MOC 2.0
Status and discussion

Interop Granada (virtual) – 17-19 November 2020

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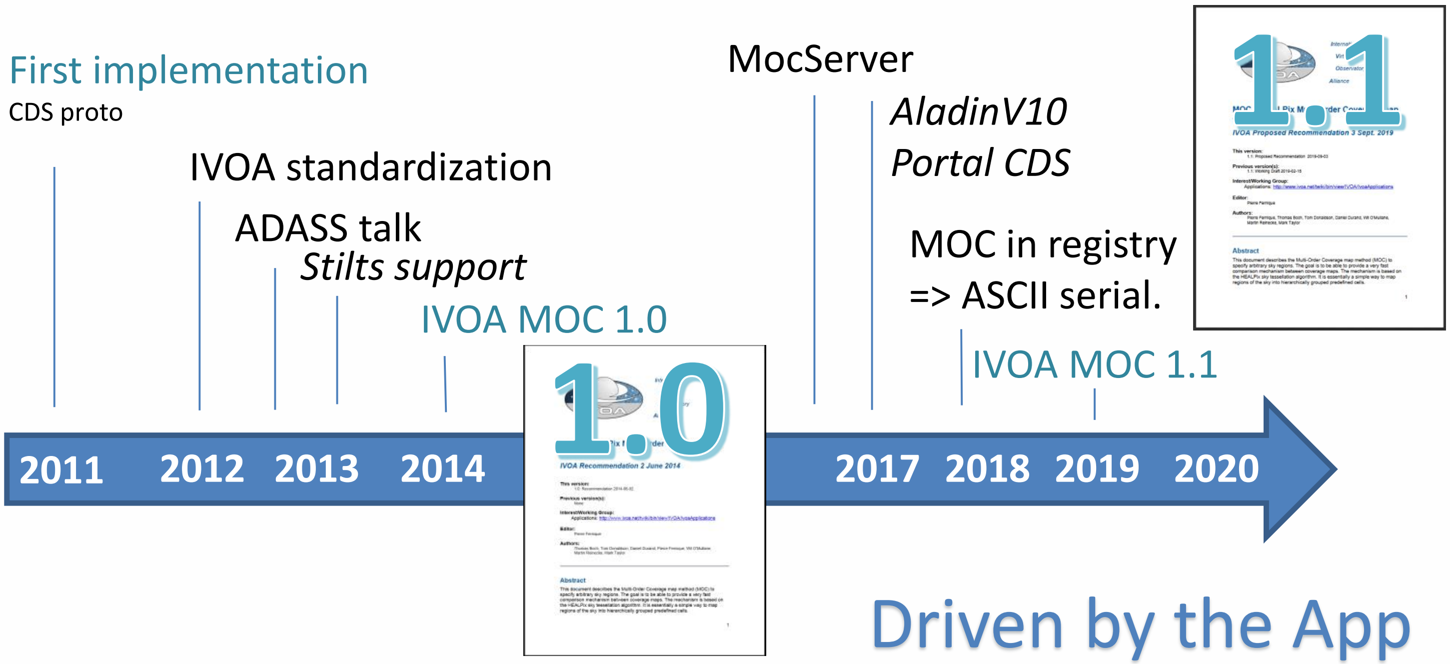
& all other authors and contributors

