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

```
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)

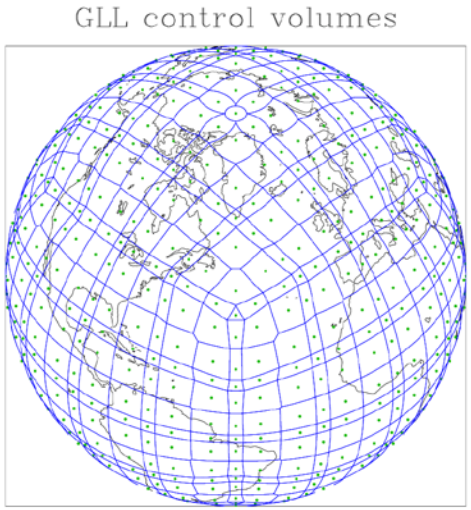
```
call ESMF_FieldRegridStore(srcField=src, dstField=dst,
                           regridMethod=ESMF_REGRID_METHOD_BILINEAR, routehandle=rh)

call ESMF_FieldRegrid(srcField=src, dstField=dst, routehandle=rh)
```

ESMF Offline: Supported Grids

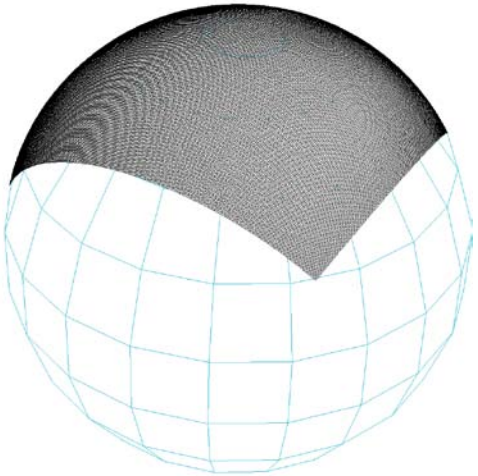
- Grids with spherical (lon, lat) coordinates

- 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



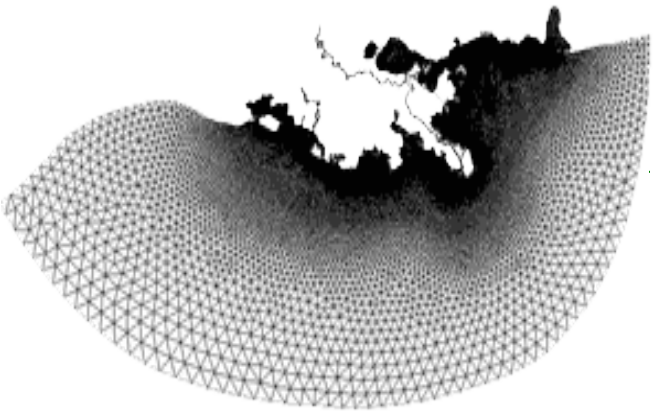
HOMME Cubed Sphere Grid with Pentagons
Courtesy Mark Taylor of Sandia


FIM Unstructured Grid

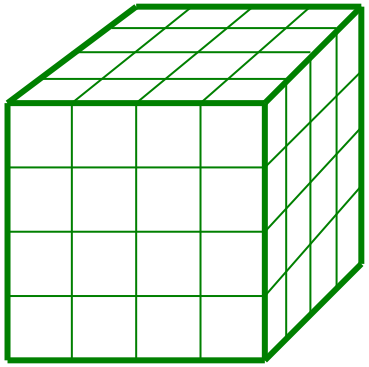

Regional Grid

Integrated Supported Grids

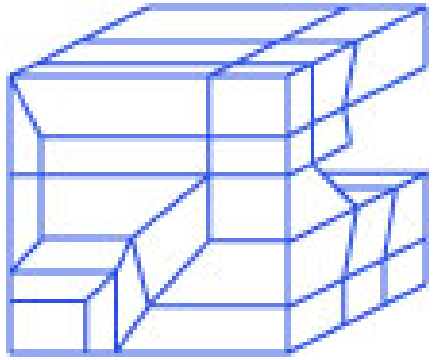
- In addition, integrated regridding supports Cartesian (x,y) coordinates:
  - Regridding between any pair of:
    - 2D meshes composed of triangles and quadrilaterals
    - 2D logically rectangular grids composed of a single patch
  - Bilinear regridding between any pair of:
    - 3D meshes composed of hexahedrons
    - 3D logically rectangular grids composed of a single patch



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



3D Grid



3D Unstructured Mesh

ESMF Offline: Unstructured Formats

The ESMF offline format allows for more explicit expression of unstructured grids.

