

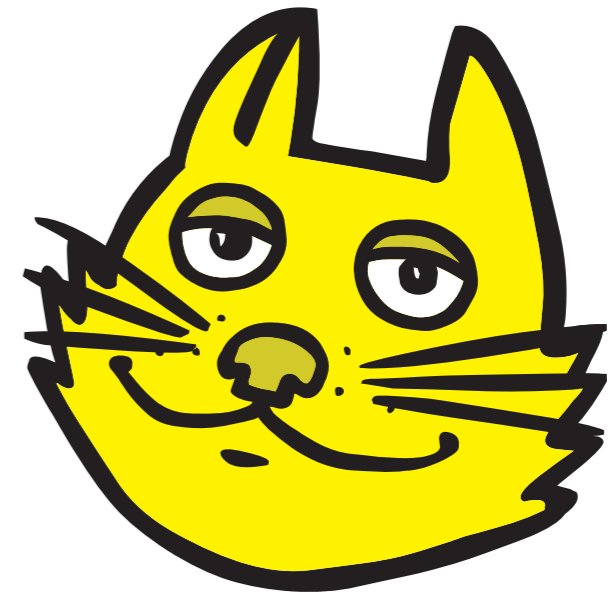
MIVOT and MANGO in TOPCAT

Mark Taylor (University of Bristol)



Applications WG
IVOA Interop
Sydney
(presented remotely)

20 May 2024



`$Id: tc-mivot.tex,v 1.15 2024/05/17 12:33:23 mbt Exp $`

Work in Progress!

Aims

- Experiment with MIVOT markup in VOTable
 - Can I parse it?
 - Can I represent this information in the internal table data model used by STIL*?
 - Can I round-trip it?
- Experiment with MANGO data model
 - Does it provide what I need for astrometry manipulation?
 - Can I extract that from the MIVOT serialization?
- Provide implementation feedback
 - *this talk*

* STIL: Starlink Tables Infrastructure Library, the table I/O library underlying TOPCAT and STILTS

Standards

As Laurent has already explained:

- **VO-DML** is a way of expressing data models in the VO
[REC-VODML-1.0-20180910](#)
- **MIVOT** embeds any VO-DML-serialized data model into VOTable
[REC-MIVOT-1.0-20230620](#)
- **MANGO** is a data model for encoding data about astronomical sources
<https://github.com/lmichel/MANGO>

Gaia Astrometry and Epoch Propagation

Aim:

Propagate Gaia positions and errors to some future/past date

Requirement:

5* parameter astrometry including full covariance matrix ($5 + 5 \times 5 = 30$ elements with some symmetry)

The `gaia_source` table supplies this information as:

- 5 astrometric parameters:

`ra, dec, parallax, pmra, pmdec`

- 5 errors:

`ra_err, dec_err, parallax_err, pmra_err, pmdec_err`

- 10 correlations:

`ra_dec_corr` `ra_parallax_corr` `ra_pmra_corr` `ra_pmdec_corr`
`dec_parallax_corr` `dec_pmra_corr` `dec_pmdec_corr`
`parallax_pmra_corr` `parallax_pmdec_corr`
`pmra_pmdec_corr`

Task:

- Encode this information in MIVOT using MANGO
- Decode it for use by TOPCAT

(* or maybe 6 parameter, but let's ignore radial velocity here)

MANGO Astrometry Encoding: Example

MIVOT-ised VOTable supplied by Laurent (VizieR [I/355/gaiadr3](#) marked up by hand)

