 404 when this resource is accessed.

2.4 /capabilities

The TAP-1.0 standard is identified using

```
ivo://ivoa.net/std/TAP
```

For TAP-1.1 we define new standard identifiers for each of the features. Asynchronous query resources (section 2.2) are described by standardID:

```
ivo://ivoa.net/std/TAP#async-1.1
```

Synchronous query resources (section 2.1) are described by standardID:

```
standardID="ivo://ivoa.net/std/TAP#sync-1.1
```

In TAP-1.0 the base URL was described with a single standard identifier; in TAP-1.1 and beyond, individual resources are described with their own standardID. This allows service providers to describe multiple resources that deliver the specified feature (e.g. with different authentication methods) in the VOSI-capabilities resource.

The VOSI standard specifies that the capability metadata is encoded as an XML document which lists each of the service's capabilities as a <capability> element. The type of this element (which defines the contents) is <http://www.ivoa.net/xml/VOResource/v1.0Capability> from the VOResource XML standard [8].

In addition, the capabilities output must also comply with the following requirements:

- * the returned document must include <capability> elements that describes the service's support for the TAP protocol using the TAP and VOSI standardID values

- * this capability element must include at least one <interface> element with its "role" attribute set to "std",

Note: VO registries recognize a service's support for a standard protocol through this capability description. In particular, a different standard Capability sub-type is used for each standard protocol to provide capability metadata that is specific to that protocol. At the time of this writing, a Capability sub-type for TAP has not yet been defined. Thus for compliance with this standard, any legal Capability description that meets the above restrictions is sufficient. However, once a VOResource extension for TAP is standardized, it is strongly recommended that TAP services emit its capabilities using that the Capability sub-type specialized for TAP.

For example, the returned capabilities document for a service supporting TAP might look as follows:

```
<?xml version="1.0" encoding="UTF-8"?>

<vosi:capabilities xmlns=""
  xmlns:vosi="http://www.ivoa.net/xml/VOSI/v1.0"
  xmlns:vs="http://www.ivoa.net/xml/VODataService/v1.0"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation="http://www.ivoa.net/xml/VOSI/v1.0
    http://www.ivoa.net/xml/VOSI/v1.0
    http://www.ivoa.net/xml/VODataService/v1.0
    http://www.ivoa.net/xml/VODataService/v1.0">

  <vosi:capability standardID="ivo://ivoa.net/std/TAP#async-1.1">
    <interface xsi:type="vs:ParamHTTP" role="std">
      <accessURL use="base"> http://myarchive.net/myTAP/async </accessURL>
    </interface>
  </vosi:capability>

  <vosi:capability standardID="ivo://ivoa.net/std/TAP#sync-1.1">
```

```

    <interface xsi:type="vs:ParamHTTP" role="std">
      <accessURL use="base"> http://myarchive.net/myTAP/sync </accessURL>
    </interface>
  </vosi:capability>

  <vosi:capability standardID="ivo://ivoa.net/std/VOSI#capabilities">
    <interface xsi:type="vs:ParamHTTP">
      <accessURL use="full">
        http://myarchive.net/myTAP/capabilities </accessURL>
      </interface>
    </vosi:capability>

  <vosi:capability standardID="ivo://ivoa.net/std/VOSI#availability">
    <interface xsi:type="vs:ParamHTTP">
      <accessURL use="full">
        http://myarchive.net/myTAP/availability
      </accessURL>
    </interface>
  </vosi:capability>

  <vosi:capability standardID="ivo://ivoa.net/std/VOSI#tables">
    <interface xsi:type="vs:ParamHTTP">
      <accessURL use="full">
        http://myarchive.net/myTAP/tables </accessURL>
      </interface>
    </vosi:capability>
</vosi:capabilities>

```

The service capabilities must be accessible from a web resource with relative URL `/capabilities` that is a direct child of the root web resource. The `/capabilities` resource must be accessible via the http GET method. The content is described by [8].

2.5 `/tables`

The table metadata should be accessible from a web resource with relative URL `/tables` that is a direct child of the root web resource. The `/tables` resource must be accessible via the http GET method. The content is described by [std:VODataService] and is equivalent to the metadata from the TAP_SCHEMA described in section 4.

Services which do not implement the `/tables` resource must respond with an HTTP response code of 404 when this resource is accessed.

2.6 /examples

A GET from this endpoint MUST yield a document with a MIME type of either application/xhtml+xml or text/html. A service that does not provide examples MUST return a 404 HTTP status on accessing this resource.

