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An Extended Vector Product Format Profile for Modeling and Simulation

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13. ABSTRACT (Maximum 200 words) The Vector Product Format (VPF) has been advancing, through prototype development, the Defense Mapping Agency's (DMA) transition from paper products to geographic information system environments. Indeed, that was VPF's main intent. Lately, however, the DMA has recognized that the VPF prototypes have not been meeting the requirements of a particular group, the Modeling and Simulation (M&S) community. Through support from the Terrain Modeling Project Office and the Defense Modeling and Simulation Office, the Digital Mapping, Charting, and Geodesy Analysis Program (DMAP) has been tasked to extend VPF to satisfy M&S Requirements. What follows is DMAP's initial profile of the Extended VPF and its first prototype. While by no means a completed standard, the EVPF profile is described by DMAP as a promising VPF alternative for the M&S community.			
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An Extended Vector Product Format (EVVPF) Profile for Modeling and Simulation

1.0 Introduction

1.1 Products in the Vector Product Format (VPF), a georelational database format, have made great strides at effectively representing what was once a "paper only" environment. The Digital Nautical Chart (DNC), Vector Smart Map (VMap), and Tactical Terrain Data are but a few such databases currently under development which, when completed, should provide excellent digital substitutes for harbor, approach, coastal, and general charts, as well as various culture datasets. In fact, VPF's strength can be observed in its digital representation of charts. It allows the collapsing of a three-dimensional (3-D) environment into two-dimensional (2-D) thematic layers, under rigorous geometric and topological guidelines.

1.2 Unfortunately, for today's modeling and simulation (M&S) community, VPF's representation of an environment is deficient in several regards. The ability to represent culture, terrain, and models in three dimensions is an absolute necessity in most M&S scenarios. While VPF allows for storage of feature height information in various attributes, VPF and its application software VPFView are essentially two dimensional.

1.3 Rich attribution of features is also desirable to the M&S community to accurately portray models in 3-D. Extensive M&S requirements analyses [1,2] have proven VPF's inadequate attribution in most of its databases.

1.4 Finally, VPF's construction of logically separate thematic layers can pose problems, especially in the format's elimination of topology (connectivity) between coverages.

2.0 Spatial Dimensions

2.1 VPF's geometrical limits extend from zero-dimensional *nodes* to one-dimensional *edges* and two-dimensional *faces*. These are represented in VPF as *primitive* tables. To naturally extend VPF into three dimensions, an additional data structure has been proposed, the Triangulated Irregular Network (TIN).

2.2 Terrain has been shown to be effectively represented and utilized for analysis as a TIN, whereby terrain is represented as network of irregularly shaped triangles. A current literature search and discussions with M&S programs have shown that TINs have become a widely used structure and can be generated from elevation posts of regular spacing, e.g., Digital Terrain Elevation Data (DTED), a commonly used dataset in M&S.

2.3 The Digital Mapping, Charting, and Geodesy Analysis Program (DMAP) proposes to transform the DTED Level 2, 30-m post spacing, within Extended Vector Product Format (EVVPF) as a TIN structure. Since there are multiple representations of TINs in relational

databases, investigations are currently underway to determine the representation best suited for VPF's geometric structure. The anticipated result is a new primitive beyond VPF's current limit of *face*, together with a corresponding feature table to store appropriate attribution. Moreover, TIN and additional formats of elevation data will comprise a single VPF coverage.

2.4 Appendix B presents DMAP's preliminary observations on the relative difficulty of integrating TINs into VPF. Of the three presented storage formats, DMAP proposes to use the triangle-based data structure. Although new file definitions must be created for this structure, it shows considerable promise in terms of storage requirements, access speed for viewing software, and simplicity.

2.5 With respect to TIN generation, many algorithms exist. Since regular grid data will be input, the current plan is to use the generation algorithm of the commercial geographic information system ARC/INFO, which can complete such transformations with minimal input from the user. For testing purposes, DMAP has successfully generated a TIN from VPF contour lines in Urban Vector Smart Map. The intent is now to apply this concept to a more realistic scenario, namely generating TINs from DTED 2.

