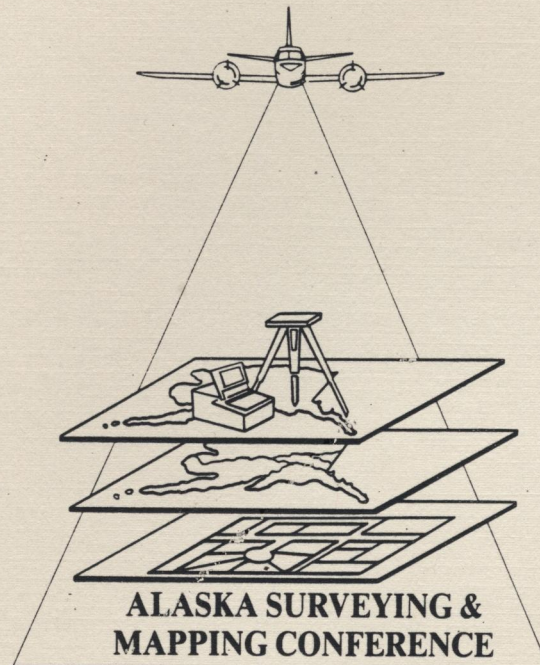


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Satellite coverage modeling using the Hipparchus geopositioning system

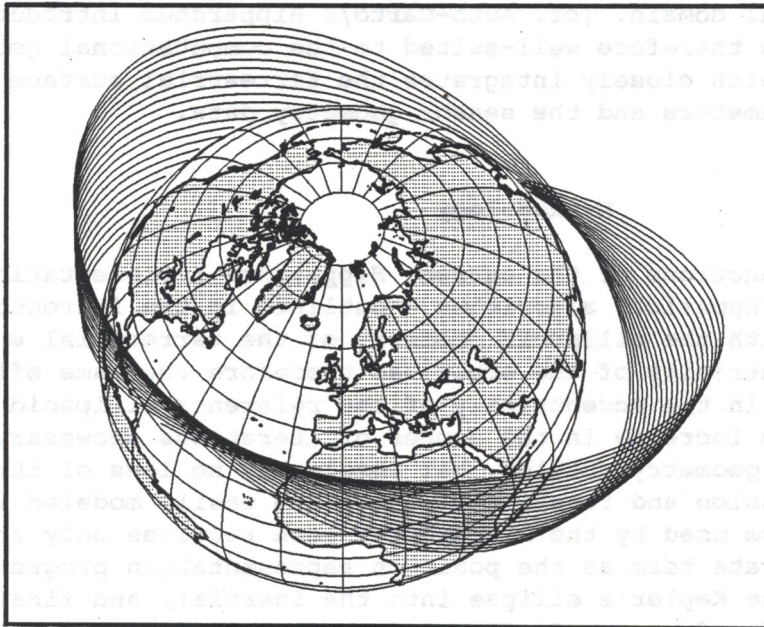
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Abstract

Mapping from space has become by far the most prolific geographical data gathering activity. The compilation and dissemination of this data is still based predominantly on the conventional mapping paradigm: a flat sheet of paper as a primary metric domain and the ultimate information repository.

For a number of reasons, this paradigm lessens the usefulness of data. The paper presents an alternative approach, examined in the context of the Hipparchus geopositioning system solution to the computational problem of the a-priori determination of the sensor swath coverage.



Hipparchus orbit modeler: depiction of an orbit with exaggerated precession and rotation of apses

Introduction

Since the early days of near-space based mapping of the earth's surface, cartographers have struggled to find effective means to capture, process and present the space-acquired data. The best known among these efforts is probably the Space Oblique Mercator (SOM) projection. It is intended to be the metric domain of the final analog data repository. Other arcane projections have been - and still are - widely used for graphical solution of the problems of satellite position nadir ground-tracking, and for the determination of the sensor swath coverage.

This approach suffers from an obvious deficiency: only a small fraction of the ground-objects with which the space-acquired data must interact will ever be readily available on a map based on one of those projections. Indeed, many such objects will only exist as transient artifacts of a geometrical computing system. (As an example, consider a digital representation of a desired or projected course of a vessel navigating through the ice-infested waters.) Consequently, object positions will be defined in some form of global coordinates, and not in the two-dimensional coordinate system of the display projection plane.

In an ever-increasing number of instances, the spatial relationships between the terrestrial object and the orbit-based data will be resolved under the covers of the geometrical computing system, and presented to a human user/operator not as an analog model, but as a natural language message. (To use the same example, a message from the vessel's navigation system might simply state that the next acquisition and downlink of a SAR ice image over the projected course will be available in two hours and fifteen minutes.)

