# Data access layer optimisation of the Gaia data processing in Barcelona for spatially arranged data

Master in Innovation and Research in Informatics

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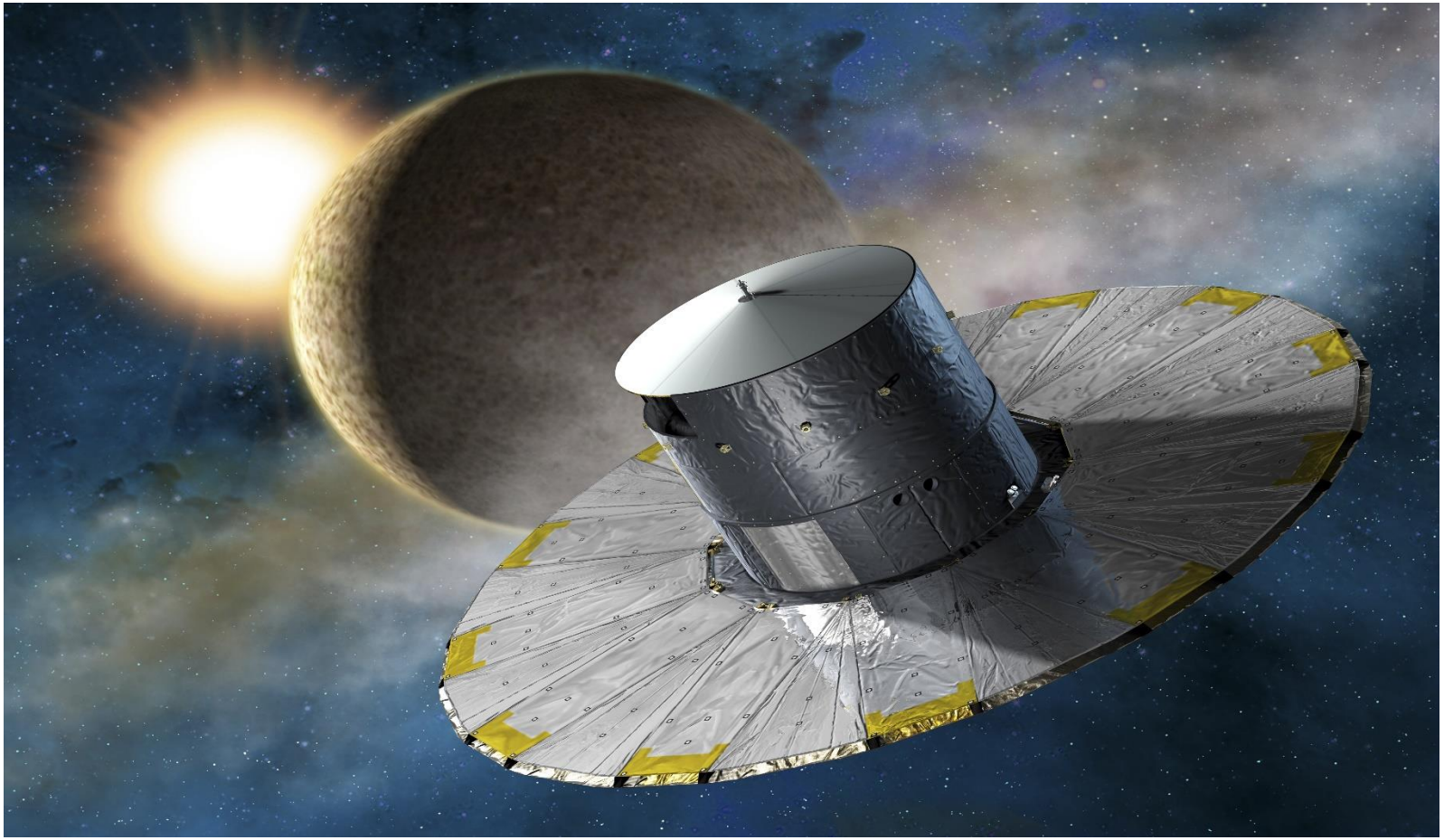
# Outline

1. The Gaia mission
2. HEALPix sphere tesselation
3. HDF5 file format
4. Implementation
5. Test and results
6. Conclusions