Observatoire astronomique de Strasbourg | ObAS

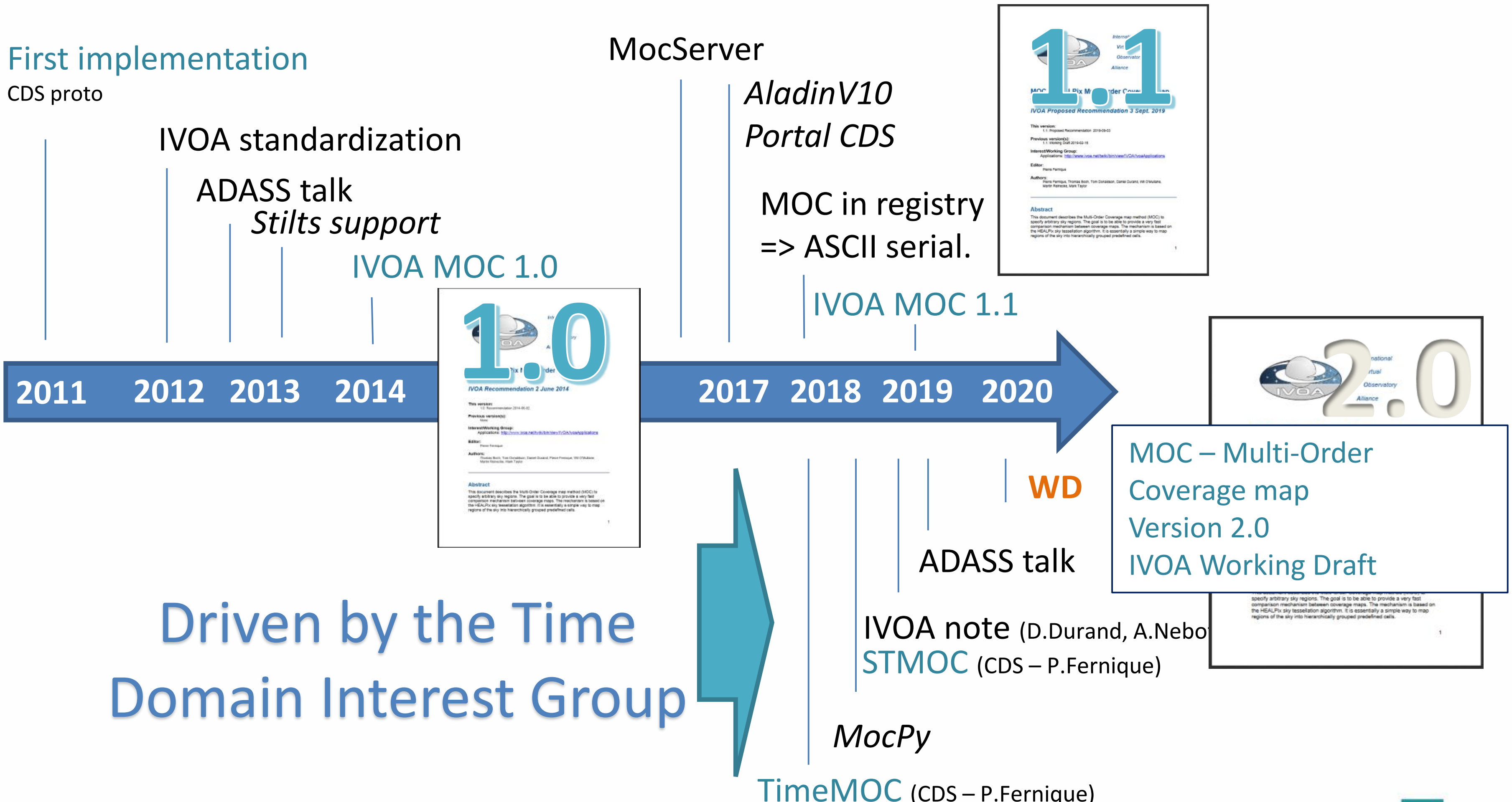
MOC standard history



Driven by the App Working Group

Space Coverage only

MOC evolution

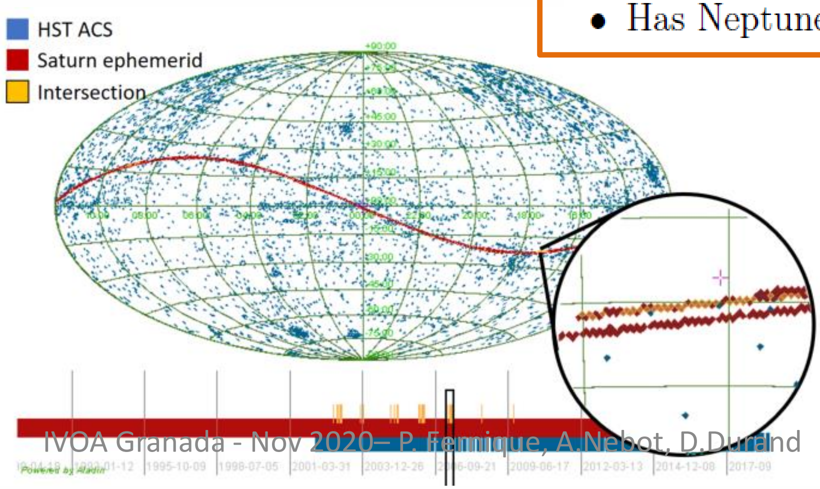


A Time Space MOC standard => MOC 2.0

- **MOC 2.0** is a generalization of MOC for manipulating **Space MOC**, **Time MOC** and **Space-Time MOC**
- Fully compatible with MOC 1.1 (=> addition of the Time convention + extension of the syntax for the MOC 2D)
- But **required to rewrite the MOC document**
  => MOC 1.0 & 1.1 were only HEALPix oriented
  => MOC 2.0 has to describe:
  - Space discretization by HEALPix
  - Time discretization based on JD

Time MOC extension: use cases

- What are the space and time coverages of the 2MASS observations and are there any observations which are coincidental with the HST archive?
- Which are the astronomical catalogs which have data for a list of Supernova events within a given window time?
- Are there quasi-simultaneous observations (within a given time window) of these two surveys for a list of eclipsing binaries?
- Find the intersection between the SDSS coverage and the ephemeris of this Near Earth Object, was it observed by SDSS? And by Galex? By both missions simultaneously? If so, are there detections within the source catalogues?
- Has Neptune been observed by DSS?



