DATA MODELS FOR RADIO ASTRONOMY IN THE VO

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ABSTRACT

Data Models are an essential part of automatic data processing, but even more so when trying to tie together data coming from many different data sources, as is the case for the International Virtual Observatory. In this talk we will review the different data models used in the IVOA, which parts of that Data Modelling work are still incomplete, specially in radio wavelengths, and the work the AMIGA group has done within the IVOA Data Modelling Working Group to overcome those shortcomings both in missing data models and support for Radio Astronomy.

Key words: Virtual Observatory; Data Modelling; Radio Astronomy.

1. INTRODUCTION

The AMIGA project (Analysing the interstellar Medium of Isolated GALaxies) was born in 2003, and intends to provide a statistical characterisation of a strictly selected sample of isolated galaxies composed by more than 1000 objects, by means of multi-wavelength data, and with a particular emphasis on radio data at cm, mm, and sub-mm wavelengths. All these data are being periodically released via the web page of the project,[1], which provides a Virtual Observatory (VO) ConeSearch interface.

AMIGA+ is the natural extension to AMIGA, with three different goals: exploitation of the AMIGA catalogue, selecting the best candidates for a detailed study of isolated galaxies; scientific extension to the millimetre and submillimetre range; and participation in the development of systems allowing the access and display of large radio astronomical databases, both single-dish and interferometric, within the VO framework.

During the AMIGA+ projects two VO-compliant radio astronomical archives were developed: the IRAM 30m antenna archive (soon to be published), and the DSS-63 archive.

Early during the development phase, a decision was made that we would not just provide a VO compatibility layer on top of these archives’ infrastructures, but that the internal archive organisation should reflect existing VO data models in order to assure that the VO interface would be able to provide the most metadata.

2. DATA MODELS

Data models are the detailed description of the set of entities needed for information storage in a particular field, and specify both the data being stored, and the relationships between them. Data models are part of the hidden VO infrastructure astronomers would normally never be involved with, but knowledge of data models can enhance the opportunities for the exploitation of the VO.

Within the VO, data models apply not only directly to the scientific data, but to the metadata describing them. As the way to structure information depends on the application domain, VO data models describe astronomical datasets in a way that is as instrument independent as possible, to ensure that the same description can be used for data with different provenance. Users must also be able to query those data models to be able to find datasets which comply with certain properties.

The IVOA Data Modelling Working Group (DMWG) started an an effort to provide a complete data model for astronomical observations, the Data Model for Observations (McDowell et al., 2005). One of the most important parts of it was the Characterisation of datasets, that is, the complete specification of where those datasets could be found in the spatial, temporal, and spectral axes, with more axes available (i.e., polarisation) for suitable datasets. The Observation data model was put on hold, and the Data Model for Astronomical Dataset Characterisation (McDowell et al., 2007) was started.

We have built a complete observation data model for single-dish radio telescopes, the Radio Astro-
nomical DA\texttt{ta Model for Single-dish telescopes (RADAMS)} (Santander-Vela et al., 2008), based on those two documents.

3. DATA MODEL ELEMENTS

When defining a VO data model, we have to specify:

**Entities** Being the data model building blocks, they group related attributes within a data model. They can be mapped to Classes in Object-Oriented Programming (OOP), or Elements in XML.

**Fields** They are the actual data elements of the model. They map to Attributes in OOP, and they can be mapped to Attributes or to Elements without children in XML.

**Relationships** The different entities and fields have hierarchical or relational relationships: an observation projects have projected observations, and all entities which share a common project ID are related, for instance. For the data model to be uniquely defined those relationships must be made explicit.

**Data types** For computers to be able to correctly interpret a data stream a Data type needs to be specified. For instance, object IDs could be Integers, but they are normally textual, so String data must be used. We could consider the restrictions which can be defined for complex data types in XML as part of the data typing.

**Units** No physical quantity can be specified without providing its units. Physical-data related Fields need Units to be specified, or Units have to be a fixed property of certain Fields, but they either need to exist as an implicit attribute of a particular field, or to have their own dedicated Field.

**Semantics** As observation metadata are related to real-world elements and quantities, VO data models should specify semantics —i.e., what is exactly meant in the real world by a particular field—to avoid ambiguities. Most of VO semantics are provided via Unified Content Descriptors (UCDs) and UT\texttt{ytypes}.

4. SEMANTICS, UCDS, UT\texttt{Y}TYPES AND IVOA VOCABULARIES

UCDs are a controlled vocabulary\textsuperscript{2}, under the supervision of the IVOA Semantics WG, which provides a list of atoms which can be used to identify fields as corresponding to specific astronomical quantities. For instance, a field containing the Right Ascension can be identified by the UCD atom pos.eq.ra, while a photometric flux in the V band can be identified by the two UCD atoms phot.flux; em.opt.V. This provides both a unified vocabulary to identify any astrophysical quantity, and an automatic knowledge discovery tool for fields with arbitrary relationships. In fact, UCDs were born out of a joint CDS/ESO data mining effort (Ortiz et al., 1999). However, UCDs can only provide data kind information, but not relationship information. In a sense, they are a kind of specialised unit, complementary—orthogonal—to physical units: in the same way that quantities with the same physical units can be very different in nature (i.e., decay time for an isotope versus oscillation period), fields with identical UCDs can also be related to different real-word phenomena. In order to allow such deeper relationships to be expressed, and disambiguate metadata fields UT\texttt{ytypes} were born.