# The Gaia mission

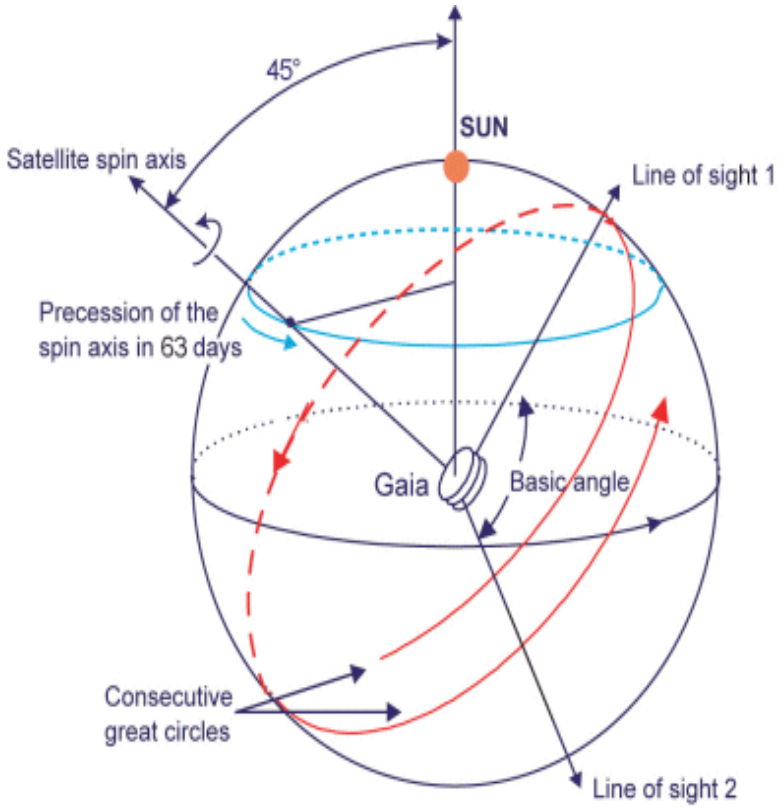


# The Gaia mission

One of the most challenging European Space Agency (ESA) space missions.

It was lunched on December 19th, 2013, from Kourou, in French Guiana.

It operates at the L2 point of the Solar System, about 1.5 million kilometers from the Earth.



# The Gaia mission

The satellite will observe each source about 85 times on average, recording:

- Colour
- Brightness
- Position

Scope of the mission: **the most precise three-dimensional map of our Galaxy,** the Milky Way.