MOC visualisation & manipulation

Another example of usage would be the visual inspection of the spatio-temporal coverage of PanSTARRS observations (see Figure 2). The choice of a temporal resolution and a spatial resolution makes it possible to obtain an MOC of a desired data volume.

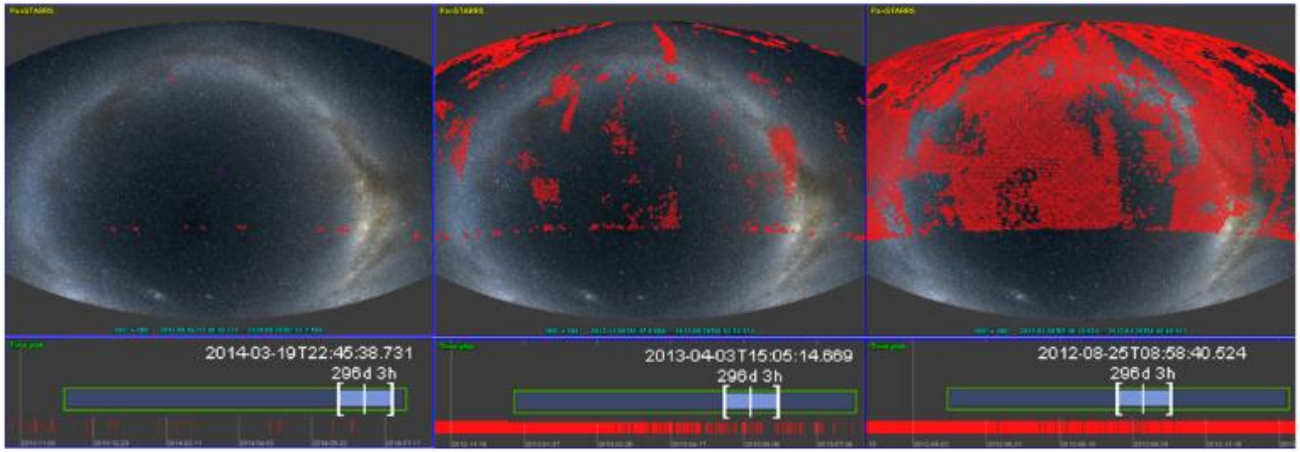
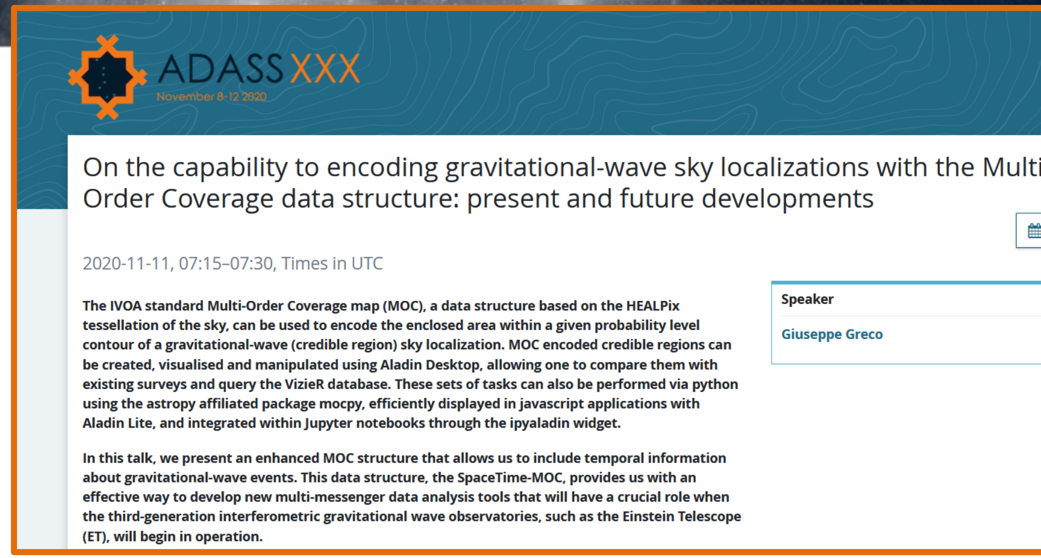


Figure 2: PanSTARRS observations and the associated spatial and temporal coverage within three different periods of time. The volume of the PanSTARRS MOC at a temporal resolution of about 17 minutes and spatial resolution of 52 arcsec is 320 MB.

