Fast Parallel Grid Remapping for Unstructured and Structured Grids

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ESMF Regridding

Regridding (or remapping or interpolation) is the process of moving data from one grid to another while preserving qualities of the original data.

ESMF regridding is:

• **Flexible**: Computes weights between a wide range of grids
  – Structured and unstructured, global and regional, multiple interpolation options, pole options ...

• **Accurate and Portable**:
  – Spherical regridding handled in 3D to avoid pole issues
  – Tested nightly on many platforms

• **Parallel and Fast**:
  – Able to compute weights in minutes which before took hours
  – Able to compute weights between very large grids

• **Community developed**: under NASA, NOAA, DOD and NSF funding
  – Well established (since 2005) community processes for prioritization, support and review.
  – Development priorities set by users through quarterly Change Review Board (CRB) meetings
Methods of Accessing Regridding

• **ESMF Offline:**
  – Application generates a NetCDF weight file from two NetCDF grid files
  – Supports SCRIP format grid files and a custom ESMF unstructured format
  – Comes with the ESMF source code distribution

  ```bash
  mpirun -np 32 ESMF_RegridWeightGen -s src_grid.nc -d dst_grid.nc -m bilinear -w weights.nc
  ```

• **Integrated:**
  – ESMF library subroutine calls which do interpolation during model run
  – Can get weights or pass directly into ESMF parallel sparse matrix multiply to apply weights
  – Can be used without other parts of ESMF (e.g. components are not needed)

  ```c
  call ESMF_FieldRegridStore(srcField=src, dstField=dst,
                             regridMethod=ESMF_REGRID_METHOD_BILINEAR, routehandle=rh)
  
  call ESMF_FieldRegrid(srcField=src, dstField=dst, routehandle=rh)
  ```
ESMF Offline: Supported Grids

- Grids with spherical (lon, lat) coordinates

- Mix and match pairs of:
  - Global 2D logically rectangular grids
  - Regional 2D logically rectangular grids
  - 2D unstructured meshes composed of polygons with any number of sides:
    - ESMF internally represents these as triangles and quadrilaterals
    - Supported elements: triangles, quadrilaterals, pentagons, hexagons,…
  - Multi-patch grids (e.g. cubed spheres) currently supported via unstructured
    - Multi-patch support expected with GridSpec
In addition, integrated regridding supports Cartesian \((x,y)\) coordinates:

- Regridding between any pair of:
  - 2D meshes composed of triangles and quadrilaterals
  - 2D logically rectangular grids composed of a single patch

- Bilinear regridding between any pair of:
  - 3D meshes composed of hexahedrons
  - 3D logically rectangular grids composed of a single patch

2D Unstructured Mesh
From www.ngdc.noaa.gov

3D Grid

3D Unstructured Mesh
The ESMF offline format allows for more explicit expression of unstructured grids.

**ESMF Offline: Unstructured Formats**

**SCRIP**

```plaintext
netcdf example-scrip {
    dimensions:
        grid_size = 100;
        grid_corners = 4;
        grid_rank = 1;
    variables:
        double grid_corner_lon(grid_size, grid_corners);
        double grid_corner_lat(grid_size, grid_corners);
        double grid_center_lat(grid_size);
        double grid_center_lon(grid_size);
        double grid_area(grid_size);
        double grid_imask(grid_size);
}
```

**ESMF**

```plaintext
netcdf example-esmf {
    dimensions:
        nodeCount = 120;
        elementCount = 100;
        maxNodePElement = 4;
        coordDim = 2;
    variables:
        double nodeCoords(numNode, coordDim);
        byte numElementConn(numElement);
        int elementConn(numElement, maxNodePElement);
        double centerCoords(numElement, coordDim);
        double elementArea(numElement);
        int elementMask(numElement);
}
```
ESMF Offline: Features

• Several interpolation types:
  – Bilinear
  – Higher order patch recovery
    • Yields better derivatives/smooth results than bilinear
    • Based on “patch recovery” used in finite element modeling [1][2]
  – First order conservative