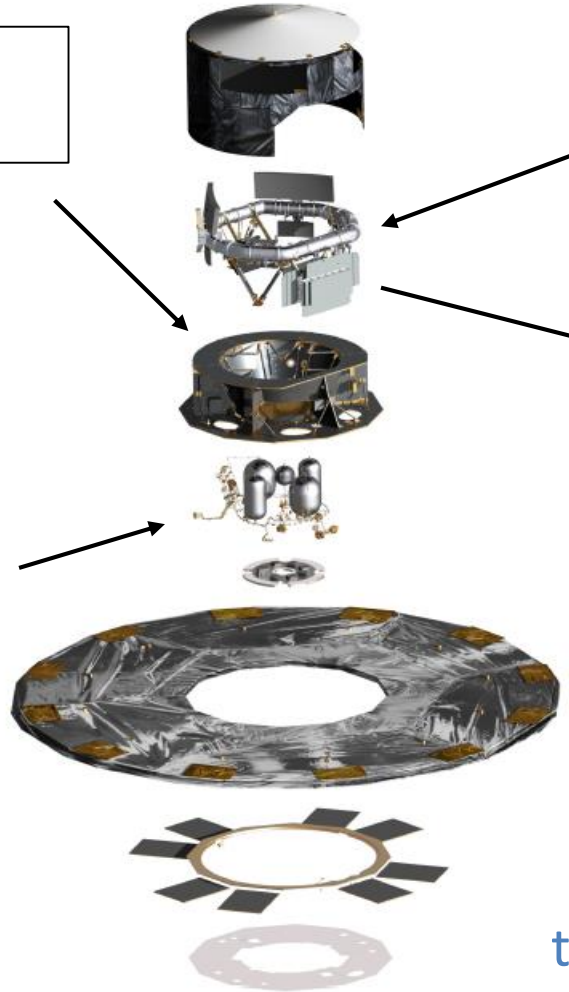
Duration of the mission: **5 years**

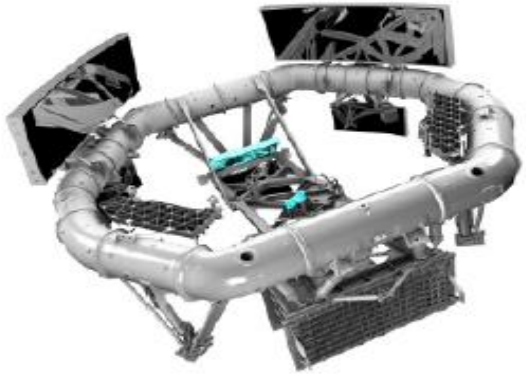
# The spacecraft

Electrical Service Module

Payload module

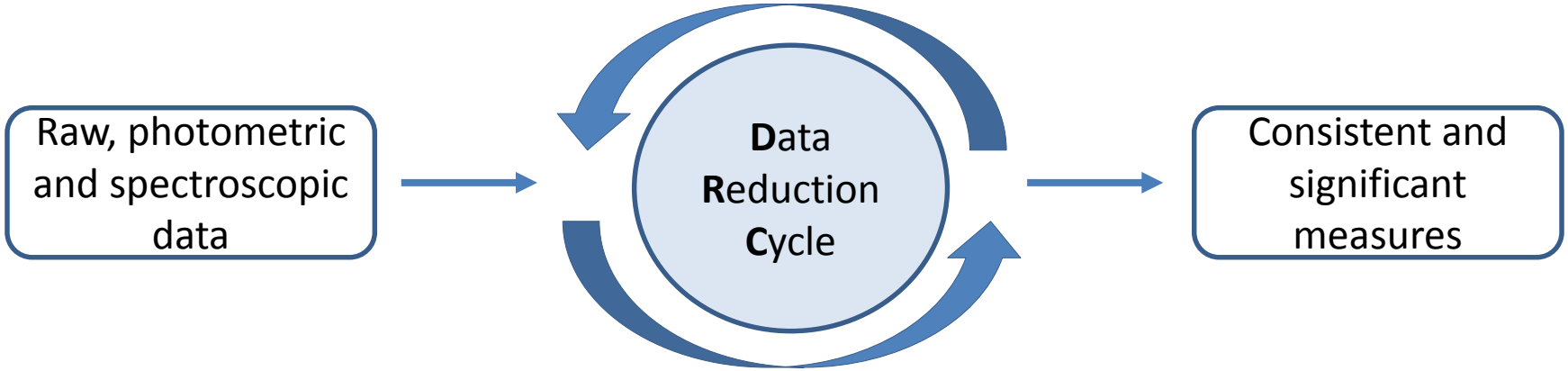
Mechanical Service Module





Gaia uses cutting edge technologies, scanning the sky in a continuous way.

# Gaia data processing



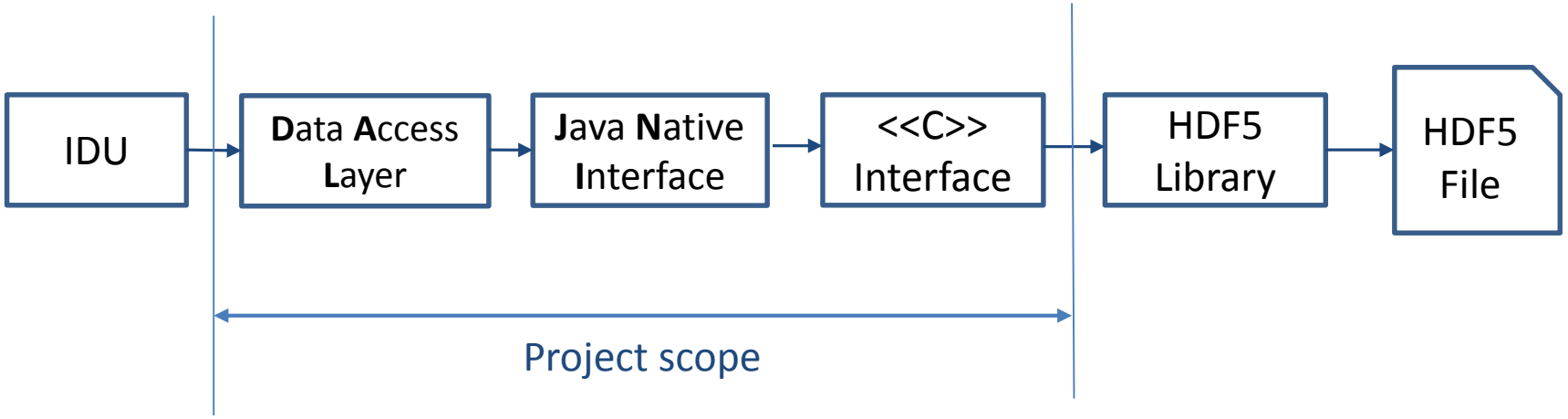

DPAC Consortium is in charge to process data.
**I**ntermediate **D**ata **U**pdating:

- **Cross-Match**: provides links between the individual detections and the source entries in the catalogue.