Expectations from GW community



On the capability to encoding gravitational-wave sky localizations with the Multi Order Coverage data structure: present and future developments

2020-11-11, 07:15–07:30, Times in UTC

The IVOA standard Multi-Order Coverage map (MOC), a data structure based on the HEALPix tessellation of the sky, can be used to encode the enclosed area within a given probability level contour of a gravitational-wave (credible region) sky localization. MOC encoded credible regions can be created, visualised and manipulated using Aladin Desktop, allowing one to compare them with existing surveys and query the VizieR database. These sets of tasks can also be performed via python using the astropy affiliated package mocpy, efficiently displayed in javascript applications with Aladin Lite, and integrated within Jupyter notebooks through the ipyaladin widget.

In this talk, we present an enhanced MOC structure that allows us to include temporal information about gravitational-wave events. This data structure, the SpaceTime-MOC, provides us with an effective way to develop new multi-messenger data analysis tools that will have a crucial role when the third-generation interferometric gravitational wave observatories, such as the Einstein Telescope (ET), will begin in operation.

Speaker

Giuseppe Greco

" **The IVOA standard Multi-Order Coverage map (MOC), a data structure based on the HEALPix tessellation of the sky, can be used to encode the enclosed area within a given probability level contour of a gravitational-wave (credible region) sky localization.**

" **In this talk, we present an enhanced MOC structure that allows us to include temporal information about gravitational-wave events. This data structure, the SpaceTime-MOC, provides us with an effective way to develop new multi-messenger data analysis tools that will have a crucial role**

MOC 2.0 effort from Gruningen

- **Editors:** A.Nebot, D.Durand & P.Fernique
- **Authors:** MOC original authors + CDS new contributors
- **Result:** WD published last week in Apps WG => Do not hesitate to have a look at it https://www.ivoa.net/documents/MOC/20201112/WD-MOC-2.0-20201112.pdf

MOC principles

3 MOC principles

The MOC standard is defined using four basic building blocks: discretization, unique reference system, hierarchization and efficient encoding:

1. Determine a proper tessellation/discretization methodology for each dimension axis (space, time, ...);
2. Fix a unique referential system for each dimension (ICRS for the spatial dimension, TCB for the temporal one), to avoid reference conversions and thus allowing to easily compare different data collections;
3. Use an hierarchical procedure and a unique representation (canonical form) for compacting and quickly manipulating each axis coverage at any level of accuracy;
4. Implement at least one serialization in a binary encoding format (other serializations are possible, e.g. ASCII).

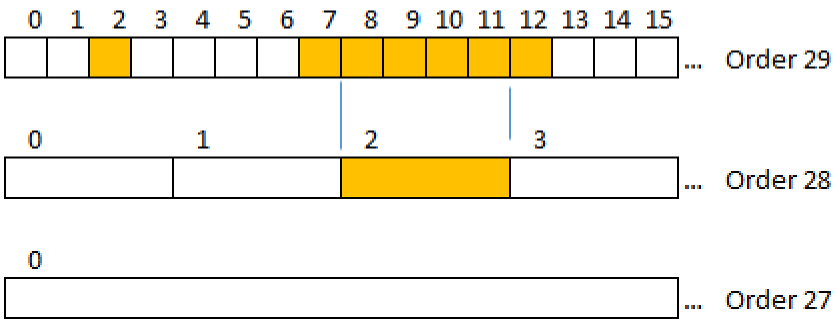
1. Discretization
2. Unique referential
3. Hierarchical and unique representation
4. Serializations

MOC principles (cont)

With these principles, a MOC consists of a list of numbers which represent the indices of the cells mapping the coverage of the spatial or temporal axis. As soon as the consecutive cells are used at order n, they will be hierarchically grouped in their parent cell at order n-1, and this recursively. This introduces the notion of orders and associated cell index. The cell boundary alignment implied by the hierarchical structure facilitates the combination of cells at different orders. Because of current technological possibilities, to operate efficiently, we are limiting to encode any pair (order, index) on 64 bits (a long), (in fact only 62 bits since we are using one bit for distinguishing space from time in binary encoding and one bit for future usage). The earlier MOC standard was limited to spatial coverage. We are reusing these principles to manipulate temporal coverages, as well as space-time coverages where we can manipulate the two physical dimensions simultaneously.

