# WHAT'S THE BIG DEAL ABOUT GLOBAL HIERARCHICAL TESSELLATION?

Organizer: *Geoffrey Dutton*
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This panel will present basic information about hierarchical tessellations (HT's) as geographic data models, and provide specific details about a few prototype systems that are either hierarchical tessellations, global tessellations, or both. Participants will advocate, criticize and discuss these models, allowing members of the audience to compare, contrast and better understand the mechanics, rationales and significance of this emerging class of nonstandard spatial data models in the context of GIS. The panel has 7 members, most of whom are engaged in research in HT data modeling, with one or more drawn from the ranks of informed critics of such activity. The panelists are:

- Chairperson TBA
- Zi-Tan Chen, ESRI, US
- Nicholas Chrisman, U. of Washington, US
- Gyorgy Fekete, NASA/Goddard, US
- Michael Goodchild, U. of California, US
- Hrvoje Lukatela, Calgary, Alberta, CN
- Hanan Samet, U. of Maryland, US
- Denis White, Oregon State U., US

Some of the questions that these panelists might address include:

- How can HT help spatial database management and analysis?
- What are "Tessellar Arithmetics" and how can they help?
- How does HT compare to raster and vector data models?
- How do properties of triangles compare with squares'?
- What properties do HT numbering schemes have?
- How does HT handle data accuracy and precision?
- Are there optimal polyhedral manifolds for HT?
- Can HT be used to model time as well as space?
- Is Orthographic the universal HT projection?

Panelists were encouraged to provide abstracts of position papers for publication in the proceedings. Those received are reproduced below.

## Combination of Global and Local Search strategy in Regular Decomposition Data Structure by Using Hierarchical Tessellation

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This presentation describes a role of hierarchical tessellation (HT) in a very large spatial data base. Large amount of spatial data can be indexed by regular decomposition data structures, like Quad Trees (QT), Quaternary Triangular Mesh (QTM), etc. All regular decomposition data structures have advantages of simple computation and elegant hierarchy, and facilitate global search.

On the other hand, most spatial features in the real world are irregular in shape and size. Therefore, an irregular decomposition data structure, for example a TIN, has more efficiency and impact in terrain surface feature representation. An irregular decomposition data structure usually has its own local neighbor finding properties. These properties can provide valuable fast local search in special cases. For instance, TIN has its own properties that make it easy to find a neighbor triangle from any given triangle. However, it is not easy to build a global search for a TIN, because its irregular shapes causes difficulties in building a hierarchy.

An optimal search strategy is a combination of the global and the local search in a large spatial data base environment. In this way, a search can benefit from both global hierarchical search and local neighbor finding properties.

The HT explores the local properties of a regular decomposition data structure. Based on knowledge of the HT, fast local search in regular data structure for features with irregular shape becomes possible. This paper discusses the concept. As an example, some experimental results of quadtree indexes a TIN for search triangles are given.

**Rendering and managing spherical data with Sphere Quadtrees**

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Most databases for spherically distributed data are not structured in a manner consistent with their geometry. as a result, such databases possess undesirable artifacts, including the introduction of "tears" in the data when they are mapped onto a flat file system. Furthermore, it is difficult to make queries about the topological relationship among the data components without performing real arithmetic. The sphere quadtree (SQT), which is based on the recursive subdivision of spherical triangles obtained by projecting the faces of an icosahedron onto a sphere, eliminates some of these problems. The SQT allows the representation of data at multiple levels and arbitrary resolution. Efficient search strategies can easily be implemented for the selection of data to be rendered or analyzed by a specific technique. Furthermore, sphere quadtrees offer significant potential for improving the accuracy and efficiency of spherical surface rendering algorithms as well as for spatial data management and geographic information systems. Most importantly, geometric and topological consistency with the data is maintained.

## Implementing a Global GIS Using Hierarchical Tessellations

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The QTM scheme described by Dutton and based on recursive subdivision of the faces of an octahedron provides a convenient and practical way of representing distributions over the surface of the earth in hierarchical, tesselated fashion. This presentation describes work at NCGIA Santa Barbara to implement a global GIS using a version of Dutton's scheme. The system makes use of the 3D display capabilities of a graphics workstation. Algorithms have been developed for the equivalent of raster/vector conversion, including filling, and the representation of lines in chain codes. Windowing is simple because of the basic transformations used to create the scheme, suggesting its use in tiling global databases. Examples are given of displays using the system, and of some simple forms of analysis.