**Challenges**:

- Number of detections to handle: **$10^{11}$! Impossible in a single process!**
- Data organization

# The scope of the project




**Contraints:**

- No database can be used because of the Marenostrum III supercomputer. All I/O operations must be based on files.
- Gaia data is stored as Zip-compressed serialized Java objects.
- The frontend software and interfaces must be in Java

# HEALPix sphere tesselation

The library allows:

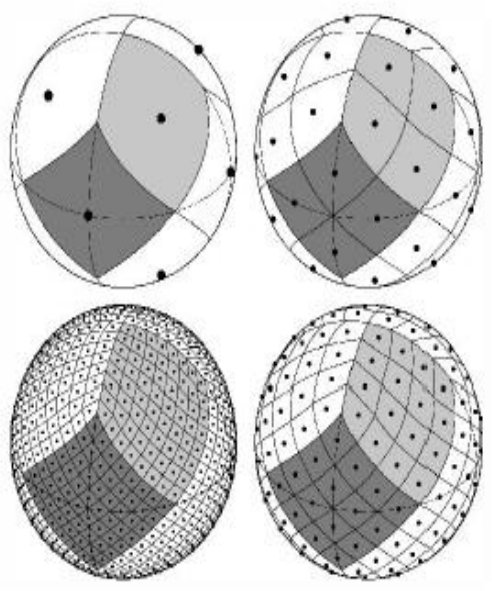
- To partition and reduce the data coming from spherical topologies in a fast and efficient way, especially in cases as IDU
- To refer to the data distributed on the sphere in a hierarchical way
- To access the data in a more direct way

The library was developed for the cosmic microwave background experiments in the 1990s.

# HEALPix sphere tesselation

**Main Features**:

- Each pixel contains the same surface of area
- 12 pixels in 3 rings around the poles and equator
- For each level: 4 new pixels, coded adding one digit between 0 and 3 to the previous base pixel



Tesselation of the spherical surface from level 0 to 3

# HDF5 file format

Powerful set of open-source libraries that allows to save, organize and manage data when it is not possible, or it is restrictive, to use traditional database systems.

Main features:

- It is portable
- It allows to refer to hierarchical data objects in a natural manner
- It allows both sequential and coordinate-style lookup

It was developed for the first time by the National Center for Supercomputing Applications (NCSA) in 1987. Today it is supported by the HDF Group, University of Illinois.

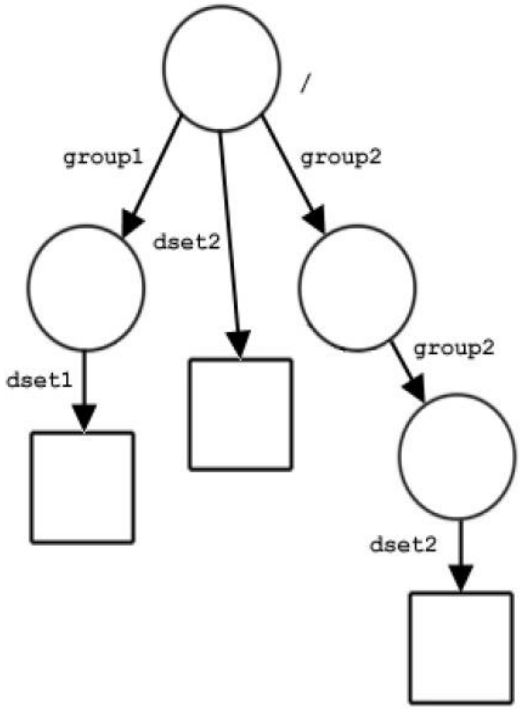
# HDF5 file format

Container of two primary type of objects:

- **Groups**: they contain other groups or objects
- **Datasets**: they contain data written in a specific format

Other types of objects:

- Dataspaces
- Datatype
- Attributes



# HDF5 file format

**Gaia Binary file format (GBIN)**

- It is not adapted for data processing
- It only allows to access the data sequentially without providing any structure within the file.
- It can not provide any of the required data organization within the file. It is required offline data arrangement
- Difficult to scale and distribute

**HDF5**

- It allows the implementation of hierarchical structure file
- Clear structure of the files
- It is not mandatory to specify the type of the data, using the **opaque** datatype
- Direct access to the data
- File self-described
- Binary data can be included
- No limit on the quantity of data

# Implementation

Two solutions:

- Full hierarchical HEALPix structure
- Flat HEALPix structure

Dataset numbering:

