Maintaining netCDF:
Updating Java Tutorial Code and
Performance Testing in Python

Unidata 2021 Summer Internship
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Project Motivation

- Working with the netCDF library
- Promoting education
- Learn about storage and efficiency
Maintaining a Codebase

- Documentation & tutorials
- Adjusting to new technology
## Documentation

Updated netCDF-Java user guide docs for 6.x and 5.x

### Coordinate Systems
- Coordinate attribute convention & examples
- Coordinate transforms

### Scientific Feature Types
- Grid datasets
- Coverage datasets

### Runtime Configuration
- Runtime loading
- System properties
- netCDF C library
Documentation Writing Changes

- Raw HTML to Markdown
- Format Updates
- Linking to relevant sites
- Updating images
Documentation: after
Tutorial Code

Creating tutorial classes

Updating & writing code

Testing
- You can use the `<b>`GridCoordSystem</b>` to find the value of a grid at a specific lat, lon point:

- // open the dataset, find the variable and its coordinate system
  
  ```java
gds = ucar.nc2.dt.grid.GridDataset.open(location);
g = gds.findGridVariable("myVariableName");
gcs = grid.getCoordinateSystem();
```

- double lat = 8.0;
- double lon = 21.0;
- // find the x,y index for a specific lat/lon position
- int[] xy = gcs.findXYindexFromLatLon(lat, lon, null); // xy[0] = x, xy[1] = y

+ You can use the `GridCoordinateSystem` to find the indices and coordinates of the 2D grid from the (x,y) projection point:

+ ({% capture rmd %}
+ {%- include codeblock netcdf-
+ javadocs/userguide/src/test/java/examples/featuretypes/GridDatasetsTutorial.java
+ &findLatLonVal %}
+ {% endcapture %}
+ {{ rmd | markdownify }}
+
+ Most `GridCoordinateSystems` have a `CoordinateAxis1DTime` time coordinate. If so, you can get the list of dates from it.

### Separate Java class

```java
public static void findLatLonVal(String yourLocationAsString, Formatter errlog, double xPointAsDouble, double yPointAsDouble) throws IOException {
    // open the dataset, find the variable and its coordinate system
    GridDataset gds = ucar.nc2.grid.GridDatasetFactory.openGridDataset(yourLocationAsString, errlog);
    GridHorizCoordinateSystem gcs = (GridHorizCoordinateSystem) gds.getGridCoordinateSystems();
    ```
Performance Testing

File format for netCDF-4

Python-based storage format
Benchmark Tests

- netCDF-3
  - No compression or chunking

- netCDF-4
  - Zlib compression

- Zarr directory store
  - Blosc compression

- Reading with Xarray
  - netCDF-4 and Zarr

- netCDF-4 Classic
  - Zlib compression
Benchmark Tests

Timing netCDF-4

```python
import timeit

# import before timeing begins
imports = "import netCDF4 as nc"

# reading code to be timed
nc4_single_values = ""

# netCDF-4 with zlib compression
dataset = nc.Dataset('Data/outputNetcdf-4.nc')

# reading single values
tas = dataset.variables['tas'][0][0][0] # air temperature
plev = dataset.variables['plev'][0] # air pressure
pr = dataset.variables['pr'][0][0][0] # precipitation flux
ua = dataset.variables['ua'][0][0][0][0] # eastward wind with 17 levels of plev
lons = dataset.variables['lon'][0]
lats = dataset.variables['lat'][0]

dataset.close()
```

# timeit statement in seconds average of 1000
nc4_single_values_time = (timeit.timeit(setup = imports, stmt = nc4_single_values, number = 1000)) / 1000
Results

Comparing Single Value Read Times Across Data Formats

<table>
<thead>
<tr>
<th>Format</th>
<th>Time (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zarr</td>
<td>1.25</td>
</tr>
<tr>
<td>Zarr with Xarray</td>
<td>2.50</td>
</tr>
<tr>
<td>netCDF-3</td>
<td>3.00</td>
</tr>
<tr>
<td>netCDF-4 + HDF5 1.8</td>
<td>17.50</td>
</tr>
<tr>
<td>netCDF-4 + HDF5 1.10</td>
<td>17.50</td>
</tr>
<tr>
<td>netCDF-4 Classic</td>
<td>17.50</td>
</tr>
</tbody>
</table>
Results

Single Value Read Times with Varying Chunk Sizes Across Lat/Lon

- netCDF4-python
- Zarr

Time (ms)

Chunk size 128x256, 64x64, 16x16, 4x4
Results

Single Value Read Times with Varying Chunk Sizes Across Lat/Lon

- netCDF4-python
- Zarr
- Zarr with Xarray
Results

Single Value Read Times with Varying Chunk Sizes Across Lat/Lon

- netCDF4-python
- Zarr
- Zarr with Xarray
- netCDF4 with Xarray

Time (ms)

Chunk size 128x256  |  Chunk size 64x64  |  Chunk size 16x16  |  Chunk size 4x4
Results

● Zarr directory store
  ○ The more chunks, the more individual files in the directory store
  ○ Opening ~2,000 files per variable
  ○ More time spent opening than reading

● netCDF-4
  ○ Only one open is needed
  ○ More seek operations to find the data

● Xarray
  ○ Leaves data unloaded until load is specified
Next Steps

- Compare reads for netCDF-Java HDF5 & Zarr implementations

- Poster at AGU Fall Meeting
Maintaining netCDF:
Updating Java Tutorial Code and Performance Testing in Python

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Supervisor: Ryan May

1. Updating netCDF Tutorial Code

Network Common Data Form (netCDF) is a combination of software libraries and APIs describing a data model for scientific multidimensional arrays.

Maintaining this codebase requires documentation, user support, testing, and adapting to new technologies. I maintained netCDF-Java documentation by updating Java tutorial code, testing code snippets, and modernizing tutorial texts to improve user understanding.

2. Comparing Data Formats

HDF5 is a file format used by netCDF-4 providing compression and chunking to the netCDF data model. Zarr is a Python-based storage format, which has support in netCDF-C and will soon in netCDF-Java.

This project compares read times for the data formats below:
- netCDF-3: no compression or chunking
- netCDF-4: zlib compression
- netCDF-4 Classic: zlib compression
- Zarr: Blosc compression
- Zarr & netCDF read with Xarray package

3. Benchmarking Results

A netCDF-4 file stores all data in one nc file; consequently, more operations are needed to find the appropriate data, but only one open is required.

Zarr directory stores save chunked data as many subdirectories and files. The more chunks, the more individual files in one Zarr directory store. With small chunk sizes, this resulted in more time spent opening than reading.

In some cases, the Xarray Python package can read faster with both netCDF-4 and Zarr directory stores until loading is specified.

Note: read speeds will vary on an object store. These comparisons are for a posix file system only.

Future Work
- Compare reads for netCDF-Java HDF5 and Zarr implementations
- Test on datasets with varying dimensions and size

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Thank you