Emerging Technology – Discrete Global Grid Systems

2019 Dec 11th

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Why DGGS – my personal journey

Everything we do collectively places excess pressure on the Earth and it’s systems

Climate change – River pollution – Biodiversity loss …
Why DGGS – my personal journey

Some changes we are 100% responsible for, others are a complex mix of natural and human induced change

Some obvious, some illusive
Individually and collectively – we need to take action, to participate

We need to see the see result – locally and globally

In extreme events we need a ‘real-time’ feedback loop that tells us what proportion of every event is our responsibility
DGGS Pocket History – 1994: Michael Goodchild

Michael Goodchild attending Spatial Analysis on a Sphere workshop listed 14 ideal criteria of global grids on a napkin.

Cells are: *equi-area, equal shape, equi-spaced, cover the globe*,
*1x point per cell, cells & points form a hierarchy, .. etc*

The report from the workshop also concluded:

‘Surprisingly few applications on the spherical domain appear in the geographic literature. This situation is apparently due to the preference for analysis over relatively small spatial scales. The success of the projection approach over these domains is undoubtedly a contributing factor’
DGGS Pocket History
2003-8: Kevin Sahr, Jon Kimerling, Denis White

It is impossible to simultaneously satisfy criteria for equi-area, equal shape and equi-spacing.

Sahr et al identify that using geodesics, hexagonal cells on icosahedron (20x triangular faces) can be made that are equi-area and minimize shape & spacing distortion.

Sahr et al also publish indexing methods for uniquely numbering all cells in the hierarchy.

They call it ISEA3H – Icosohedral Equal-area Aperture 3 Hexagons
DGGS Pocket History
2001-11: Gorski et al, & Gibb et al

Gorski et al, looking for a way to store and efficiently process large volumes of data from NASA’s Wilkinson Microwave Anisotropy Probe, develop a family of spherical solutions they call HEALPix.

Gibb, looking for global rectangular solution for storing and processing satellite imagery and other environmental vector data on a super-computer, picks one of the HEALPix solutions and adapts it for terrestrial use on the ellipsoid.

Gibb et al also publish an indexing method for uniquely numbering every cell in the hierarchy.

We called it rHEALPix – rotated Hierarchical Equal-Area Pixelisation
DGGS Pocket History
2000-2014 Matt Purss, Robert Gibb, Perry Peterson et al

Perry working in Canada creates ‘The PYXIS Innovation’ a commercial DGGS GIS Globe using ISEA3H, now called ‘Digital Earth’.

Robert working in NZ researches SCENZ-Grid as a solution for multi-resolution raster processing for scaling up raster and vector processing & develops rHEALPix DGGS using rectangular cells.

Geoscience Australia while creating the Geoscience Australia Datacube containing decades of Australian LandSat imagery, sends a team lead by Matt on a global search for state-of-the-art global datacube architectures.

Matt backed by Geoscience Australia, invites Robert and Perry to form the core of an OGC DGGS SWG, and eight other organisations join them.
Conventional Approaches Don’t Scale – Geoscience Aust experience

A transition from siloed data to integrated information is now an operational requirement
**DGGS evolution to an International Standard**

1994: Michael Goodchild outlined ideal criteria for global analytical grids,

2003-8: Kevin Sahr, Jon Kimerling, Denis White published ISEA3H DGGS,

2003: Perry Petersen forms PYXIS to commercialise an ISEA3H based DGGS,

2001-5: Gorski et al at NASA develop HEALPix for data on the celestial sphere,

2010-11: Gibb et al develop rHEALPix for data on the terrestrial ellipsoid,

2010-13: GA leads development 1\textsuperscript{st} GA Datacube with 30yrs daily Landsat images,

2014-Feb: Matt (GA), Gibb, Perry + eight others form OGC DGGS SWG,


2017-Dec: OGC propose AS Topic 21 as a joint OGC – ISO TC/211 standard,

2019-Feb: ISO TC/211 votes to proceed on work on ISO 19170 DGGS standard,

2018: Michael Goodchild publishes “*Reimagining the history of GIS*”.
DGGS as an International Standard is disruptive

- **Lat, Long** was developed for analogue navigation,
- **ISO19107:2003** only provided for planar geometries,
- **ISO19111:2007** only recognises coordinates (eg x,y) for spatial location,
- **ISO19123:2005** coverages (rasters, grids, mesh, lattices, polygons, lines, TINs, Voronoi etc) have to use projections and flat earth geometry,
- **Coordinates** sit uncomfortably with modern linked data systems,
- **Vectors, rasters, point clouds, social tag clouds** are held at arms length by their disparate data models and disparate algebra & algorithms,
- No common data model for spatio-temporal precision & uncertainty, and
- No common data model for data provenance.

DGGS are designed to support global approaches to rapidly solving multi-disciplinary big-data problems in a data agnostic, digital first, fully networked world.

*Their efficiency has spinoff for smaller problems too.*
DGGS as an International Standard is disruptive

Reference System Information

Coordinate Reference Systems

Spatial Referencing by Names

DGGS

Geometry and Topology

Observation and Measurement
Infinite number line

base 10

\[ -35,243.26 \]
Finite number line
base9, base10, base6

8° 3' 5 2'' 4 3.2 6 W
Simplistically 2D Coordinate Reference Systems (CRS) are formed from a pair of number lines, typically perpendicular to each other, that are either

- Angular Latitude, Longitude referring to the whole globe, or
- Linear Northing, Eastings on a projected flat surface referring to part of the globe.