- Numbering using counters
- Numbering using attributes

Java Native Interface

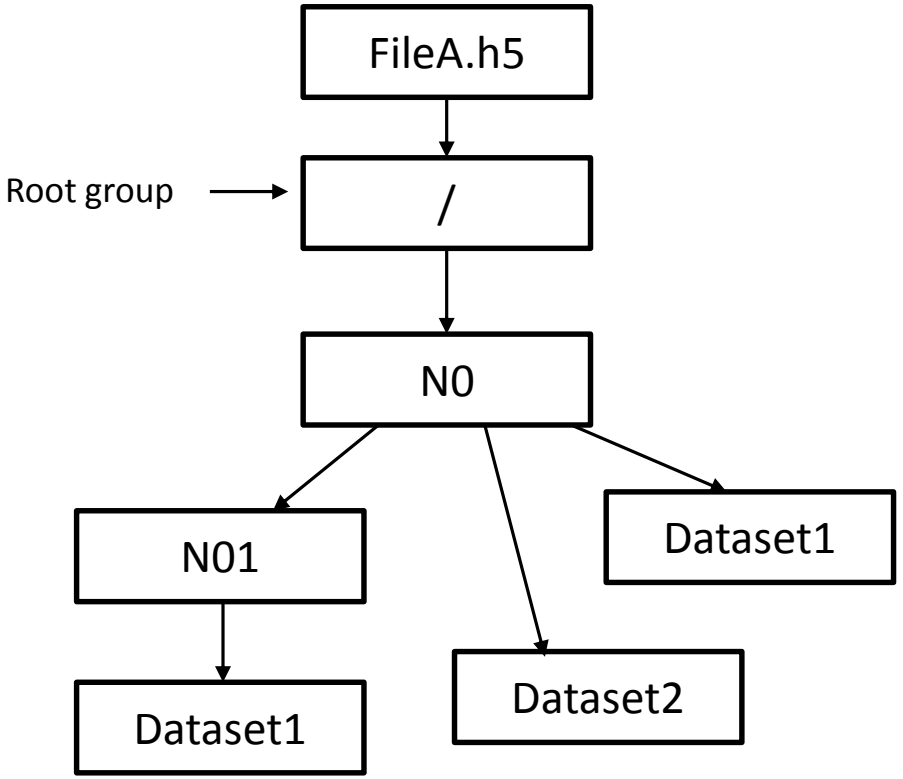
DpcbTools interface

# Full hierarchical HEALPix structure

Hierarchical tree structure following the HEALPix structure

Groups accessible through full or relative paths:

- /N0/N01/Dataset1: full path to Dataset1
- N01/Dataset1: relative path, from N0, to Dataset1

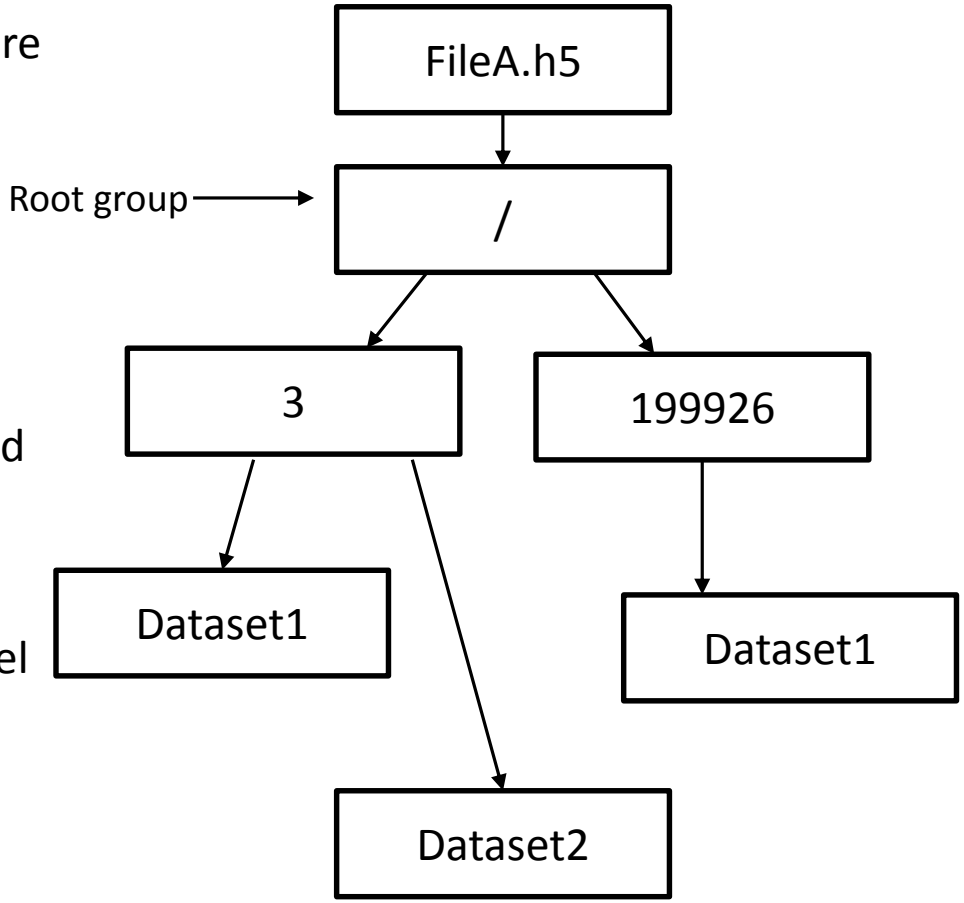


# Flat HEALPix structure

All groups are at the HDF5 root level and are identified by a unique HEALPix numerical identifier