- 5 parameters: easy!

```
<TEMPLATES>
  <INSTANCE dmtype="mango:EpochPosition">
    <ATTRIBUTE dmrole="mango:EpochPosition.longitude" dmtype="ivoa:RealQuantity" ref="RA_ICRS" />
    <ATTRIBUTE dmrole="mango:EpochPosition.latitude" dmtype="ivoa:RealQuantity" ref="DE_ICRS" />
    <ATTRIBUTE dmrole="mango:EpochPosition.parallax" dmtype="ivoa:RealQuantity" unit="mas" ref="Plx" />
    <ATTRIBUTE dmrole="mango:EpochPosition.radialVelocity" dmtype="ivoa:RealQuantity" unit="km/s" ref="RV" />
    <ATTRIBUTE dmrole="mango:EpochPosition.pmLongitude" dmtype="ivoa:RealQuantity" unit="mas/yr" ref="pmRA" />
    <ATTRIBUTE dmrole="mango:EpochPosition.pmLatitude" dmtype="ivoa:RealQuantity" unit="mas/yr" ref="pmDE" />
    <ATTRIBUTE dmrole="mango:EpochPosition.epoch" dmtype="coords:Epoch" value="2016.5" />
    <ATTRIBUTE dmrole="mango:EpochPosition.pmCosDeltApplied" dmtype="ivoa:boolean" value="true" />
    ...
  </INSTANCE>
</TEMPLATES>
```

MANGO Astrometry Encoding: Example

MIVOT-ised VOTable supplied by Laurent (VizieR [I/355/gaiadr3](#) marked up by hand)

- 5 errors: uh oh...

```
...
<!-- Errors on individual quantities -->
<INSTANCE dmrole="mango:EpochPosition.errors" dmttype="mango:EpochPositionErrors">
  <!-- Error on parallax -->
  <INSTANCE dmrole="mango:EpochPositionErrors.parallax" dmttype="mango:ErrorTypes.PropertyError1D">
    <ATTRIBUTE dmrole="mango:ErrorTypes.PropertyError1D.sigma" dmttype="ivoa:real" unit="mas" ref="e_Plx" />
  </INSTANCE>
  <!-- Error on radial velocity -->
  <INSTANCE dmrole="mango:EpochPositionErrors.radialVelocity" dmttype="mango:ErrorTypes.PropertyError1D">
    <ATTRIBUTE dmrole="mango:ErrorTypes.PropertyError1D.sigma" dmttype="ivoa:real" unit="km/s" ref="e_RV" />
  </INSTANCE>
  <!-- Error on position (diagonal matrix) -->
  <INSTANCE dmrole="mango:EpochPositionErrors.position" dmttype="mango:ErrorTypes.ErrorMatrix">
    <!-- Error matrix for 2D quantities -->
    <ATTRIBUTE dmrole="mango:ErrorTypes.ErrorMatrix.sigma1" dmttype="ivoa:real" unit="mas" ref="e_RA_ICRS" />
    <ATTRIBUTE dmrole="mango:ErrorTypes.ErrorMatrix.sigma2" dmttype="ivoa:real" unit="mas" ref="e_DE_ICRS" />
  </INSTANCE>
  <!-- Error on proper motion (diagonal matrix) -->
  <INSTANCE dmrole="mango:EpochPositionErrors.properMotion" dmttype="mango:ErrorTypes.ErrorMatrix">
    <!-- Error matrix for 2D quantities -->
    <ATTRIBUTE dmrole="mango:ErrorTypes.ErrorMatrix.sigma1" dmttype="ivoa:real" unit="mas/yr" ref="e_pmRA" />
    <ATTRIBUTE dmrole="mango:ErrorTypes.ErrorMatrix.sigma2" dmttype="ivoa:real" unit="mas/yr" ref="e_pmDE" />
  </INSTANCE>
</INSTANCE>
...
```

MANGO Astrometry Encoding: Example

MIVOT-ised VOTable supplied by Laurent (VizieR [I/355/gaiadr3](#) marked up by hand)