HIPPARCHUS is one among a number of new numerical geopositioning paradigms, which expand their computational domain beyond the usual two-dimensional GIS mapping projection plane. It is implemented as MS-DOS and UNIX library of C-language functions, which an application system can use to perform spatial object modeling and geometrical computations. The modeling of objects - as well as the evaluation of their spatial relationships - is carried out in the full three-dimensional domain. (cf. Auto-Carto/8 Hipparchus introduction paper). The system is therefore well-suited to the computational geometry and temporal modelling which closely integrates the terrestrial surface objects with the orbital parameters and the sensor geometry data.

Methodology

The orbit modeling functions of the current Hipparchus implementation use essentially the same numerical algorithms - outlined in the introduction paper - as those dealing with the ellipsoid geometry of the terrestrial surface. Increase in the eccentricity of the orbit has therefore the same effect as that of the increase in the eccentricity of the reference ellipsoid of a planetary surface: an increase in the number of iterations necessary to resolve a particular geometry problem, but absolutely no loss of the spatial precision. The precession and rotation of apsides are easily modeled in the isometric vector space used by the Hipparchus: each requires only an additional rotation rate term as the position representation progresses consecutively from the Kepler's ellipse into the inertial, and finally, into the sidereal frame of reference. Similar treatment is used to represent the external orientation of the sensor geometry, and the swath limits. The definition of the sensor geometry is free from any restrictions: side-looking, non-symmetrical swaths are modelled simply by the appropriate selection of the swath-limit angles. The nadir normal - an essential reference line for the sensor external orientation definition - is dynamically re-constructed as the true ellipsoid surface normal. The intersection of the instantaneous position and the receiver cone is likewise dynamic; the influence of the altitude change caused by any degree of the orbit eccentricity is always taken into the account.

The primitives of the Hipparchus terrestrial object repertoire are the points, the lines and the areas. Neither the line nor the area objects are restricted to being simply-connected, but the ring-set defining an area object must be

topologically consistent, with no second-order singularity points. The implementation provides an efficient method of the evaluation of unions and intersections of all union-compatible objects, and for the spatial-proximity criterion based intersections of those that are not union compatible.

The problem of the swath coverage determination is therefore reduced to that of the construction of the Hipparchus area object defining the terrestrial limits of the swath, in order to request its intersection with the object of interest. Since the application code presents the vertices of the ring(s) defining an area to the Hipparchus engine in a form of a counter-clockwise queue, a simple - yet effective - method can be used by the orbit modeler to construct the swath area: as the coverage limits are computed with the requested temporal density, right-limit points are placed in a queue, while left-limit points are pushed on a stack. The stack and queue are simply "tied together" (at the either end) and passed - as a single queue - to the area object constructor. The previously mentioned topological consistency requirement necessitates that this process is partitioned into the time periods in which the swath does not cross itself; however, the area representing the complete coverage for days - or even weeks - can easily be obtained by finding the union of the required number of single orbit swaths.

The nadir-track line construction is trivial; any time period can be modeled with almost any temporal density.

Graphical presentation of the swath and object-of-interest intersections follows the common Hipparchus rendering methodology. It must be noted however, that the casting of the resulting object into the particular planar projection geometry and scale of the screen or the plotter surface is performed only as a part of the rendering procedure. The numerical spatial resolution of the terrestrial objects is in the millimetric range; the orbit modeler is capable of the same level of resolution up to the geo-synchronous orbit altitudes.