- List of numbers
  => 2,7,8,9,10,11,12

- As soon as the **consecutive cells** are **used at order n**, they will be **hierarchically grouped in their parent cell at order n-1**, and this recursively
  => **29**/2,7,12 **28**/2



TMOC principle

3.2 Time MOC conventions

In order to represent time coverage, we need to select a-priori the total range of time that we will cover with the notation. Following the same SMOC principles, we need to use a discrete time axis which each unit element of this axis has a constant duration. We adopt the Julian Date convention, very common in astronomy and a nominal resolution of 1μs.

- Discretization based on JD

We opt for the TCB reference according to the IAU 2006 definition (https://www.iau.org/static/resolutions/IAU2006_Resol3.pdf). Our choice is motivated by the fact that this system is linear by construction and has been adopted by numerous missions such as Gaia.

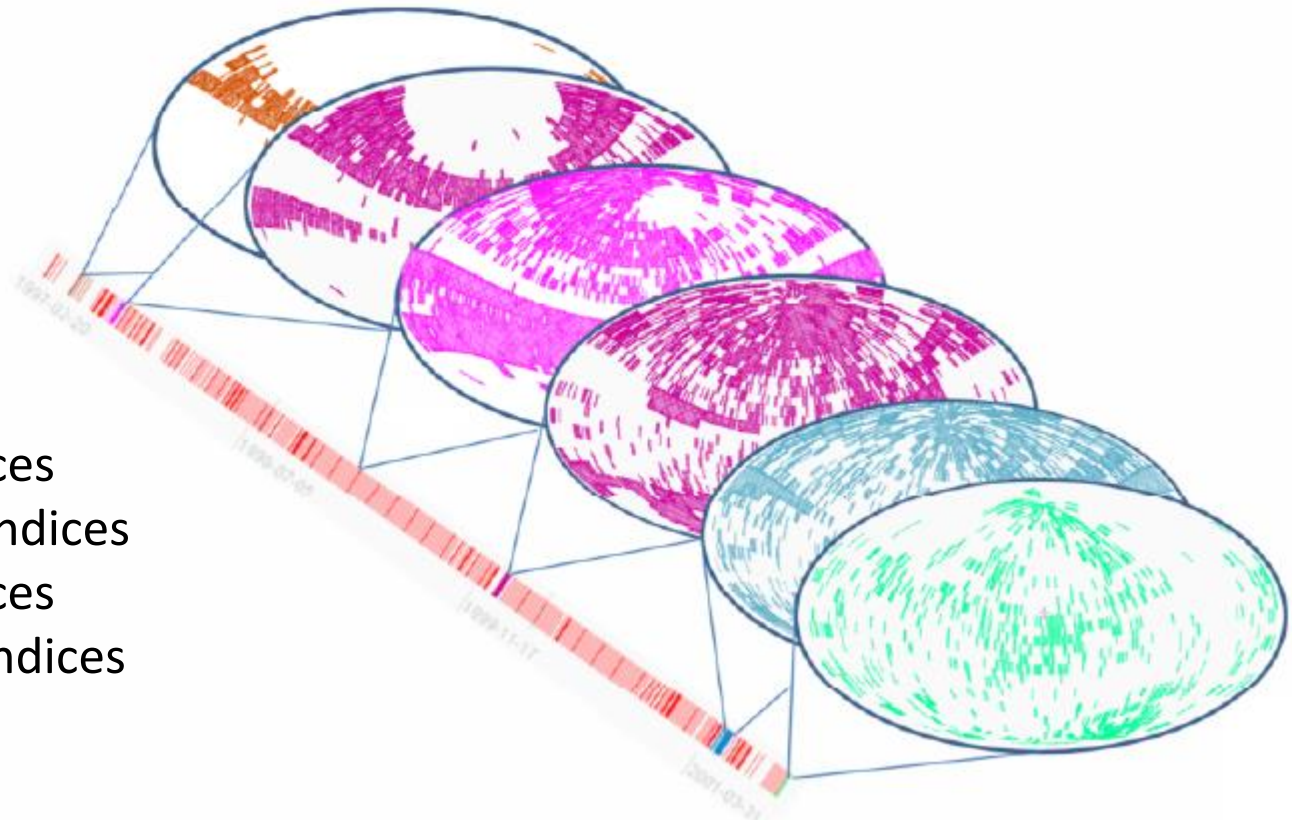
- TCB reference

This way we can address 2^{62} cells in an unsigned 64-bit integer, i.e. a little bit more than 73000 years at 1μ resolution, enough for most astronomical time events.