If present, the endpoint must be represented in a capability in the TAP service's registry record. The capability's standardID is defined by [std:DALI]. A capability element could hence look like this:

```
<capability standardID="ivo://ivoa.net/std/DALI#examples">
  <interface xsi:type="vr:WebBrowser">
    <accessURL use="full">http://myarchive.net/myTAP/examples</accessURL>
  </interface>
</capability>
```

TAP defines two additional properties for the examples vocabulary:

- * query – each example MUST have a unique child element with simple text content having a property attribute valued query. It contains the query itself, preferably with extra whitespace for easy human consumption and editing. This will usually be a HTML pre element.

- * table – examples MAY also have descendants with property attributes having the value table. These must have pure text content and contain fully qualified table names to which the query is somehow "pertaining". Suitable HTML elements holding these include span, or a (which would allow linking to further information on the table).

When using elements with src or href attributes to carry the property attributes, note that the element content must be repeated in a content attribute, as otherwise RDFa clients would interpret the embedded link rather than the element content as the object in the triple.

TODO: add example(s) here

2.7 Parameters

The {async} and {sync} web-resources must accept the parameters listed in the following sub-sections. In a synchronous request, the parameters select the representation returned in the response message. In an asynchronous request, the parameters select the representation of the eventual query result rather than the response to the initial request.

Requirements on the presence and values of parameters described below are enforced only when the TAP request is executed (not when individual HTTP requests are handled). Thus, for asynchronous TAP queries, the

parameter requirements must be satisfied (and errors returned if not) only when the query is run in (in the sense of UWS job execution). Specifically, asynchronous queries may be created with with no parameters and multiple, subsequent HTTP POST actions may specify the parameters in any order.

Not all combinations of the parameters are meaningful. For example, if a request carries LANG=ADQL then the SELECT parameter (from PQL) is spurious. If a service receives a spurious parameter in an otherwise correct request, then the service must ignore the spurious parameter, must respond to the request normally and must not report errors concerning the spurious parameter.

2.7.1 REQUEST - remove?

This parameter distinguishes current service operations, makes it possible to extend the service specification (with additional or custom operations), and specifies how other parameters should be interpreted. If a TAP service attempts to execute a TAP request without this parameter or with an incorrect value for this parameter, then the service must reject the request and return an error document as the result.

These are the standard values of the parameter:

doQuery: execute a query

getCapabilities: return VOSI-capabilities metadata

All requests to execute a query using a query language must include REQUEST=doQuery and must include the LANG parameter. For other values of REQUEST, additional parameters may or may not be required. The REQUEST=getCapabilities service operation must be supported for synchronous (/sync) requests and is not defined for asynchronous (/async) requests.

For synchronous queries, the HTTP request must also include additional parameters (see below) with the details of the query. These are used for metadata queries and data queries.

For asynchronous queries, the additional parameters may be included with the HTTP request that creates the query (the UWS job) or they may be POSTed directly to the created job resource, in one or more separate HTTP requests. The parameter names remain the same in both cases.

2.7.2 LANG

The LANG parameter specifies the query language. The service must support LANG and the client must provide a value with REQUEST=doQuery.

The only standard values for the LANG parameter is ADQL (a required language). Support for other languages and the LANG value to use with them is described in the service capabilities.

For example, an ADQL query would be performed with

```
REQUEST=doQuery
LANG=ADQL
QUERY=<ADQL query string>
```

A PQL query would be performed with

```
REQUEST=doQuery
LANG=PQL
<PQL-specific parameters>
```

The value of LANG is a string specifying the language and optionally the language version used for the query parameter(s), as defined by the service capabilities. The client may specify the version of the query language, e.g. LANG=ADQL-2.0 (the syntax should be as shown) or it may omit the version, e.g. LANG=ADQL. The service should return an “unknown query language” error as described in section 3.3 if an unsupported language or an incompatible language version is specified.

2.7.3 QUERY

The QUERY parameter is used to specify the ADQL query. It may also be used to specify the query for other values of LANG (e.g. LANG=<some RDBMS-specific SQL variant>) which are not specified in this document but may be described in the service capabilities.

A service must support the QUERY parameter because ADQL is a required language. The case sensitivity of the query string is defined solely by the query language specification. In the case of ADQL 2.0, for example, the query is not case sensitive except for character literals; schema, table, and column names, function names, and other ADQL keywords are not case sensitive.