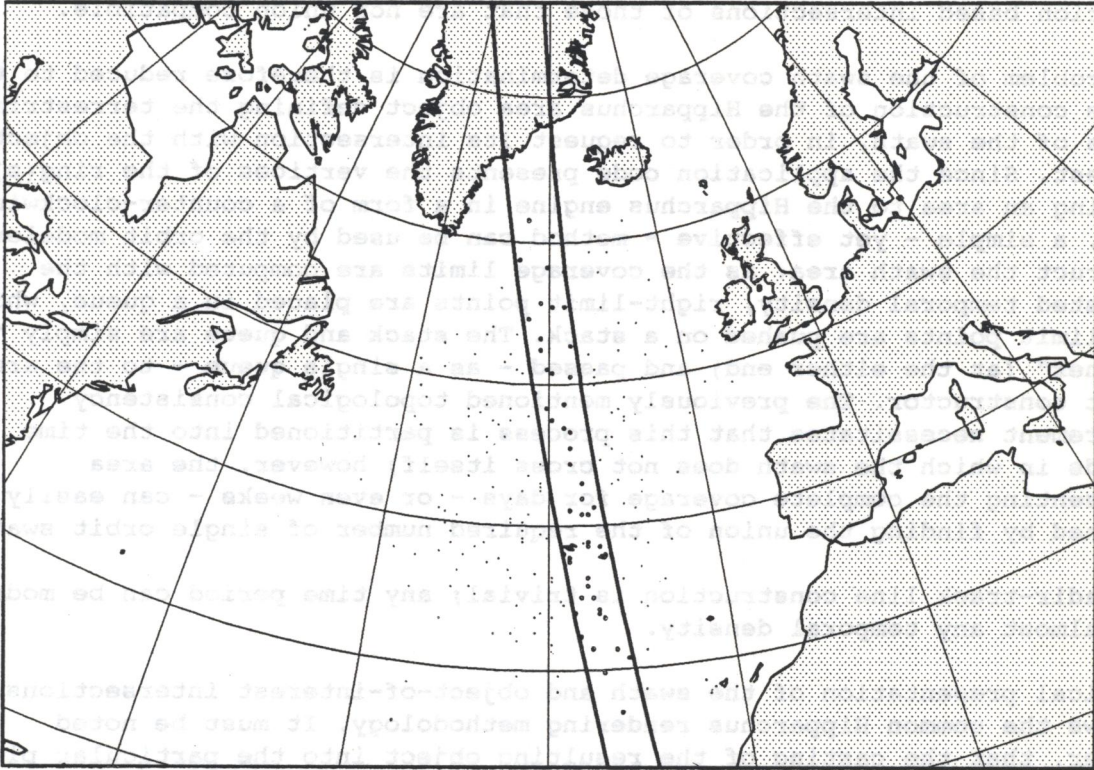
Examples:

Following examples were all computed on an 80386/387 processor operating at 16 MHz clock speed. Hipparchus spatial index was of a relatively low density: approximately 500 cells, favoring the coastlines and the polar caps. Temporal density is equal in all three examples; the swath limits were computed at 2 minute intervals. In all examples, a non-symmetrical swath was defined with a near elevation angle of 38 degrees 45 minutes, and the far elevation angle of 42 degrees and 20 minutes. The orbit used was a common low-eccentricity, sun-synchronous polar orbit. Ground resolution of the computational data is in the order of millimeters.

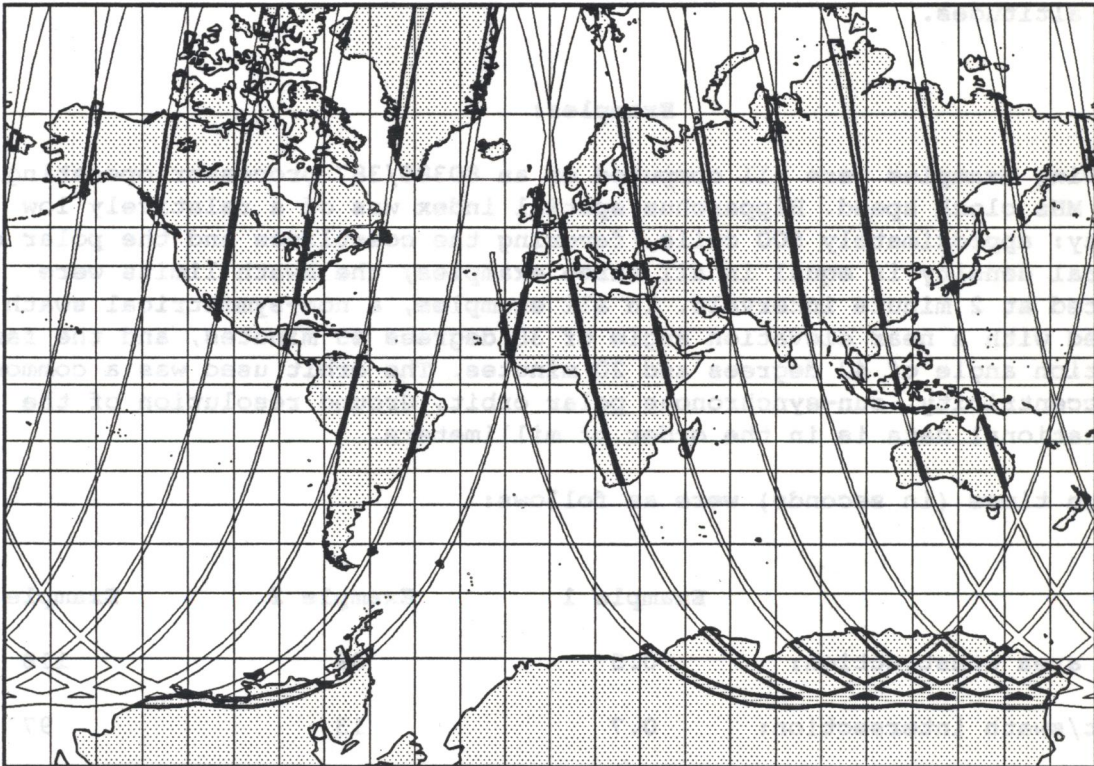
The run times (in seconds) were as follows:

