Abstract. With VODDataService 1.2, service providers in the Virtual Observatory (VO) have a reasonably straightforward way to declare where in space, time, and spectrum the data within a resource (i.e., service or data collection) lie. Here, we discuss the mechanism and design choices, current limitations (e.g., regarding non-electromagnetic or solar system resources) as well as ways to overcome them. We also show how users and clients can already run queries against resource coverage using a scheme that is expected to become part of RegTAP 1.2 (or a separate standard). We conclude with an ardent plea to all resource creators to provide STC metadata – only wide adoption will make this facility useful.

1. Introduction

Last year, Demleitner (2018) proposed a roadmap for how to finally provide means for resource discovery using space, time, and spectral constraints in the Virtual Observatory. This is not only useful in itself, it is also a precondition for efficient blind discovery, i.e., finding research artefacts not by previous knowledge of particular data collections (“2MASS magnitudes”) but by physical properties (“fluxes around 2 µm for red giants in the LMC”).

The roadmap proposed five concrete steps to be taken, of which three are rather technical in nature. The remaining two were an update to the VODDataService standard that enables data providers to declare the coverage of their resources, and an update to the resource discovery protocol RegTAP that lets clients use these coverages in their queries.

In late 2019, a Proposed Recommendation for VODDataService 1.2 is available (Plante et al. 2019), and the ideas for RegTAP evolution laid out in the roadmap have a prototype implementation. This contribution reports on both.

2. Declaring Space-Time Coverage

To declare where data within a resource is located in the VO phase space, VODDataService 1.2 defines three new child elements of the pre-existing coverage element:

- **spatial** – zero or one allowed. Contains an ASCII MOC (Fernique et al. 2014), written in the ICRS.
- **temporal** – zero or more allowed. Contains a space-separated pair of floats giving an MJD interval.
• spectral – zero or more allowed. Contains a space-separated pair of floats giving an energy interval observed. Energies are given in Joules.

Diverging from the original roadmap, spectral coverage is now represented with energy, which which not only is medium-independent (the standard choice in the VO, wavelength, is not) but also retains its meaning across different messengers (e.g., neutrinos or charged particles in the solar system). The choice of Joule as the unit is somewhat arbitrary but at least does not favour astronomers working in any particular part of the spectrum, and it emphasises that user interfaces have to provide elements adapting to their users’ preferred units.

While we do not expect the resulting differences to matter much in discovery of extrasolar data, all coordinates should be given as observed from the solar system barycenter, and times should use TDB.

With this, the coverage for a resource of a longer observation campaign (here, the Palomar-Leyden Trojan surveys) could look like this:

<coverage>
  <spatial>3/282,410
        4/40,323,326,329,332,387,390,396,648-650,1083,1085,1087,
         1101-1103,1123,1125,1132-1134,1136,1138-1139,1144,1146-1147,
        ...
  </spatial>
  <temporal>37190 37250</temporal>
  <temporal>38776 38802</temporal>
  <temporal>41022 41107</temporal>
  <temporal>41387 41409</temporal>
  <temporal>41936 41979</temporal>
  <temporal>43416 43454</temporal>
  <spectral>3.01e-19 6.02e-19</spectral>
  <waveband>Optical</waveband>
</coverage>

While the standard is agnostic on the resolutions on all axes, as a good compromise between the desires for compact registry records and specificity in discovery we currently recommend a maximal level of 6 in the spatial coverage.

3. Discovery Using Space-Time Metadata

To enable discovery on these coverages, the roadmap suggested an extension to RegTAP that, adapted for the change of spectral modelling, is already implemented on the RegTAP service at http://dc.g-vo.org/tap. Three tables are added:

• rr.stc.spatial with columns ivoid, coverage, ref_system_name, where coverage contains a MOC-typed geometry which so far only supports the CONTAINS function with POINTs. ref_system_name is NULL for ICRS. Non-celestial data will have non-empty values in that column.

• rr.stc.temporal with columns ivoid, time_start, time_end (with MJD values).

• rr.stc.spectral with columns ivoid, spectral_start, spectral_end (in Joules of energy).
A straightforward case to illustrate the use of these tables would be the discovery of data for messengers around the rest mass of electrons for the center of the LMC. In ADQL, this could be written as:

```sql
SELECT ivoid
FROM rr.stc_spatial
NATURAL JOIN rr.stc_temporal
WHERE
  1=CONTAINS(POINT(80.9, -69.8), coverage)
  AND ref_system_name IS NULL
  AND ivo_interval_overlaps(500, 550,
    in_unit(spectral_start, 'keV'),
    in_unit(spectral_end, 'keV'))
```

The new syntax for geometry construction and the `in_unit` extension are from ADQL 2.1. The `ivo_interval_overlaps` is a simple user defined function also proposed in the Roadmap.

Another, perhaps only bibliometrically useful, example is the creation of a density map of VO resources; with an ADQL extension proprietary to DaCHS (Demleitner et al. 2014) that generates integer series, here is a query to produce a HEALPix map (12287 is the largest HEALPix index on level 5):

```sql
SELECT hpx, COUNT(*)
FROM generate_series(0, 12287) AS hpx
JOIN rr.stc_spatial
ON (1=CONTAINS(ivo_healpix_center(5, hpx), coverage))
```

Fig. 1 shows a visualisation of this data prepared using TOPCAT (Taylor 2005). We note that the high impact projects like SDSS and Kepler had on astronomy shows in this plot.

4. Further Directions

While the core functionality envisioned by the roadmap is now available, the scheme can and will be evolved. Issues we would like to see addressed include:
Solar system data: Right now, the spatial coverage is always given in the ICRS. We believe this is adequate for celestial (in the sense of: outside of the solar system) data. It is clearly rather useless for resources covering solar system objects and phenomena. At this point we hope to cover these wider use cases with properly defined terms in \texttt{ref\_system\_name}.

Redshift/Distance: The first version of the data model for space-time coordinate offered redshift as another axis, and one could make a point that distance is part of the spatial location. It is, however, hard to define a distance measure that works naturally from solar system science to cosmology. Since the number of resources that can even sensibly give distances appears to be low, we have postponed this question for now.

Non-EM messengers: There is no way to look for “Neutrino” or “Gravitational Wave” by this scheme yet (but GeV-neutrinos can be told from from eV-neutrinos). It seems at this point that no new VOResource feature is strictly required to solve this. The most straightforward solution would be to expand the waveband vocabulary to new messengers, even though the element name “waveband” might then appear a slight misnomer. An alternative avoiding this might be to reserve terms given in subject for this purpose.

5. Takeup

Unfortunately, not many registry resources declare their STC coverage yet. As of 2019-09-23, the VO registry contained 15131 resources with \textit{spatial} coverage (but over 90\% of these are actually harvested from their footprint URLs and thus do not give inline coverages yet), 80 resources with \textit{temporal} coverage (originating from 5 authorities), and 75 resources with \textit{spectral} coverage (originating from 4 authorities).

At least on temporal and spectral, this is clearly not enough to even start basing user interfaces on it.

We therefore conclude with an ardent plea to publishers of VO services to add coverage information to their registry records.

References

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