Within the ADQL query, the service must support the use of timestamp values as described in [std:DALI].

If the tables that are queried through a service contain columns with spatial coordinates and the service supports spatial querying via the ADQL “region” constructs, the service must support the INTERSECTS function and it must support the following geometry functions: REGION, POINT, BOX, CIRCLE, COORD1, COORD2, COORDSYS. Support for the AREA,

CONTAINS, and POLYGON functions are optional. If the service supports the REGION function, it must support region encoding in STC-S format (see section 6); the extent of STC-S support within the REGION function is left up to the implementation. Coordinate system specification for POINT, BOX, CIRCLE, and POLYGON must use values from STC-S as described in ???.

Note: Although it is allowed by the ADQL syntax, clients should be careful when mixing constants and column references for coordinate system and coordinate values. For example, POINT('ICRS', t.ra, t.dec) does not cause t.ra and t.dec to be transformed to ICRS; it simply tells the service to treat the values as being expressed in that coordinate system.

2.7.4 FORMAT and RESPONSEFORMAT

The RESPONSEFORMAT parameter is fully described in [std:DALI]. For backwards compatibility, TAP-1.1 must also accept the FORMAT parameter as equivalent to RESPONSEFORMAT.

2.7.5 MAXREC

The MAXREC parameter and its effect on the query result is fully described in [std:DALI]. If the result set is truncated in this fashion, it must include an overflow indicator as specified in section XREF.

For the special value of MAXREC=0, the service is not required to execute the query; a successful MAXREC=0 request does not necessarily mean that the query is valid and the overflow indicator does not necessarily mean that there is at least one row satisfying the query. The service may perform validation and may try to execute the query, in which case a MAXREC=0 request can fail. A query with MAXREC=0 can be used with a simple query (e.g. SELECT * FROM some_table) to extract and examine the VOTable metadata (assuming FORMAT=votable). Note: in this version of TAP, this is the only mechanism to learn some of the detailed metadata, such as coordinate systems used.

2.7.6 RUNID

The RUNID parameter is fully described in [std:DALI].

2.7.7 VERSION

The VERSION parameter is fully described in [std:DALI].

2.7.8 UPLOAD

The UPLOAD parameter is described in [std:DALI]. Services should support the upload of temporary tables (in [std:VOTable] format) via the standard UPLOAD parameter. The table-name(s) must be legal ADQL table names as defined in [std:ADQL] but restricted as described below XREF. URIs maybe be simple URLs (e.g. with a URI scheme of http) or URIs (e.g. with a URI scheme of vos or param) that must be resolved to give the location of the table content. See section XREF for details.

If table upload supported, the service must accept tables in VOTable format. The client specifies the name of the uploaded table; this name must be a legal ADQL table name with no catalog or schema (i.e., a string following the regular identifier production of [std:ADQL]). Uploaded tables must be referred to in queries as TAP_UPLOAD.<tablename>, where <tablename> is the specified by the user. Tables in the TAP_UPLOAD schema are transient and persist only for the lifetime of the query (although caching might be used behind the scenes) and are never visible in the TAP_SCHEMA metadata.

The [std:DALI] UPLOAD parameter supports both external resources and in-line content. For external resources, one provides a URI (usually an HTTP URL) the TAP service can use to obtain the table content. For example,

```
HTTP POST http://example.com/tap/async/42
UPLOAD=mytable,http://otherplace.com/path/votable.xml
```

The service would retrieve the table from the provided URL and make it visible to the query as TAP_UPLOAD.mytable.

If the TAP service supports VOspace (TBD: how to declare this?), one may specify an upload table using a URI to a table stored in a VOspace, for example:

```
HTTP POST http://example.com/tap/async/42
UPLOAD=mytable,vos://space/path/votable.xml
```

The service would resolve the URI, contact the VOspace, retrieve the table, and make it visible to the query as TAP_UPLOAD.mytable.

UPLOADS are accumulating, i.e., each UPLOAD parameter given will create one or more tables in TAP_UPLOAD. When the table names from two or more upload items agree after case folding, the service behaviour is unspecified. Clients thus cannot reliably overwrite uploaded tables; to correct errors, they have to tear down the existing job and create a new one. In principle, any number of tables can be uploaded using the UPLOAD parameter and any combination of URI schemes supported by the service as long as they are assigned unique table names within the query. Services may limit the size and number of uploaded tables; if the service refuses to accept the entire table it must respond with an error as described in section 3.3.