- Pixel range: [0; 12(Nsize)$^2$-1], where:
  - Nsize = $2^k$.
  - K: level at which the data are considered

- For this project:
  - [0; 201326591], as 12 is the highest level



# Dataset numbering

## Two alternatives

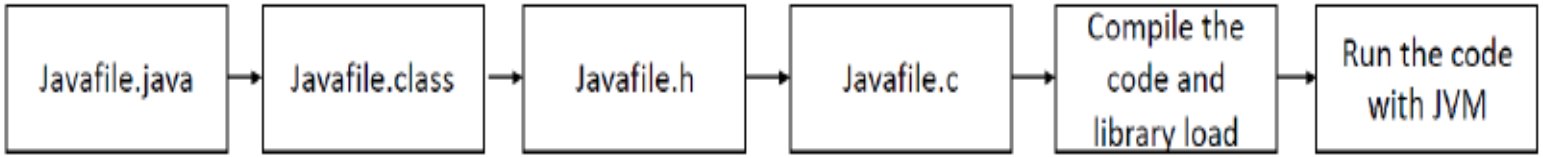
**Counters**

- Linear and straightforward
- First dataset: Dataset1
- The group already exists: using the H5L interface and updating a counter variable

**Attributes**

- To store meta-data
- First dataset: Dataset1 and NUM_OF_DATASET_ATTR
- The group already exists: using the H5A interface and updating the attribute

# Java Native Interface



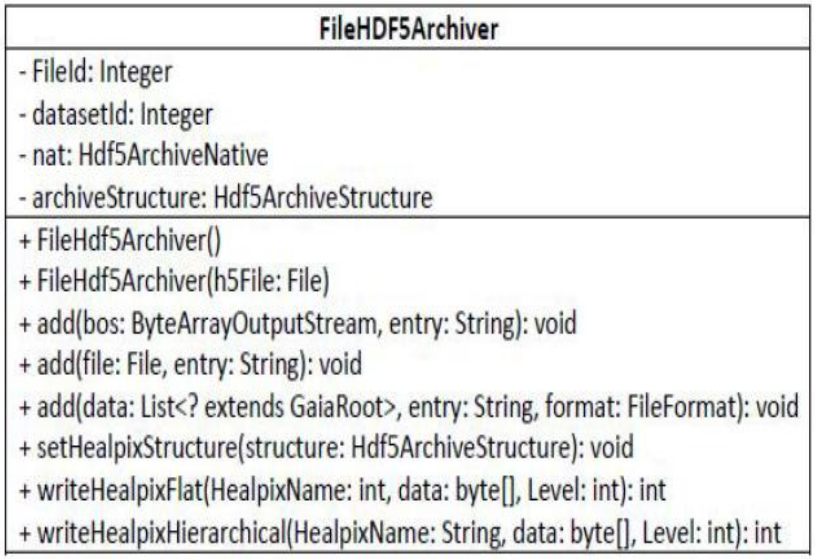

- Prototype of the function: *Java_package_and_classname_function_name*(JNI arguments)

- They have to be loaded and may return values back to the Java VM

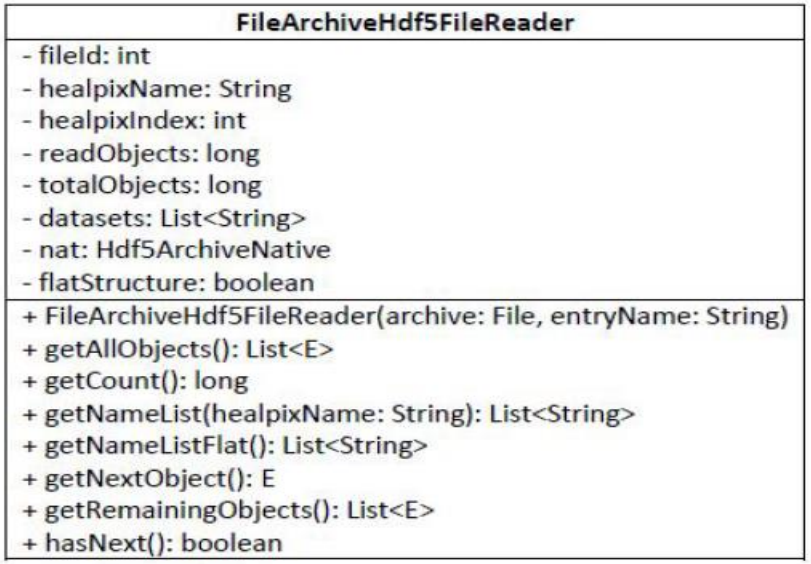
# DpcbTools interface

The Java part of this project has been integrated into a software library named DpcbTools, in coordination with the Barcelona IDU/DPCB team.