- Able to address 73 000 years at 1µs resolution from JD=0

STMOC principle

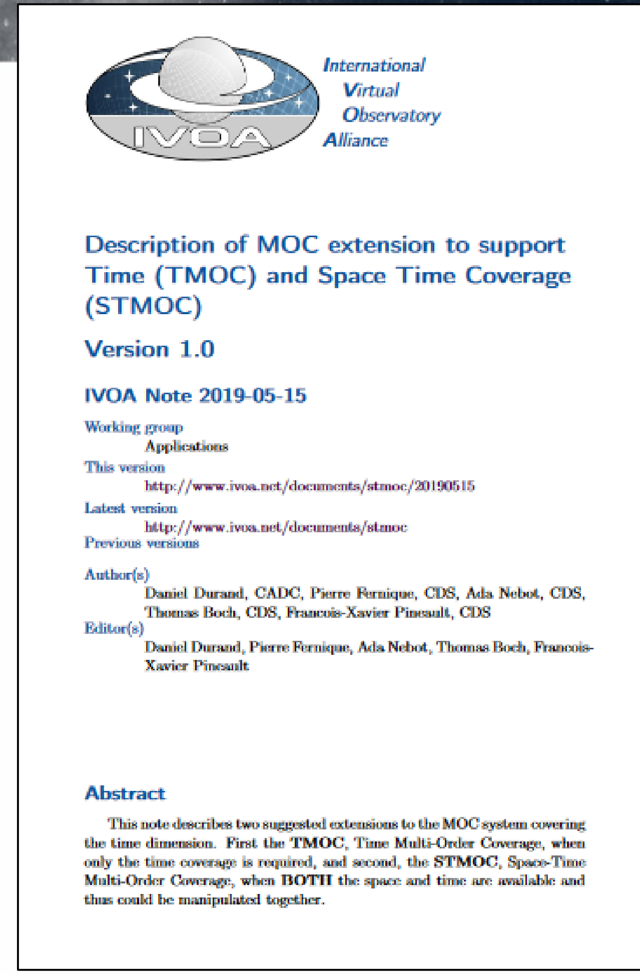
Our approach is to combine these two dimensions - time and space - by associating to each time period (coded according to the TMOC convention), its spatial region (coded according to the SMOC convention). For that, we interleave the information of time coverage with the information of space coverage for this period.



Time indices
-> **Space** indices
Time indices
-> **space** indices
…

3 changes since time MOC note

1. The **temporal** aspect is **no longer dependent** on the **coding** from **HEALPix** => Factor of 2 between each time order (4 for space order)
2. For **time**, we have simplified the **serialization** by using **intervals** (RANGE)
3. **New section** describing the **MOC usage constraints**



International Virtual Observatory Alliance

Description of MOC extension to support Time (TMOC) and Space Time Coverage (STMOC)

Version 1.0

IVOA Note 2019-05-15

Working group
Applications
This version
http://www.ivoa.net/documents/stmoc/20190515
Latest version
http://www.ivoa.net/documents/stmoc
Previous versions

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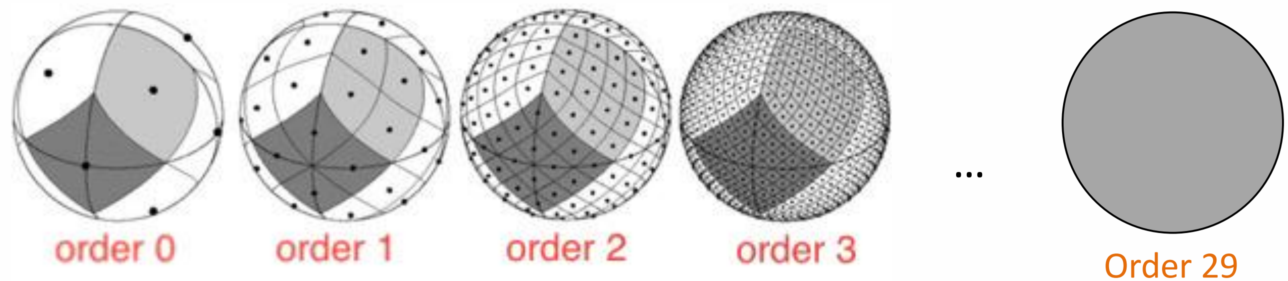
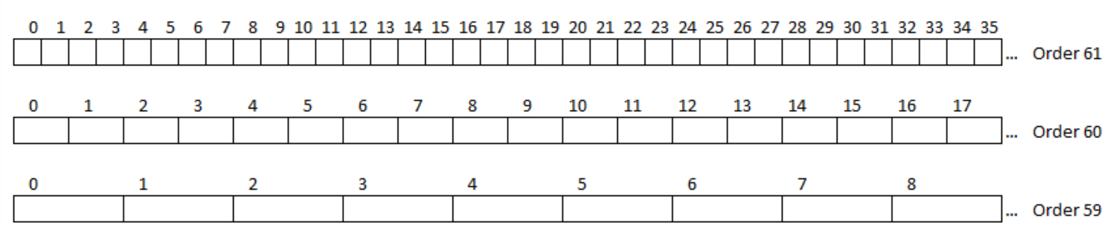
Abstract

This note describes two suggested extensions to the MOC system covering the time dimension. First the **TMOC**, Time Multi-Order Coverage, when only the time coverage is required, and second, the **STMOC**, Space-Time Multi-Order Coverage, when **BOTH** the space and time are available and thus could be manipulated together.