3 Use of VOTable

The [std:VOTable] format is the standard format for output (query results) and input (table upload) in a TAP service.

3.1 INFO elements

The RESOURCE element must contain an INFO element with attribute name="QUERY_STATUS" indicating the success of the operation. For RESOURCE elements that contain a TABLE element, this INFO element must appear lexically before the TABLE. The following values are defined for this INFO element's value attribute:

"OK", meaning that the query executed successfully and a result table is included in the resource

"ERROR", meaning that an error was detected at the level of the TAP protocol or the query failed to execute

The content of the INFO element conveying the status should be a message suitable for display to the user describing the status.

```
<INFO name="QUERY_STATUS" value="OK"/>
```

```
<INFO name="QUERY_STATUS" value="OK">Successful query</INFO>
```

```
<INFO name="QUERY_STATUS" value="ERROR">  
  value out of range in POS=45,91  
</INFO>
```

Additional INFO elements may be provided, e.g., to echo the input parameters back to the client in the query response (a useful feature for debugging or to self-document the query response), but clients should not depend on these.

```
<RESOURCE type='results'>
<INFO name="QUERY_STATUS" value="ERROR">
  unrecognized operation
</INFO>
<INFO name="SPECIFICATION" value="TAP"/>
<INFO name='VERSION' value='1.0'>
<INFO name="REQUEST" value="doQuery"/>
<INFO name="baseUrl" value="http://webtest.aoc.nrao.edu/ivoa-dal"/>
<INFO name="serviceVersion" value="1.0"/
...
</RESOURCE>
```

If an overflow occurs (result exceeds MAXREC), the service must close the table and append another INFO element to the RESOURCE (after the TABLE) with name="QUERY_STATUS" and the value="OVERFLOW".

```
<RESOURCE type='results'>
<INFO name="QUERY_STATUS" value="OK"/>
...
<TABLE>...</TABLE>
<INFO name="QUERY_STATUS" value="OVERFLOW"/>
</RESOURCE>
```

In the above example, the TABLE should have exactly MAXREC rows.

If an error occurs while writing the rows of the VOTable, the service must close the table and append another INFO element to the RESOURCE, after the TABLE, with name="QUERY_STATUS" and the value="ERROR".

```
<RESOURCE type='results'>
<INFO name="QUERY_STATUS" value="OK"/>
...
<TABLE>...</TABLE>
<INFO name="QUERY_STATUS" value="ERROR" />
</RESOURCE>
```

The content of these trailing INFO elements is optional and intended for users; client software should not depend on it.

Thus, one INFO element with name="QUERY_STATUS" and value="OK" or value="ERROR" must be included before the TABLE. If the TABLE does not contain the entire query result, one INFO element with

value="OVERFLOW" or value="ERROR" must be included after the table.

3.2 Successful Queries

The result of a query depends on the query language used and may be one or more tables in one or more resources. Unsupportable combinations of query result and FORMAT (e.g. queries that produce multiple tables and an inherently single-table format like CSV) will cause the request to fail. Currently, an ADQL query result must be a single table (in a single file).

The output table must include the same number and order of columns as specified in the SELECT clause of the query. For VOTable output, the name attribute of FIELD elements must be the same as the column names (or aliases if specified in the query) from the query and the datatype, arraysize, and xtype attributes of FIELD elements must be set using the mapping specified in section 2.5 . The xtype attribute in the output must match the datatype for the column in the TAP_SCHEMA.

VOTable structure follows the rules in section 2.9 and must be returned with an allowed VOTable MIME type (application/x-votable+xml or text/xml). If the RESPONSEFORMAT parameter (section 2.7.4) of the request specified a specific VOTable MIME type, the requested MIME type must be used in the HTTP response.

CSV formatted data should represent the output table with one row of text per table row, with the table column values rendered as text and separated by commas. If a column value contains a comma the entire column value should be enclosed in double quotes. Text lines may be arbitrarily long. The first data row should give the column name as the data value. CSV data must be returned with a MIME type of text/csv; if the optional header line (with column names) is included, the MIME type must be text/csv;header=present. Full details of CSV format are defined in RFC 4180 [std:CSV].

TSV formatted data should represent the output table with one row of text per table row, with the table column values rendered as text and separated by the TAB character. TSV data must be returned with a MIME type of text/tab-separated-values [std:TSV]. Column values may not contain the TAB character.

3.3 Errors

If the service detects an exceptional condition, it must return an error document with an appropriate HTTP-status code. TAP distinguishes three classes of exceptions.