### FileHdf5Archiver




### FileArchiveHdf5FileReader



# Results

Test the feasibility and performance when creating the complete HDF5 file structures

HDF5 Hierarchical file format

| Level | Creation time [s] | File Size | Number of groups | Number of Healpix pixels |
|---|---|---|---|---|
| 0 | 0.012 | 10 KB | 12 | 12 |
| 1 | 0.017 | 48 KB | 60 | 48 |
| 2 | 0.013 | 199 KB | 252 | 192 |
| 3 | 0.028 | 802 KB | 1020 | 768 |
| 4 | 0.093 | 3 MB | 4092 | 3072 |
| 5 | 0.378 | 13 MB | 16380 | 12288 |
| 6 | 1.654 | 52 MB | 65532 | 49152 |
| 7 | 16.563 | 206 MB | 262140 | 196608 |
| 8 | 27.610 | 824 MB | 1048572 | 786432 |
| 9 | 233.954 | 3 GB | 4194300 | 3145728 |
| 10 | 461.757 | 13 GB | 16777212 | 12582912 |
| 11 | N/A | N/A | 67108860 | 50331648 |
| 12 | N/A | N/A | 268435452 | 201326592 |

HDF5 Flat file format

| Level | Creation time [s] | File Size | Number of groups | Number of Healpix pixels |
|---|---|---|---|---|
| 0 | 0.018 | 10 KB | 12 | 12 |
| 1 | 0.014 | 39 KB | 48 | 48 |
| 2 | 0.020 | 155 KB | 492 | 492 |
| 3 | 0.027 | 615 KB | 768 | 768 |
| 4 | 0.075 | 2 MB | 3072 | 3072 |
| 5 | 0.253 | 10 MB | 12288 | 12288 |
| 6 | 1.177 | 39 MB | 49152 | 49152 |
| 7 | 4.731 | 157 MB | 196608 | 196608 |
| 8 | 22.163 | 629 MB | 786432 | 786432 |
| 9 | 12125.837 | 3GB | 3145728 | 3145728 |
| 10 | N/A | N/A | 12582912 | 12582912 |
| 11 | N/A | N/A | 50331648 | 50331648 |
| 12 | N/A | N/A | 201326592 | 201326592 |

# Results

- File format considered: HDF5-based alternatives, TAR and ZIP
- Set of data considered: AstroObservation and Match
- File system considered: GPFS and local 500 GB IBM hard drive
- Iterations executed: 3 times for each test
- Size of set of data: 1GB

# Results

| Level | TAR | ZIP | HDF5_H | HDF5_F |
|---|---|---|---|---|
| 0 | 22.05 | 16.98 | 21.77 | **22.50** |
| 2 | 21.84 | 17.04 | 21.92 | **22.43** |
| 4 | 22.28 | 17.06 | 21.98 | **22.41** |
| 6 | **22.51** | 17.21 | 22.43 | 16.37 |

Write results on the GPFS file system for AstroObservation data in [MiB/s]

| Level | TAR | ZIP | HDF5_H | HDF5_F |
|---|---|---|---|---|
| 0 | 22.05 | 16.98 | 21.77 | **22.50** |
| 2 | 21.84 | 17.04 | 21.92 | **22.43** |
| 4 | 22.28 | 17.06 | 21.98 | **22.41** |
| 6 | **22.51** | 17.21 | 22.43 | 16.37 |

Write results on the GPFS file system for Match data in [MiB/s]

# Results - Global

| Write Level | Read Level | TAR | ZIP | HDF5_H | HDF5_F |
|---|---|---|---|---|---|
| 0 | 0 | 81.52 | 83.55 | **147.96** | 146.66 |
| | 2 | 24.57 | 26.44 | **46.14** | 45.56 |
| | 4 | 5.38 | 5.65 | **10.05** | **10.05** |
| | 6 | 0.96 | 1.00 | **1.74** | **1.74** |
| 2 | 0 | 68.42 | 82.87 | **143.07** | 141.16 |
| | 2 | 53.63 | 81.57 | 128.31 | **137.07** |
| | 4 | 12.38 | 17.96 | **30.69** | 30.51 |
| | 6 | 2.07 | 2.79 | **4.83** | 4.82 |
| 4 | 0 | 47.71 | 81.81 | **132.27** | 96.09 |
| | 2 | 39.33 | 80.74 | **121.83** | 95.84 |
| | 4 | 21.73 | 76.25 | **77.59** | 70.77 |
| | 6 | 3.92 | 10.68 | **12.58** | 11.38 |
| 6 | 0 | 15.75 | **69.79** | 25.12 | 8.48 |
| | 2 | 14.45 | **67.12** | 18.27 | 7.88 |
| | 4 | 11.42 | **62.15** | 8.00 | 5.15 |
| | 6 | 4.94 | **49.17** | 1.94 | 1.81 |