- 10 correlations: eek!

```
<!-- Correlation between quantities -->
<INSTANCE dmrole="mango:EpochPosition.correlations" dmttype="mango:EpochPositionCorrelations">
  <!-- Position/proper-motion correlation -->
  <INSTANCE dmrole="mango:EpochPositionCorrelations.positionPm" dmttype="mango:Correlation22">
    <ATTRIBUTE dmrole="mango:QuantityCorrelation.isCovariance" dmttype="ivoa:boolean" value="false" />
    <ATTRIBUTE dmrole="mango:Correlation22.a2b1" dmttype="ivoa:real" ref="DEpmRAcor" />
    <ATTRIBUTE dmrole="mango:Correlation22.a2b2" dmttype="ivoa:real" ref="DEpmDEcor" />
    <ATTRIBUTE dmrole="mango:Correlation22.a1b1" dmttype="ivoa:real" ref="RApmRAcor" />
    <ATTRIBUTE dmrole="mango:Correlation22.a1b2" dmttype="ivoa:real" ref="RApmDEcor" />
  </INSTANCE>

  <!-- parallax/proper-motion correlation -->
  <INSTANCE dmrole="mango:EpochPositionCorrelations.parallaxPm" dmttype="mango:Correlation12">
    <ATTRIBUTE dmrole="mango:QuantityCorrelation.isCovariance" dmttype="ivoa:boolean" value="false" />
    <ATTRIBUTE dmrole="mango:Correlation12.a1b1" dmttype="ivoa:real" ref="PlxpmRAcor" />
    <ATTRIBUTE dmrole="mango:Correlation12.a1b2" dmttype="ivoa:real" ref="PlxpmDEcor" />
  </INSTANCE>

  <!-- position/parallax correlation -->
  <INSTANCE dmrole="mango:EpochPositionCorrelations.positionParallax" dmttype="mango:Correlation21">
    <ATTRIBUTE dmrole="mango:QuantityCorrelation.isCovariance" dmttype="ivoa:boolean" value="false" />
    <ATTRIBUTE dmrole="mango:Correlation21.a2b1" dmttype="ivoa:real" ref="DEPlxcor" />
    <ATTRIBUTE dmrole="mango:Correlation21.a1b1" dmttype="ivoa:real" ref="RAPlxcor" />
  </INSTANCE>

  <!-- position/position correlation -->
  <INSTANCE dmrole="mango:EpochPositionCorrelations.positionPosition" dmttype="mango:Correlation22">
    <ATTRIBUTE dmrole="mango:QuantityCorrelation.isCovariance" dmttype="ivoa:boolean" value="false" />
    <ATTRIBUTE dmrole="mango:Correlation22.a2b1" dmttype="ivoa:real" ref="RADEcor" />
    <ATTRIBUTE dmrole="mango:Correlation22.a1b2" dmttype="ivoa:real" ref="RADEcor" />
  </INSTANCE>

  <!-- proper-motion/proper-motion correlation -->
  <INSTANCE dmrole="mango:EpochPositionCorrelations.properMotionPm" dmttype="mango:Correlation22">
    <ATTRIBUTE dmrole="mango:QuantityCorrelation.isCovariance" dmttype="ivoa:boolean" value="false" />
    <ATTRIBUTE dmrole="mango:Correlation22.a2b1" dmttype="ivoa:real" ref="pmRApmDEcor" />
    <ATTRIBUTE dmrole="mango:Correlation22.a1b2" dmttype="ivoa:real" ref="pmRApmDEcor" />
  </INSTANCE>
</INSTANCE>
```


MANGO Astrometry Encoding: Comments

The encoding is complicated!

- Some specifics:
 - ▷ Some errors specified as diagonal elements of matrix with no off-diagonals
 - ▷ 5-parameter covariance matrix split up into (artificial from Gaia point of view) submatrices
 - ▷ Matrix element/specifications hard to remember
 - ▷ Some correlations appear multiple times, others don't
- Generally hard to get right
 - ▷ It took several iterations between Laurent and me to get version without (apparent?) errors
 - ▷ I can code a parser from the example document, but I don't think I could from MANGO text
 - ▷ I'm not confident my parser would work for a different VOTable with MANGO markup
 - ▷ If the encoding ends up looking like this, we need very robust validators! And people need to use them.