The fixed origin, and orientation on the earth’s surface and the units of measure for the number lines’ ticks complete the CRS.

But what if the units of measure are cells of uniform area on the surface of the earth? ... that is the basis of DGGS.
DGGS Equal Area Earth Reference System
rHEALPix
What are Discrete Global Grid Systems?

Equal Area Tessellations of the Earth’s Surface Model

Fixed Cell Hierarchy

Simple cell Types:
- Rectangular
- Triangular
- Hexagonal

nD Spatial Analyses become 1D Array Processes

Globally Unique Cell Indices

Tetrahedron
Cube
Octahedron
Dodecahedron
Icosahedron

Equal Area Tessellations of the Earth’s Surface Model

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nD Spatial Analyses become 1D Array Processes

Globally Unique Cell Indices

Tetrahedron
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Some flavours of DGGS
Some flavours of DGGS
Traditional GIS approaches are not the answer

Vectorised

FeatureID: 61
FeatureType: Lake
FeatureName: Lake Burley Griffin

FeatureID: 11
FeatureType: Road
FeatureName: Parks Way

Rasterised

Red: Road
Blue: Lake
Traditional GIS approaches are not the answer

Vector world

FeatureID:  61
FeatureType:  Lake
FeatureName:  Lake Burley Griffin

FeatureID:  11
FeatureType:  Road
FeatureName:  Parks Way

Red: Road
Blue: Lake

Raster world

DGGS world

FeatureID:  11
FeatureType:  Road
FeatureName:  Parks Way

FeatureID:  61
FeatureType:  Lake
FeatureName:  Lake Burley Griffin
DGGS Opportunities to bridge the divide(s)

- **Point**
- **Vector**
- **Polygon**
DGGS Clouds...

- DGGS **Cell/Point Clouds**

- DGGS **Tag Clouds**
DGGS Imagery / Grids...

- **DGGS Raster**

  cell size(s) is chosen to reflect the source cell-size(s)

- **DGGS Data Tiles (any/all types)**

  cell sizes are chosen to reflect the computational tiling needs
DGGS Maps/Viewer/Globe ...

- **DGGS map or globe Viewer**
  - cell size(s) is chosen to reflect the map resolution

- **DGGS map or globe Tiles**
  - cell sizes are chosen to reflect the map tiling/zoom/LoD needs
DGGS Adoption – DGGS GIS – Global Grid Systems’ Digital Earth

Welcome to Digital Earth

Free public access  
Private enterprise access

DGGS  
How it works  
About us
DGGS Adoption – embedded DGGS

Planet Risk & Real Factors
DGGS Adoption – Open Source in github: DSTL/Riskaware OpenEAGGR, Uber H3 & Google S2
DGGS Adoption in github – Australia Loc-I – AusPIX (rHEALPix)

A socio-technical architecture

also small rHEALPix research projects being run by OpenWorkLtd, University of New Brunswick & University of Calgari
DGGS Adoption – China 3D DGGS and Belt & Road projects
DGGS Adoption – watch this space ...

**Canada:** Environment Canada funding development of DGGS API Standard

**UN-GGIM:** In developing a global Statistical Geospatial Framework, UN-GGIM affirms that DGGS meet the requirement for global common geography for dissemination of statistics.

**GEBCO – TSCOM:** Thierry Schmidt (Shom) & Andy Hogarth having DGGS discussions within OGC Marine DWG to collaborate through OGC Testbed in developing 3D and Time in DGGS for Seabed 2030.
Thank you :)

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3D DGGS

Any 2D-DGGS tessellation can be extruded radially, to form a series of 2D-DGGS compliant spherical surfaces.

With an appropriate sequence of extrusion radii* the voxels will be equal volume, not only at each radius but through the sequence of all radii.

Every concentric spherical slice through the cells is a valid 2D-DGGS.

Each voxel can be recursively tessellated by tessellating the bottom face and extruding it to meet the top face through a finer sequence of equi-volume radii.

* This is trivially true for spherical surfaces. I strongly suspect it is also true for ellipsoidal surfaces and the resulting voxels. I suspect though that ellipsoidal solutions will be less important for 3-D DGGS than for 2-D DGGS.
Cubic cells fit together in a regular lattice

Any re-arrangement of regular subdivision of the cells, will also be space-filling.

One such rearrangement is the **rhombic dodecahedron**, comprising 12-rhombic faces.

It has some special properties for 3-D DGGS:

- **Opposite faces** are parallel and aligned,
- 12x voxel face neighbours provide a variety of directions for differential equations,
- 4x 2-D DGGS compliant slice surfaces,
- Like hexagons, tessellated voxels are not perfectly nested.
Rhombic Dodecahedra can also be arranged face up, instead of vertex up with:

- 2x 2-D DGGS compliant slice surfaces, alternating squares and hexagons. Each hexagon has an area that is 3x area of the square.
Example: 3-D DGGS based on cubic 3-D Initial Discrete Global Grid voxels

unit base hypercube

scaled spherical hypercube with equi-volume cubic voxels

first 3x3x3 refined tessellation into cubic voxels,

https://commons.wikimedia.org/wiki/File:Hypercube.svg
https://en.wikipedia.org/wiki/Tesseract#/media/File:Stereographic_polytope_8cell.png
http://antwrp.gsfc.nasa.gov/apod/image/0304/bluremarble2k_big.jpg
http://roice3.org/papers/abstracting_rubiks_cube.pdf, Fig 2b