Read results on the GPFS file system in [MiB/s] for AstroObservation data

| Write Level | Read Level | TAR | ZIP | HDF5_H | HDF5_F |
|---|---|---|---|---|---|
| 0 | 0 | 47.78 | 50.40 | 51.66 | **54.25** |
| | 2 | 48.05 | 55.26 | 53.40 | **63.86** |
| | 4 | 7.75 | 8.03 | 8.73 | **8.84** |
| | 6 | 0.51 | 0.53 | **0.57** | **0.57** |
| 2 | 0 | 47.95 | 50.91 | 54.14 | **56.15** |
| | 2 | 48.40 | 50.99 | **57.74** | 53.05 |
| | 4 | 7.81 | 7.99 | 8.48 | **8.79** |
| | 6 | 0.52 | 0.53 | 0.58 | **0.78** |
| 4 | 0 | 47.12 | 44.78 | 61.55 | **63.39** |
| | 2 | 45.81 | 54.76 | 62.62 | **65.43** |
| | 4 | 34.92 | 44.05 | 60.18 | **61.36** |
| | 6 | 2.84 | 3.79 | 4.63 | **4.65** |
| 6 | 0 | 20.22 | 53.06 | **59.23** | 38.99 |
| | 2 | 20.58 | 49.50 | **58.93** | 38.52 |
| | 4 | 18.97 | 48.64 | **54.55** | 34.17 |
| | 6 | 8.26 | **45.49** | 27.09 | 21.07 |

Read results on the GPFS file system in [MiB/s] for Match data

# Results - Single

| Write Level | Read Level | TAR | ZIP | HDF5_H | HDF5_F |
|---|---|---|---|---|---|
| 0 | 0 | 68.94 | 81.23 | 136.70 | **142.72** |
| | 2 | 17.63 | 20.66 | **36.50** | 36.34 |
| | 4 | 3.82 | 4.40 | 7.47 | **7.76** |
| | 6 | 0.71 | 0.83 | **1.44** | **1.44** |
| 2 | 0 | 55.62 | 80.53 | **136.90** | 133.95 |
| | 2 | 37.35 | 71.50 | 108.01 | **108.08** |
| | 4 | 7.98 | 15.19 | **24.19** | 23.84 |
| | 6 | 1.50 | 2.88 | **4.47** | 4.39 |
| 4 | 0 | 37.81 | 76.37 | **117.88** | 78.05 |
| | 2 | 27.25 | 68.52 | **82.63** | 60.93 |
| | 4 | 14.82 | 53.84 | **74.09** | 42.43 |
| | 6 | 2.84 | **10.09** | 8.84 | 7.91 |
| 6 | 0 | 15.80 | **58.45** | 17.35 | 7.45 |
| | 2 | 12.76 | **51.26** | 12.09 | 5.67 |
| | 4 | 8.42 | **41.39** | 6.22 | 3.85 |
| | 6 | 4.28 | **29.80** | 1.95 | 1.82 |

Read results on the GPFS file system in [MiB/s] for AstroObservation data

| Write Level | Read Level | TAR | ZIP | HDF5_H | HDF5_F |
|---|---|---|---|---|---|
| 0 | 0 | 53.50 | 59.49 | 75.30 | **76.33** |
| | 2 | 54.80 | 58.38 | 75.38 | **77.64** |
| | 4 | 11.87 | 13.36 | **16.57** | 16.27 |
| | 6 | 0.80 | 0.86 | 1.04 | **1.43** |
| 2 | 0 | 53.71 | 58.61 | 75.24 | **77.12** |
| | 2 | 53.69 | 59.42 | 75.84 | **75.93** |
| | 4 | 11.72 | 13.33 | **16.12** | 16.09 |
| | 6 | 0.79 | 0.86 | **1.04** | **1.04** |
| 4 | 0 | 51.07 | 58.13 | **77.17** | 76.76 |
| | 2 | 51.57 | 58.03 | 72.76 | **74.34** |
| | 4 | 45.33 | 59.09 | 47.33 | **75.88** |
| | 6 | 2.90 | 3.91 | 1.09 | **5.03** |
| 6 | 0 | 25.82 | 57.84 | **64.77** | 47.09 |
| | 2 | 26.06 | 58.08 | **61.01** | 45.50 |
| | 4 | 21.08 | 57.81 | **57.92** | 39.69 |
| | 6 | 9.57 | **54.50** | 29.92 | 25.66 |

Read results on the GPFS file system in [MiB/s] for Match data

# Conclusions

- In many cases the performance is increased by more than 50%.
- The work presented has substantially contributed to the optimization of the DAL
- The work will help to collect and store the data in a very more efficient way.
- The data can now be stored according to their spatial distribution in fewer well structured

**Future work:**

- To explore the native HDF5 compression algorithms
- To include time information within the spatially distributed data structure

# Thank you