Errors in the use of the HTTP protocol.

Errors in the use of the TAP protocol, including both invalid requests and failure of the service to complete valid requests.

Error documents for HTTP-level errors are not specified in the TAP protocol. Responses to these errors are typically generated by service containers and cannot be controlled by TAP implementations. There are several cases where a TAP service could return an HTTP error. First, the `/async` endpoint could return a 404 (not found) error if the client accesses a job within the UWS joblist that does not exist. Second, access to a resource could result in an HTTP 401 (not authorized) error if authentication is required or an HTTP 403 (forbidden) error if the client is not allowed to access the resource.

Error documents for TAP errors must be VOTable documents; any result-format specified in the request is ignored. If the error document is being retrieved from the `/async/<jobid>/error` resource (specified by UWS) after an asynchronous query, the HTTP status code should be 200. If the error document is being returned directly after a synchronous query, the service may use an appropriate HTTP status code, including 200 (successfully returning a response to the request) and various 4xx and 5xx values. The exception condition must be described to the client using a status code in the VOTable header. Section 2.9 specifies the use of VOTable for error documents in TAP services.

3.4 Overflows

If a query is executed by a TAP service, the number of rows in the table of results may exceed a limit requested by the user (using the `MAXREC` parameter) or a limit set by the service implementation (the default or maximum value of `MAXREC`). In these cases, the query is said to have 'overflowed'. Typically, a TAP service will not detect an overflow until some part of the table of results has been sent to the client.

If an overflow occurs, the TAP service must produce a table of results that is valid, in the required output format, and which contains all the results up to the point of overflow. Since an output overflow is not an error condition,

the MIME type of the output must be the same as for any successful query and the HTTP status-code must be as for a successful, complete query.

If the output format is VOTable, section 2.9.1 describes the method by which the overflow is reported. No method of reporting an overflow is defined for formats other than VOTable.

3.5 VOTable vs RDBMS Tables and Columns

TODO: describe the bi-directional mapping of VOTable <-> RDBMS table aka the old section on uploading tables... should this come earlier in the doc?

The column names in the transient database table are taken directly from the name attribute of the VOTable FIELD and PARAM elements. TODO: add column name restrictions here to avoid quoted identifiers. The datatypes of the transient table are determined from the FIELD and PARAM attributes as follows:

TODO: something like the table from TAP-1.0

The default mapping of data types are shown above (no arraysize or xtype). If the xtype attribute is set, this is the preferred internal datatype. If xtype is not set, then the datatype and arraysize indicate the most suitable internal datatype. Note that the last column of Table (x) is not normative. Implementations SHOULD try to make sure that the actual types chosen are at least signature-compatible with the recommended types (i.e., integers should remain integers, floating-point values floating-point values, etc.), such that clients can reliably write queries against uploaded tables.

For columns with xtype adql:REGION, this is particularly critical, since databases typically use different types to represent various STC-S objects. Clients are advised to assume that such columns will be approximated with polygons in the actual database table.

In the arraysize column above, [1] means the arraysize is not set or is set to 1, n means arraysize is set to a specific value, * means arraysize="*", and n* means arraysize="n*" (variable size up to length n). A blank means the arraysize is not set.

Binary values (unsignedByte in VOTable, BINARY, VARBINARY, or BLOB in ADQL) can be expressed as specified by the VOTable standard. By default, VOTable allows them to be written as an array of decimal numbers, e.g. 12 56 0 255 0 0 255 (one number per byte value).

For columns of type BLOB or CLOB, most database systems support reference to these columns in the select clause but not in any other part

of the query. Services may use these types to indicate that columns may only be selected. For example, if service implementors want to make URL(s) available as column values in the results, but do not actually store the URL(s) in the database, they would specify a column with `xtype="adql:CLOB"` and the column with URL(s) could be referenced in the SELECT clause of a query, but could not be used in the WHERE clause. The service could then process the query result and insert the URL(s) or, more likely, transform a column value (an identifier) into a URL while writing the results.

TIMESTAMP values are specified as described in [std:DALI]. The `xtype="adql:TIMESTAMP"` attribute must be specified in an uploaded VOTable in order for the values to be inserted in a column of type TIMESTAMP; without the `xtype`, the values would be inserted into a CHAR(n) or VARCHAR column.