## The Truncated Icosahedron as the basis for a global sampling design for environmental monitoring

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A comprehensive environmental monitoring program based on a sound statistical design is necessary to provide estimates of the status of, and trends in, the condition of ecological resources. A systematic sampling grid can provide the adaptive capability required in a broad purpose monitoring program, but how shall the globe or large areas of it be covered by such a grid? Criteria for determining the cartography and geometry of the sampling grid include equal areas across the domain of sampling, regular and compact shape of sampling areas, and hierarchical enhancement and reduction of the grid.

Analysis of systematic subdivisions of projections of the Platonic solids (tetrahedron, hexahedron, octahedron, dodecahedron, and icosahedron) onto the globe show that subdivisions of the dodecahedron and icosahedron produced the most regular set of triangles, but differences among triangles are unacceptably large. In addition, analysis of Lambert azimuthal equal-area map projections for the triangular subdivision of each Platonic solid show that distortions in shape reach unacceptably large maximum values for each solid.

Acceptably small shape distortions (maximum about 2%) can be obtained by subdividing the globe into a truncated icosahedron, an Archimedean polyhedron (commonly used as the tessellation for soccer balls) consisting of twenty hexagons and twelve pentagons. A hexagon face of the truncated icosahedron can be positioned

to cover the entire conterminous U.S.; adjacent hexagons cover Alaska and Hawaii. A hexagon from this model can be decomposed into a grid of equilateral, equal-area triangles whose vertex positions can be projected into geodetic latitude and longitude coordinates on the spheroid.

This triangular grid of sample points has advantages in spatial analysis over square or hexagonal grids. The geometry for enhancement and reduction provides for a hierarchical structure, and includes provision for density changes by factors of 3, 4, and 7. Points in the triangular grid placed on the truncated icosahedron hexagon can be addressed with a hierarchical system based on the systematic decomposition from the hexagon, or by a system similar to the quadrangle labeling convention of the U.S. Geological Survey.

## The Evolution of Geopositioning Paradigms

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Numerical geopositioning paradigms, used in virtually all of the current geometronical systems, are derived by a simple-minded transplant of the procedures and numerical apparatus of the classical cartography into the realm of digital computing. Such systems suffer from two major faults:

1) Full functionality of their spatial modeling is restricted to a single planar area; usually less than one percent of the planetary surface. Modeling of the time-space relationships between the near-space objects and the terrestrial surface is imprecise and/or inefficient.
2) Geometry relationship derived from the planar digital model is, at best, an imprecise approximation of the corresponding relationship in the object space; at worst, it is an exact opposite.

The purpose for the creation of most geometronical systems is no longer the automated production of an analog, graphical model, from which a human observer derives spatial relationships. In many disciplines, the human map user has been partially or completely replaced by a layer of discipline-specific software; layer which depends on the geometronical system - and its database - for the selection, manipulation and delivery of digitally encoded spatial information. Among the spatial processing requirements of a typical application system, two stand out:

1) From the numerical representation of spatial objects, their geometric relationships - unions, intersections, proximity sections, distances, etc. - must be derived, with at least an order of magnitude higher spatial resolution and precision than that which is employed by the measurements and activities carried out in the object-space.
2) Among a large number of objects, populating the digital model and its database, the system must select those that conform to a criterion based on the spatial extent of another, possibly transient, object. This criterion is frequently combined with non-spatial selection criteria.

HIPPARCHUS is one among a number of new numerical geopositioning paradigms, which provide these facilities, while avoiding the faults mentioned above. Its reference surface - and the data domain - is an ellipsoid of rotation; its repertoire of spatial primitives consists of points, lines and areas on the terrestrial surface, as well as the time-position relationship of the closed orbits and their sensor geometry.

In order to construct an index into a collection of objects, the domain is partitioned, and the fragment identifiers are used as the search arguments of either an implicit or explicit index table. Spherical or spheroidal surface partitioning presents a greater challenge than that of a planar one; beyond five Platonic solids, spherical surface can not be sub-divided into a finite number of regular polygons. The spherical surface can be partitioned using one of the two divergent structure classes: pseudo-regular (Pythagorean) or irregular (Platonic). Of the latter, spheroidal equivalent of the planar Voronoi tessellation - combined with the vector algebra based manipulation of the spherical coordinates - seems to yield an extremely efficient implementation of the critical spatial algorithms. It is, however, the combination of both partitioning techniques that will likely provide a base for the future numerical geopositioning paradigms.