• Masking (currently only for logically rectangular grids):
  – Source
  – Destination

• Options for unmapped destination points: error or ignore

• Pole options for global spherical logically rectangular Grids:
  – Full circle average: artificial pole is average of all source points next to pole
  – N-point average: artificial pole is average of n top source neighbors of dest point
  – Teeth: gap at pole filled by triangles
  – No pole: error if destination point lies above top row of source points
ESMF Offline: Testing/Support

- Library regression testing:
  - Running daily on 20+ platforms
  - Unit tests, regrid test harness, more complex system tests cover regridding core capabilities
  - Interpolation error checked, for conservative, integration error also checked
  - Additional ESMF Offline regression testing also run nightly

- Support and examples
  - Dozens of examples
  - Contact esmf_support@list.woc.noaa.gov for support
Higher order interpolation leads to reduced noise in wind stress values
- Grids: CAM atmosphere lat/lon to POP ocean displaced pole lat/lon
- ESMF patch interpolation reduced imprint of coarser resolution atmosphere grid on ocean for interpolated wind stress values. Interpolation weights used in CCSM4 and subsequent IPCC runs

Better interpolation of cubed sphere (unstructured) and lat/lon ocean
- Grids: HOMME cubed sphere atmosphere to lat/lon ocean grid
- ESMF conservative regridding enabled easier integration of a high resolution dynamical core into CAM, reduced distortion near the pole.

Enables CLM land model to run on cubed sphere
- Grids: Land lat/lon to HOMME cubed sphere
- ESMF parallel bilinear mapping from lat/lon to HOMME cubed sphere allowed investigation of high resolution land model to move forward for CESM.

Better values at poles for unstructured to lat/lon remapping
- Grids: MPAS unstructured grid to POP ocean grid
- ESMF conservative interpolation solved problems with negative weights at the pole.
ESMF Offline: Timing Example

- Previous solution takes 635s (20x) to compute conservative weights
- Previous solution unable to compute bilinear weights from cubed sphere

- Platform: Crag XT4, jaguar at ORNL
- Version: ESMF_5_2_0_beta_snapshot_07
- fv0.47x0.63: CAM Finite Volume grid, 576x384
- ne60np4: 0.5 degree cubed sphere grid with pentagons, 180x180x6
User reported times using integrated regridding

- **10800x5400 lat/lon grid to 1440x1440x6 NASA cubed sphere**
  - User: NASA Global Modeling and Assimilation Office
  - Interpolating topography data
  - Higher order patch recovery interpolation
  - Approximately **1 minute** including I/O on 96 cores of Discover

- **10800x5400 lat/lon grid to 1440x1440x6 NASA cubed sphere**
  - User: NASA Global Modeling and Assimilation Office
  - Interpolating topography data
  - Conservative interpolation
  - Approximately **1.5 minute** including I/O on 96 cores of Discover

- **16 million triangle mesh to 16 million triangle mesh**
  - User: Community Surface Dynamics Modeling System
  - Testing ESMF regridding for possible inclusion in a community toolkit
  - Bilinear interpolation
  - Approximately **1 minute** on 64 cores of their Linux cluster
Releases

• 5.2.0 February 2011
  – Described in this talk

• 5.2r May 2011
  – Remove divided weights generated when polygons have 5+ sides (affects size of weight matrix, not accuracy)
  – Python wrapper for ESMF Offline (Ryan O’Kuinghttons, NOAA/CIRES)

• 5.3.0 within several months:
  – Support for the GridSpec file format (Summer intern)
  – Fully parallel I/O for reading in grids (Peggy Li, JPL)
  – Further time and memory optimizations (Peggy Li, JPL)
  – 3D conservative (Robert Oehmke, NOAA/CIRES)
  – Web service interface for ESMF Offline (Luca Cinquini, NOAA/CIRES)

• Candidate development for future releases:
  – Support for GIS coordinate systems
  – Second order conservative
• Patch interpolation:

We are eagerly seeking new cases to try. Come talk to us, or write esmf_support@list.woc.noaa.gov