POINT and REGION values are specified in STC-S format (see section 6). The `xtype="adql:POINT"` attribute must be specified in an uploaded VOTable in order for the char values to be parsed and treated as POINTs (e.g. to be used with some of the ADQL region functions). For regions, the `xtype="adql:REGION"` attribute must be specified in an uploaded VOTable in order for the char values to be parsed and treated as REGIONs (e.g. to be used with some of the ADQL region functions).

4 Metadata: TAP_SCHEMA

There are several approaches to getting metadata for a given TAP service. All TAP services must support a set of tables in a schema named TAP_SCHEMA that describe the tables and columns included in the service. In addition to the TAP_SCHEMA, there are two other ways to get metadata from a TAP service. First, the VOSI tables resource provides metadata on all tables and columns; this resource is described in 2.2.5 . The VOSI tables resource provides the same metadata as the TAP_SCHEMA but in a rigorously controlled format; the information in the TAP_SCHEMA is equivalent to that defined by the VODataService [7]. Second, the client may specify a query of one or more tables setting the MAXREC parameter to 0 so that only the metadata regarding the requested fields is returned. Use of MAXREC is described in section 2.7.5.

The TAP_SCHEMA provides access to table, column, and join key metadata through the TAP query mechanisms themselves. Users can discover tables or columns that meet their specific criteria by querying the tables described below. The service may enhance the TAP_SCHEMA with ad-

ditional metadata where that seems appropriate; since it is self-describing, the TAP_SCHEMA may be queried to determine if any extended schema metadata is defined by the service. Services must provide these tables and make them accessible by all supported query mechanisms.

The qualified names in the tables of the TAP schema must follow the rules defined in section 2.4. The names must be stated in a form that is acceptable as an operand of a query.

All columns in the TAP_SCHEMA tables are of type VARCHAR except for size, principal, indexed, and std (in Columns) which are INTEGER values.

Implementors are permitted to include additional tables in the TAP_SCHEMA to describe additional aspects of their service not covered by this specification. Implementors may also include additional columns in the standard tables described below. For example, one could include a column with a timestamp saying when metadata values were last modified.

4.1 Schemas

The table TAP_SCHEMA.schemas must contain the following columns:

column name	datatype	not-null
schema_name	VARCHAR	true
utype	VARCHAR	false
description	VARCHAR	false

The schema_name values must be unique and may be qualified by the catalog name or not depending on the implementation requirements. The fully qualified schema name is defined by the ADQL language and follows the pattern [catalog.]schema. The schema metadata are included for reference and are not used directly to construct queries.

4.2 Tables

The table TAP_SCHEMA.tables must contain the following columns:

column name	datatype	not-null
schema_name	VARCHAR	true
table_name	VARCHAR	true
table_type	VARCHAR	true
utype	VARCHAR	false
description	VARCHAR	false

The table_name values must be unique. The value of the table_name should be the string that is recommended for use in querying the table; it

may or may not be qualified by schema and catalog name(s) depending on the implementation requirements. The fully qualified table name is defined by the ADQL language and follows the pattern `[[catalog.]schema.]table`.

4.3 Columns

The table `TAP_SCHEMA.columns` must contain the following columns:

column name	datatype	not-null
<code>table_name</code>	<code>VARCHAR</code>	<code>true</code>
<code>column_name</code>	<code>VARCHAR</code>	<code>true</code>
<code>datatype</code>	<code>VARCHAR</code>	<code>true</code>
<code>"size" arraysize? datasize?</code>	<code>INTEGER</code>	<code>false</code>
<code>description</code>	<code>VARCHAR</code>	<code>false</code>
<code>utype</code>	<code>VARCHAR</code>	<code>false</code>
<code>unit</code>	<code>VARCHAR</code>	<code>false</code>
<code>ucd</code>	<code>VARCHAR</code>	<code>false</code>
<code>indexed</code>	<code>BOOLEAN?</code>	<code>true</code>
<code>principal</code>	<code>BOOLEAN?</code>	<code>true</code>
<code>std</code>	<code>BOOLEAN?</code>	<code>true</code>

The `table_name,column_name` (pair) values must be unique.

Data types and how they map to VOTable datatypes are described in Section `xrefsec:vot-rdbms` above. The “size” gives the length of variable length datatypes, for example `varchar(256)`; this size does not map to the VOTable `arraysize` attribute when the latter specifies the size and shape of a multi-dimensional array. To use the size column in a query, it must be put in double quotes since it collides with an ADQL reserved word. Since delimited identifiers are case-sensitive, for the size column both clients and servers MUST always (in particular, in the DDL for `TAP_SCHEMA`) use lower case exclusively. In the next major version of TAP, this column will be called `arraysize`.