	Example 1	Example 2	Example 3
Swath area construction:	0.5	39	118
Object/swath intersection:	0.7	13	97

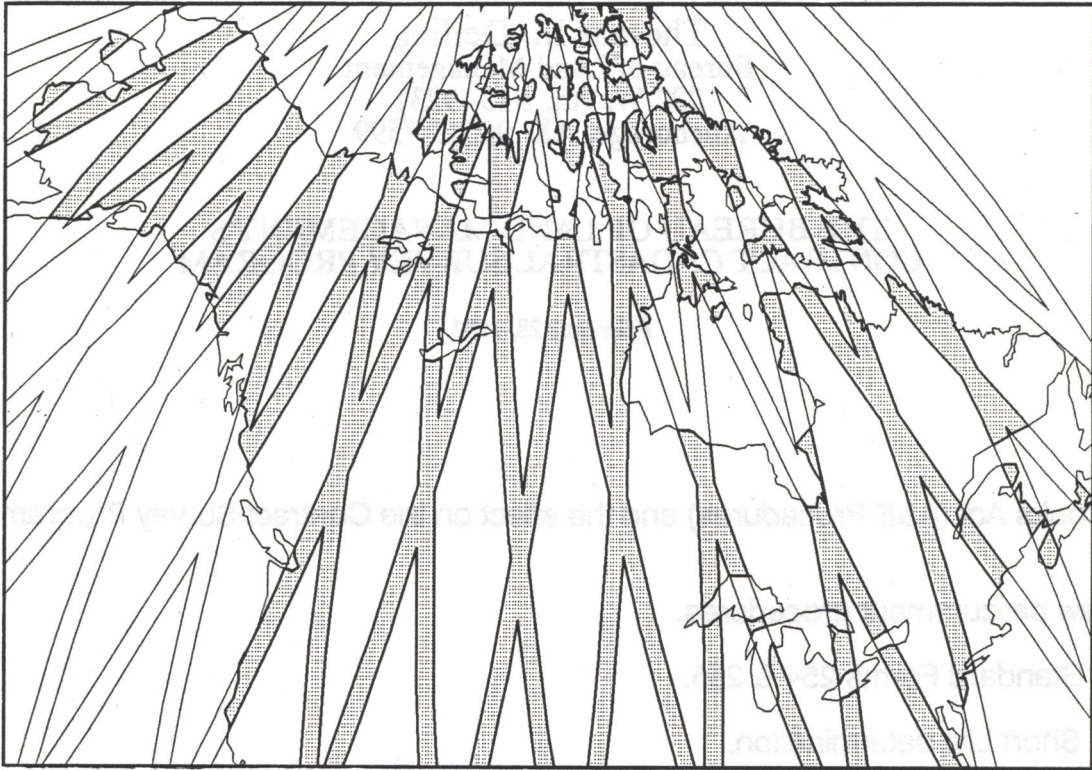
Hardcopy rendering has been produced using the Hipparchus HPGL interface.



Example 1: Single orbit coverage of a multiple point object.



Example 2: 12-hour coverage of the global landmass.



Example 3: Three-day coverage of the north-american landmass (detail)

Conclusion

Compared to the downstream applications which use the giga-pixel volumes of the space-acquired mapping data, swath coverage computations are not a particularly demanding application. The examples demonstrate, however, that it can be carried out effectively in the full three-dimensional spatial frame of reference on the low-end computing equipment. This suggests that with the appropriate hardware-power scale factor, it might be practical to disseminate and process space-acquired mapping data not in some arbitrary planar projection system, but in its natural frame of reference - that of the surface of an ellipsoid of rotation. This would improve the usability of data, especially if the assumption that such data will be more and more used in purely digital down-stream application systems - and not to be graphically presented to a human observer - proves to be correct.