Maybe this complexity is justified

- Perhaps it enables encoding of non-Gaia-like astrometry

Or maybe not

- Do we currently have examples of astrometry tables requiring this flexibility?
- Or do we expect them in the foreseeable future?

MANGO Astrometry Encoding: Alternative

A flat model would be much easier to work with:

```
<TEMPLATES>
<INSTANCE dmtype="mango:EpochPosition">
  <REFERENCE dmref="_spacesys_icrs" dmrole="mango:EpochPosition.coordSys" />
  <ATTRIBUTE dmrole="mango:EpochPosition.epoch" dmtype="coords:Epoch" value="2016.5" />
  <ATTRIBUTE dmrole="mango:EpochPosition.pmCosDeltApplied" dmtype="ivoa:boolean" value="true" />
  <ATTRIBUTE dmrole="mango:QuantityCorrelation.isCovariance" dmtype="ivoa:boolean" value="false" />

  <ATTRIBUTE dmrole="mango:EpochPosition.longitude" dmtype="ivoa:RealQuantity" ref="RA_ICRS" />
  <ATTRIBUTE dmrole="mango:EpochPosition.latitude" dmtype="ivoa:RealQuantity" ref="DE_ICRS" />
  <ATTRIBUTE dmrole="mango:EpochPosition.parallax" dmtype="ivoa:RealQuantity" unit="mas" ref="Plx" />
  <ATTRIBUTE dmrole="mango:EpochPosition.pmLongitude" dmtype="ivoa:RealQuantity" unit="mas/yr" ref="pmRA" />
  <ATTRIBUTE dmrole="mango:EpochPosition.pmLatitude" dmtype="ivoa:RealQuantity" unit="mas/yr" ref="pmDE" />

  <ATTRIBUTE dmrole="mango:EpochPosition.lonErr" dmtype="ivoa:RealQuantity" ref="e_RA_ICRS" />
  <ATTRIBUTE dmrole="mango:EpochPosition.latErr" dmtype="ivoa:RealQuantity" ref="e_DEC_ICRS" />
  <ATTRIBUTE dmrole="mango:EpochPosition.parallaxErr" dmtype="ivoa:RealQuantity" ref="e_Plx" />
  <ATTRIBUTE dmrole="mango:EpochPosition.pmlonErr" dmtype="ivoa:RealQuantity" ref="e_pmRA" />
  <ATTRIBUTE dmrole="mango:EpochPosition.pmlatErr" dmtype="ivoa:RealQuantity" ref="e_pmDE" />

  <ATTRIBUTE dmrole="mango:EpochPosition.lonLatCor" dmtype="ivoa:RealQuantity" ref="RADEcor" />
  <ATTRIBUTE dmrole="mango:EpochPosition.lonParallaxCor" dmtype="ivoa:RealQuantity" ref="RAPlxcor" />
  <ATTRIBUTE dmrole="mango:EpochPosition.lonPmlonCor" dmtype="ivoa:RealQuantity" ref="RAPmRAcor" />
  <ATTRIBUTE dmrole="mango:EpochPosition.lonPmlatCor" dmtype="ivoa:RealQuantity" ref="RAPmDEcor" />
  <ATTRIBUTE dmrole="mango:EpochPosition.latParallaxCor" dmtype="ivoa:RealQuantity" ref="DEPlxcor" />
  <ATTRIBUTE dmrole="mango:EpochPosition.latPmlonCor" dmtype="ivoa:RealQuantity" ref="DEpmRAcor" />
  <ATTRIBUTE dmrole="mango:EpochPosition.latPmlatCor" dmtype="ivoa:RealQuantity" ref="DEpmDEcor" />
  <ATTRIBUTE dmrole="mango:EpochPosition.parallaxPmlonCor" dmtype="ivoa:RealQuantity" ref="PlxpmRAcor" />
  <ATTRIBUTE dmrole="mango:EpochPosition.parallaxPmlatCor" dmtype="ivoa:RealQuantity" ref="PlxpmDEcor" />
  <ATTRIBUTE dmrole="mango:EpochPosition.pmlonPmlatCor" dmtype="ivoa:RealQuantity" ref="pmRAPmDEcor" />
</INSTANCE>
</TEMPLATES>
```