The “principal” flag indicates that the column is considered a core part the content; clients can use this hint to make the principal column(s) visible, for example by selecting them by default in generating an ADQL query. In cases where the services selects the columns to return (such as PQL without a `SELECT` parameter), the principal column indicates those columns that are returned by default.

The “indexed” flag indicates that the column is indexed, potentially making queries run much faster if this column is used in a constraint.

The “std” is included for compatibility with the registry, which uses this

value to indicate that a given column is defined by some standard, as opposed to a custom column defined by a particular service.

4.4 Foreign Keys

The table `TAP_SCHEMA.keys` must contain the following columns to describe foreign key relations between tables:

column name	datatype	not-null
<code>key_id</code>	<code>VARCHAR</code>	true
<code>from_table</code>	<code>VARCHAR</code>	true
<code>target_table</code>	<code>VARCHAR</code>	true
<code>description</code>	<code>VARCHAR</code>	false
<code>utype</code>	<code>VARCHAR</code>	false

The `key_id` values are unique and used only to join with the `TAP_SCHEMA.key_columns` table below. There may be one or more rows with different `key_id` values and a pair of tables to denote one or more ways to join the tables.

The table `TAP_SCHEMA.key_columns` must contain the following columns to describe the columns that make up a foreign key:

column name	datatype	not-null
<code>key_id</code>	<code>VARCHAR</code>	true
<code>from_column</code>	<code>VARCHAR</code>	true
<code>target_column</code>	<code>VARCHAR</code>	true

There may be one or more rows with a specific `key_id` to denote single or multi-column keys.

A TAP service must provide the tables listed above and may provide other tables in the `TAP_SCHEMA` namespace.

5 Examples

The UWS pattern is specified in [std:UWS] and its application to TAP in section 2.2. This section gives examples of the exchange of messages between a TAP client and service when using UWS to run an asynchronous query.

5.1 Example: Asynchronous Query

Consider a TAP service at `http://example.com/tap`. TAP mandates that the asynchronous requests be directed to `http://example.com/tap/async` (e.g.

for anonymous queries). This URL points to the list of 'jobs'; i.e. the list of queries currently or recently executed.

5.1.1 Creating a Query

To create a new query, the client POSTs a request to the job list:

```
HTTP POST http://example.com/tap/async
REQUEST=doQuery
LANG=ADQL
QUERY=SELECT TOP 100 * FROM foo
```

The service then creates a job and assigns that job a name and a URL based on the name. Suppose that the name is 42, then the URL will be `http://example.com/tap/async/42` because the jobs are always children of the job list. While the job is in the PENDING phase, additional parameters may be specified by additional POSTs to the job resource, for example:

```
HTTP POST http://example.com/tap/async/42
UPLOAD=mytable,http://a.b.c/mytable.xml
```

After each such POST, the service issues an HTTP redirection to the job's URL, where the modified state may be accessed:

```
HTTP status 303 'See other'
Location: http://example.com/tap/async/42
```

All TAP-specific parameters are stored using the paramList mechanism of UWS and are included in the XML representation of the job:

```
HTTP GET http://example.com/tap/async/42
```

or directly from the parameters resource:

```
HTTP GET http://example.com/tap /async/42/parameters
```

Individual parameters cannot be accessed as separate web resources.

The UWS pattern requires the following resources to describe and control the job:

```
http://example.com/tap/async/42/phase
http://example.com/tap/async/42/quote
http://example.com/tap/async/42/executionduration
http://example.com/tap/async/42/destruction
http://example.com/tap/async/42/results
http://example.com/tap/async/42/error
```

The quote resource specifies the predicted completion time for the job (query), assuming it is started immediately. In practice, it is very hard to estimate the time a query will take; for TAP services it is recommended that this be set to the current time plus the maximum amount of time the query will be allowed to run (see termination below).