SCRIP

```
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

```
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/smoother 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

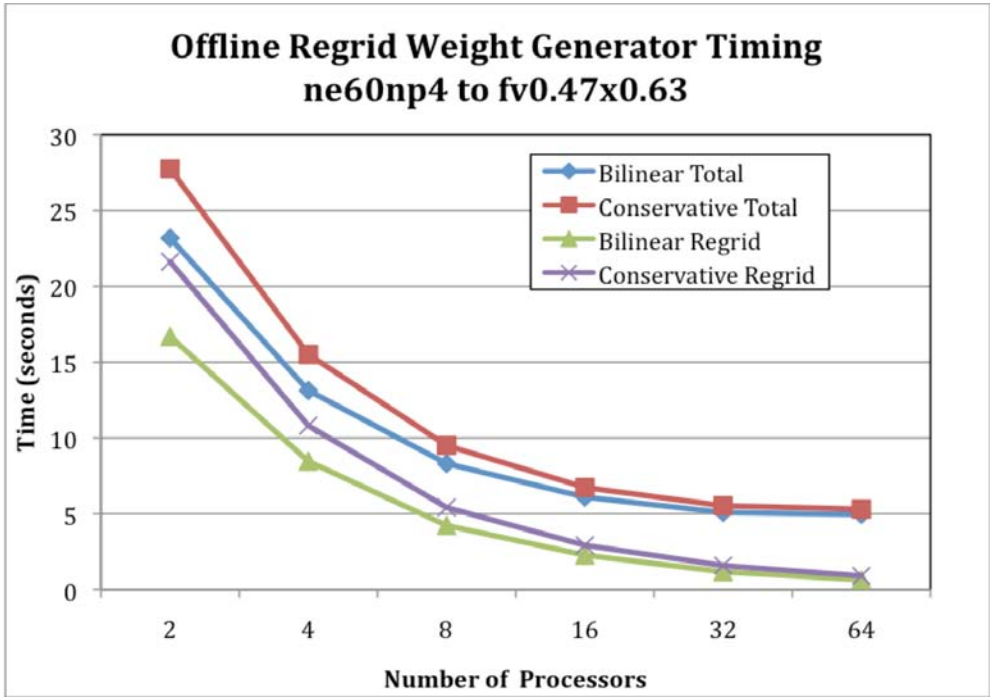
- Library regression testing:
  - Running daily on 20+ platforms
    - See: www.earthsystemmodeling.org/developers/test/daily/week_results/compiler_sort.shtml
  - Unit tests, regrid test harness, more complex system tests cover regridding core capabilities
  - Interpolation error checked, for conservative, 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

ESMF Offline Use in CESM Climate Model

- **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

Large Grids from Users

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

References

- Patch interpolation:
  1. Khoei S.A., Gharehbaghi A. R. The superconvergent patch recovery technique and data transfer operators in 3d plasticity problems. *Finite Elements in Analysis and Design*, 43(8), 2007.
  2. Hung K.C, Gu H., Zong Z. A modified superconvergent patch recovery method and its application to large deformation problems. *Finite Elements in Analysis and Design*, 40(5-6), 2004.

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