Yes the details look a bit Gaia-specific

- But Gaia is the main(?) example for this, and will be for a while
- Would doing it like this cause problems for any important use cases?

Parsed DM Manipulation

MIVOT describes structured objects per-table/per-row

- Data structure elements reference columns by column name/ID

This is not very suitable for TOPCAT to use in its internal table data model

- TOPCAT users can add/remove/rename/edit column metadata
- So a per-table structure referencing columns could become invalid after load
- (do similar considerations apply to TAP services constructing MIVOT??)

So TOPCAT reconstructs an inverted model of MIVOT DM at load time

- each column contains a description of its role(s) in the MIVOT structure
- This works (I think), but it's not very elegant

Round-tripping should be possible, but:

- It requires some effort
- I haven't tried it yet
- The round-tripped MIVOT markup might look cosmetically different from the input one

Additional Requirements

- MIVOT example describes one `mango:EpochPosition` instance
- Sometimes multiple (named?) instances may be required
 - Following a join of two tables with epoch astrometry
 - Following propagation of epoch astrometry
- I suppose(?) MIVOT can cope with this (`COLLECTION?`)
- But it will add more complication to the client-side processing

Implementation Progress

Epoch astrometry propagation window

- Extracts astrometry columns from input table using MIVOT/MANGO markup
- Uses them as defaults to populate fields in astrometry propagation query window
- Adds new columns as instructed calculating propagated astrometry

Status

- Missing features, not robust, various bugs
- But looks OK as proof of concept

The screenshot shows a software window titled "Astrometry Transformation". It is divided into two main sections: "Input" and "Output".

Input Section: This section contains a list of parameters, each with a dropdown menu for the value and another dropdown menu for the unit. The parameters and their current values are:

epoch:	2016.5	yr
lon:	RA_ICRS	deg
lat:	DE_ICRS	deg
parallax:	Plx	mas
pmlon:	pmRA	mas/yr
pmlat:	pmDE	mas/yr
rv:	RV	km/s
lonErr:	e_RA_ICRS	mas
latErr:	e_DE_ICRS	mas
parallaxErr:	e_Plx	mas
pmlonErr:	e_pmRA	mas/yr
pmlatErr:	e_pmDE	mas/yr
rvErr:	e_RV	km/s
lonLatCorr:	RADEcor	
lonParallaxCorr:	RAPlxcor	
lonPmlonCorr:	RApmRAcor	
lonPmlatCorr:	RApmDEcor	
latParallaxCorr:	DEPlxcor	
latPmlonCorr:	DEpmRAcor	
latPmlatCorr:	DEpmDEcor	
parallaxPmlonCorr:	PlxpmRAcor	
parallaxPmlatCorr:	PlxpmDEcor	
pmlonPmlatCorr:	pmRApmDEcor	

Output Section: This section contains three fields:

- Epoch: 2024.5
- Conversions: Covariances
- Suffix: 2024

At the bottom of the window, there are "OK" and "Cancel" buttons.

Conclusions

- MIVOT markup in VOTable is not too hard to parse
- MANGO can represent astrometry (e.g. Gaia 5/6-parameter fits with or without covariances)
 - but the representation is (unnecessarily?) complicated
 - I suggest flattening and simplifying it
- Representing MIVOT data in a TOPCAT table can be done
 - the implementation code is not very pretty
 - but that's probably unavoidable given what it's trying to do
- Multiple MANGO astrometry instances per table may be necessary