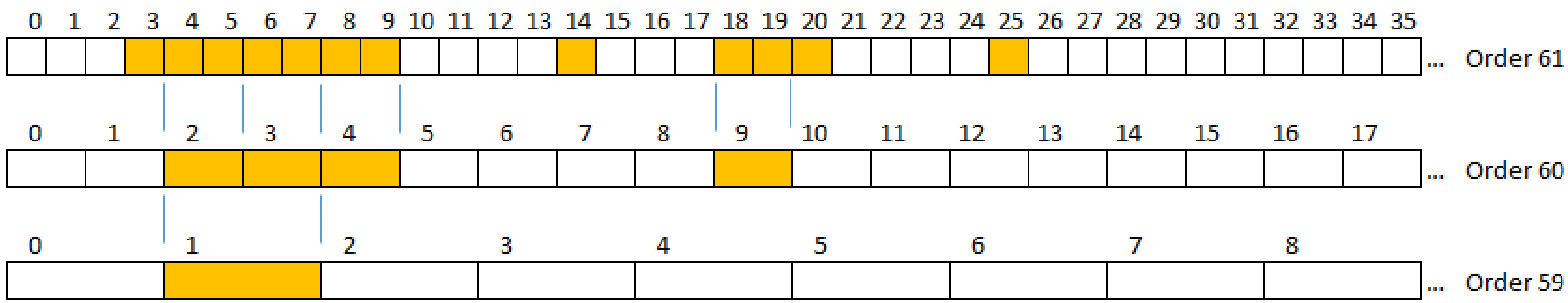
Factor 4 for Space, 2 for Time



1. The factor 4 is HEALPix dependent.
2. The first approach has been to keep the same to reuse the same code:
   => very fast implementation
   => but only 30 orders (coded in long int)
3. The final choice has been to **move to factor 2 for time**
   => a few modifications in the code
   => **62 orders** (coded in long int)



Serialization by ranges



- The hierarchical notation is possible in time
  => **61**/3,14,20,25 **60**/4,9 **59**/1
- But range notation expressed at the deepest order is more natural for time (=number of µs since JD=0)
  => 2-10 14-15 18-21 25-26

Backward compatibility

RANGE packaging has been introduced for MOC2.0. This method is generally faster than the previous one for reading or writing a MOC because the internal representation of MOC in memory is often range oriented. However, we recommend to use the first method for SMOC for compatibility with existing library not yet compatible with MOC2.0.

MOC usage constraints

7 MOC usage constraints

7.1 Canonical form

The speed of MOC operations - creation, union, intersection, etc is directly dependent on the speed of the equality test. It is therefore essential to always express a MOC in a canonical way

=> FAST: Cells sorted, well-grouped, etc...

7.2 Volume vs. Resolution

In order to handle easily MOCs, it is recommended to adjust the maximum resolution, i.e. the deepest order, to obtain a representation of the desired data volume even if it means degrading the accuracy of the coverage

=> Upper coverage approximation (see use cases)

MOC usage constraints (cont)

7.3 Working resolution

The MOC has been designed to be able to handle efficiently observation coverages (images, catalogs, ...). During the construction of the MOC, we must then ensure that at the chosen nominal resolution, any cell of the MOC contains at least one observation (no empty cell). To keep this assumption, during operations (unions, intersections ...) between 2 or more MOCs (e.g: MocA ∪ MocB ∪ MocC) of different resolutions, the operations must always be done at the worst (lowest) resolution of the original MOCs in order not to lose any observations, nor to create empty cells (see Figure 11), and finally to guarantee the set logical properties (commutativity, associativity,...).

- MOC designed
  for **observations coverage**
  => no empty cell
  => work at the worst resolution of all involved MOC
  (ex MocA U MocB U MoacC)

Note that MOC usage can be diverted to also manipulate surfaces unrelated to observations. When it is used this way such operations (over-sampling, surface dilatation or surface erosion) can be applied. And in this context it is necessary to work at the best (highest) resolution of the involved MOCs for preserving the properties of the surfaces operations (commutativity, associativity, ...).