UT\texttt{ytypes} are created from a hierarchical data model by enumerating the different parents a particular field has in that hierarchy. For instance, a field containing the Right Ascension in equatorial coordinates for where an instrument was pointed to corresponds to the spatial coverage characterisation, in particular to the Location property, and thus it would sport a UT\texttt{ype} of characterisation.coverage.spatial.location, the UCD would be pos.eq.ra, and its units could be any angular unit.

But even with the help of units, UCDs and UT\texttt{ytypes}, sometimes it can be difficult to tag a particular piece of data with meaningful semantics, specially for data which does not have a direct place in a VO data model. For that we can borrow techniques from the Semantic Web (an effort for providing web documents with semantics, so that, for instance, a table of camera prices can be tagged so that software tools can identify in it prices, if possible belonging to digital cameras, even to particular brands), and provide one or more standardised astronomical vocabularies. The IVOA Semantics WG\textsuperscript{3} has started recreating controlled vocabularies such as UCDs in Semantic Web form, and even the IAU thesaurus has been recreated in that way (Derriere et al., 2008). We are using them in the IRAM 30m archive in order to provide semantics to data coming from antenna engineering terms.

5. ROLE OF DATA MODELS IN THE VO

We can identify in the VO four different phases, and we can see that in all of them data models play a central role:

**Discovery** Datasets available in the VO have to be discoverable for them to appear automatically in VO tools. The VO Registry holds data for existing datasets so that they can be easily discovered.

\textsuperscript{2}http://www.ivoa.net/Documents/latest/UCDlist.html

\textsuperscript{3}http://www.ivoa.net/cgi-bin/twiki/bin/view/IVOAVoaSemantics
The data model for Space-Time Coordinates (STC), dataset Characterisation (CharDM), Resource metadata (ResDM), and the UCD and IVOA thesaurus (IVOAT) are relevant in this phase.

**Evaluation** Datasets have to be evaluated in order to assess their applicability to the kind of analysis we might wish to perform; for instance, in order to do image mosaicing we need a certain coordinate overlap, and in order to do image stacking we need an almost complete overlap, and comparable resolutions. The main data model involved in this phase is the CharDM.

**Data Access** There is an implicit data model in the IVOA data access protocols, the Data Access Layer, which is centred on targets (coordinates with tolerances/search radii), and uses several properties from the CharDM, such as the Coverage in several axes.

**Transformation** When creating a new dataset, or transforming an existing one, a new CharDM instance needs to be created. If the transformed data set is a spectrum, the Spectral data model (SpecDM) is needed both for obtaining the complete description of the original data and describing the transformed product. There is no existing data model yet for images or for more complex data within the VO. In addition, in order to trace the origin of the transformed image we would need to use a Provenance data model, that apart from being an integral part of the Observation data model (ObsDM), it should be built in a stand-alone form so that it can be applied to newly generated, non-observational data.

6. RADAMS STRUCTURE AND PROPERTIES

After having presented the importance of VO data models for the different activities involved in VO data queries, analyses and transformations, we will present the main RADAMS features.

Figure 1 shows the RADAMS main structure, which can be seen as a combination of the Observation data model and the CharDM data model, but fully specifying classes that were only laid out by the ObsDM. Some particular adaptations of the CharDM to radio astronomy, specifically for the Sensitivity class, have been performed, and the Target class is able to deal with radio catalogues.

However, RADAMS main contributions come from the ObsDM classes which have been completely specified:

**Packaging** We have developed a VOPack packaging standard, which embeds characterisation information for any packaged observation set, and can specify the recursive inclusion of other packages.
Policy  The Policy class that we have developed is able to accommodate different user roles determined from the user identification and the explicit or implicit policies for each particular dataset.

Provenance Initially specified only for radio astronomy data, we are working to make it more general, and to be able to use it outside of observational scopes, so that software tools which provide dataset transformations can document the origin of their processed datasets.

The RADAMS has been implemented in two archives: the Telescope Access for Public Archive System (TAPAS) for the IRAM 30m, to be announced in the February 2009 IRAM Newsletter, and the scientific archive of NASA’s Deeps Space Center in Madrid 70 m antenna, DSS-63, and has shown that VO data models can be used as a blueprint for archives which are being built from scratch for VO compatibility.

7. FUTURE WORK

In the future, we plan to have the RADAMS Provenance data model, part of the author’s thesis (to be published in 2009), contributed to the IVOA DMWG, and have it integrated with the ObsDM.

We are starting also a collaboration with the ALMA Scientific Archive team in order to create in the future both a data model for ALMA data cubes which can be integrated in a future IVOA data model for multidimensional data, and providing VO compatibility to the ALMA Science Archive.

8. CONCLUSIONS

Data models are one of the three bases interoperability relies on. As the data models for astrophysical observations’ metadata must be interoperable across different software packages and instrument domains, not every detail can be included in the data models, or can be described using IVOA’s UCDs and UTypes. Semantic web technologies, such as thesauri expressed in W3C standards, can be used to provide additional semantics.

However, the IVOA high-level data modelling efforts are complete enough as to have guided the development of the RADAMS data model. The RADAMS has been successfully used to create two operational radio astronomical archives for two very different antennas and instrument systems, such as the IRAM 30m and the DSS-63.

In the future, the ObsDM must be complete enough to support the complex datasets to be produced by ALMA and radio telescopes further ahead in time, such as the LOFAR and other SKA pathfinders.

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