The termination resource specifies the amount of time (in seconds) the job (query) will be allowed to run before being aborted by the service. The termination time is set by the service and can be read from the job or directly from the termination resource:

```
HTTP GET http://example.com/tap/async/42/executionduration
```

The service may allow the client to change the termination:

```
HTTP POST http://example.com/tap/async/42/executionduration
TERMINATION=600
```

The destruction resource specifies when the service will destroy the job. The service is only required to keep a job for a finite period of time, after which it may destroy the job, including the result. After this time, the client will receive an HTTP 404 'not found' status if it tries to get any information about the job. The destruction time of the job is chosen by the service and the client can read it from the job or directly from the destruction resource:

```
HTTP GET http://example.com/tap/async/42/destruction
```

The service may allow the client to change the destruction time:

```
HTTP POST http://example.com/tap/async/42/destruction
DESTRUCTION=2008-11-11T11:11:11Z
```

5.1.2 Running a Query

The phase URL shows the progress of the job. When the job is created by the service it will normally be set to PENDING, but might be set to ERROR if the service has rejected the job. If the phase is ERROR, then the error URL should lead to a an error document explaining the problem. If the phase is PENDING, then the client needs to commit the job for execution.

The client runs the job by posting to the phase URL:

```
HTTP POST http://example.com/tap /async/42/phase
PHASE=RUN
```

The service replies with a redirection to the job URL

```
HTTP status 303 'see other'  
Location: http://example.com/tap /async/42
```

The phase will now have changed to either QUEUED or EXECUTING, depending on the service implementation. The client tracks the execution by polling the phase URL:

```
HTTP GET http://example.com/tap/async/42/phase
```

A job in the QUEUED or EXECUTING phase may be aborted by posting to the phase URL:

```
HTTP POST http://example.com/tap/async/42/phase  
PHASE=ABORT
```

When the query is complete, the phase changes to COMPLETED. The client then retrieves the result from the results list:

```
HTTP GET http://example.com/tap/async/42/results/result
```

The client knows that the table of results is at the URL /result relative to the results list because the TAP protocol requires this naming. A generic UWS client could find the name of the result and retrieve it by examining either the job description:

```
HTTP GET http://example.com/tap/async/42
```

or by looking specifically at the result list:

```
HTTP GET http://example.com/tap/async/42/results
```

If the service cannot run the query, then the final phase is ERROR and there is no table of results. In this case, the client should expect an HTTP 404 'not found' status if it tries to retrieve the result. The client should look instead at the error resource to find out what went wrong:

```
HTTP GET http://example.com/tap/async/42/error
```

If the job was aborted (by the client or the service), the final phase will be ABORTED and there is no table or results. As with errors, the client should look at the error resource to find out what went wrong.

The basic sequence can be executed from a web browser or from a shell script using the curl utility:

```
curl -d 'REQUEST=doQuery&LANG=PQL&POS=12,34&SIZE=0.5&FROM=foo' \  
      http://example.com/tap/async
```

[read Location header from curl output]

```
curl -d 'PHASE=RUN' http://example.com/tap/async/42
```

```
curl http://example.com/tap/async/42/phase
```

[repeat until phase is COMPLETED]

```
curl http://example.com/tap/42/results/result
```

5.1.3 Example: Synchronous Query

TODO

5.1.4 Example: DALI-examples Document

TODO

6 Use of STC-S in TAP - deprecated

NOTE: The old section 6 is not included from TAP-1.0 since it was informative and does not belong in this document. If we need to define syntax for points, circles, and polygons then that should be done in [std:DALI], which already defines timestamp syntax.

7 VOSpace Integration - deprecated

Note: some text moved to the UPLOAD section; may propose DEST parameter for outout.

8 Use of HTTP - deprecated

Note: This section is in or belongs in DALI.

A Changes from Previous Versions

A.1 Changes from TAP-1.0

Restructured the document and removed text that duplicates material from DALI. Rewrite the overly long introduction with some basic use cases to help define the scope and tell readers what TAP is supposed to accomplish.

Made clarifications: restricted allowed table names for UPLOAD, clarified that multiple UPLOAD parameters accumulate, deprecated the size column in TAP_SCHEMA.columns and added advice to quote it as a delimited identifier, made presence of a TABLE element on VOTable output only required for successful queries, added optional DALI-examples endpoint (text TBD).

Defined standardID values for the async and sync resource types and explicitly allow for multiple of each resource (typically to support authentication). The fixed paths /async and /sync are still required and are to provide anonymous query access, which should be compatible with existing services.

References

Arviset, C., Gaudet, S. & the IVOA Technical Coordination Group (2010), 'IVOA architecture', IVOA Note.

URL: <http://www.ivoa.net/documents/Notes/IVOAArchitecture>

Bradner, S. (1997), 'Key words for use in RFCs to indicate requirement levels', RFC 2119.

URL: <http://www.ietf.org/rfc/rfc2119.txt>