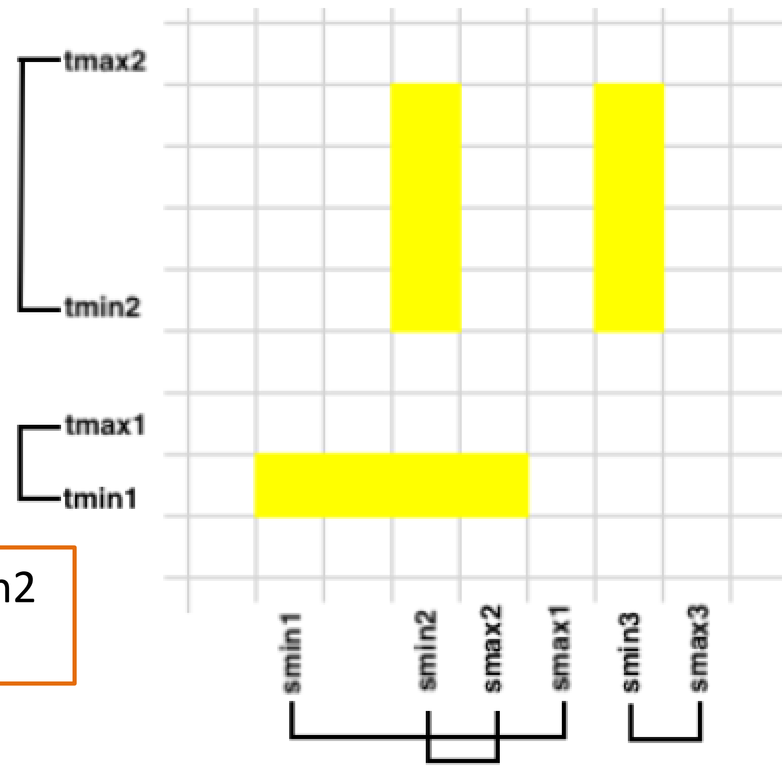
- MOC used
  for **surface manipulation**
  => work at the best resolution of all involved MOC

STMOC serialization

5.1 Binary Serialization

The binary serialization of a STMOC is a FITS binary table following the RANGE packaging presented previously, which interleaves time range(s) and their corresponding space coverage ranges. Following the binary RANGE serialization method described below, each range (time or space) is coded as two 64-bit signed integers ([min..max[). To distinguish time and space indices, the time indices **must** have the 64th bits forced to 1 - i. e. represented as a negative integer.

- Reuse MOC 1.1 **binary FITS table** serialization
- But **RANGE encoding**
- **Interleaving Time coverage items** with their **associated Space coverage**
- Bit 63 used to distinguish space indices (0) from time indices (1) => negative values



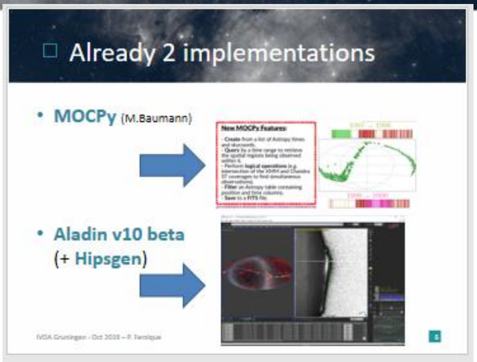
=> -tmin1 –tmax2 smin1 smax1 –tmin2 –tmax2 smin2 smax2 smin3 smax3

FITS keywords in detail

- MOC order:
  1. Old proposal: MOCORDER, MOCORD_1
  2. New proposal: **MOCORD_S, MOCORD_T** (+ MOCORDER for compatibility)
- Reference systems:
  1. Current proposal: explicit: COOSYS=C, TIMESYS=TCB
  2. Alternative proposals:
     1. Implicit (no mention)
        => but compatibility problem for COOSYS
     2. COOSYS=C , no TIMESYS (implicit)

Next steps

- Waiting your **feedback** on the current WD
- **Adapt** the 2 **implementations** to MOC 2.0
- **To be ready for a RFC** before next Interop



- Also:
  - Generate more STMOCs (+convert previous)
    (from **VizieR catalogs,** and **HiPS**, and other **VO providers**)
    http://alasky.u-strasbg.fr/footprints/STMOC/
  - Ingest them in
    the CDS **MocServer**:
    => Aladin Resource Tree by Space & Time
    => …
  - Explore « THiPS » potential
    = built a « temporal HiPS » but for time series

IVOA Working Draft 2020-11-12

Working group
Applications

This version
http://www.ivoa.net/documents/moc/20201112

Latest version
http://www.ivoa.net/documents/moc

Previous versions
Version1.1
Version1.0

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Questions ? Feedback ? Comments ?