3.0 Feature and Attribution Content

3.1 For an object to be modeled successfully, sufficient attribution must be supplied. The required amount of attribution, of course, depends on those programs modeling the object. Once sufficient and appropriate attribution is available in a given form, successful modeling can take place within a program's own system/simulation.

3.2 To that end, DMAP has based the feature and attribute content on the most up-to-date requirements analyses of 38 Army programs and 110 Navy/Marine Corps programs involved with M&S [1,2]. Additionally, feature and attribute content of the prototype VPF product will contain features and attributes made available in all current VPF prototypes (DNC, Digital Topographic Data, World Vector Shoreline, VMap 0, VMap 1, VMap 2, UVMap), with redundant features eliminated.

3.3 Additionally, Digital Feature Analysis Data (DFAD), a product which is currently used by many M&S programs as a source of cultural information, will be analyzed and incorporated into the extended VPF prototype. (As an aside note, much of DFAD has been integrated into VMap Level 1.) Compared with several current VPF products, DFAD seems limited in feature content. However, its rich attribution satisfies many M&S requirements. No difficulties are anticipated with incorporating such attribution.

3.4 The following section introduces DMAP's initial coverage and feature profile separated into logical thematic groupings that will evolve into VPF thematic coverages. All available Feature and Attribute Coding Catalog (FACC) codes are represented, and those with no code are not yet available in FACC. Once codes are established, all features should be stored in VPF's relational format with equal ease.

4.0 Proposed EVPF Profile

4.1 Appendix C describes required features, grouped into the proposed 12 EVPF coverages *Aeronautical Information, Beach, Data Quality, Demarcation, Elevation, Hydrography, Industry, Physical Geography, Population, Transportation, Utilities, and Vegetation*, with some temporary subheadings for clarity. References to geometry (area, line, and point) are minimized so as to avoid future conflicts with scale. Blanks indicate FACC codes to be developed, and "*" indicates "not a currently identified requirement." DMAP recommends the latter features for inclusion on the basis of future requirement indications. Approximately 20 new FACC features are proposed here, and many other codes required by Navy and Army M&S programs exist in the FACC, but not in any current VPF product.

4.2 Attribution is "to be determined" and will fulfill all requirements without causing multiple representation of entities, as stipulated by VPF. New attribution, including physical measurements relating to infrared properties, emissive properties, reflective properties, and thermal conductivity, will be integrated with standard attribution to satisfy remaining requirements. Some new attribution codes will obviously be needed to supplement the FACC, which may present future technical challenges. Once completed, however, the resulting profile of features and attributes should surpass content of any given VPF product to date.

5.0 Thematic Coverages

5.1 VPF allows similar data objects to be grouped into coverages for the purpose of defining topology. VPF stipulates that topology, by definition, does not extend between coverages. A simple example illustrates the impact of such a restriction: If roads are in coverage Transportation and bridges are in coverage Hydrography, no information about connectedness between road and bridge can be inferred. Careful requirements analyses and mission requirements have been studied to determine coverage content for the existing VPF products.

5.2 Coverages must exist not only for topological reasons but for topography preservation as well. For example, a lake area exists in a land area. Since both area features cannot geometrically exist within a single VPF coverage, separate coverages are required.

5.3 Perhaps the most ambitious (and time consuming) extension to VPF would be to "connect" information between coverages. Clearly, separate coverages reinforce logical separation of data and data manageability. On the other hand, connection between coverages could allow for more enhanced operations, such as thinning, an important concept in M&S. DFAD allows for a way of "stacking" features, thereby in a sense, introducing topography information into the 2-D representations of features. EVPF should have similar capability. However, for the initial prototype, the separate, individually connected coverages of section 4.0 will be the extent of connectedness.

6.0 Software Considerations

6.1 In creating a preliminary prototypical EVPF database for M&S, software must be developed not only to generate TINs, as discussed in Section 2.0, but also to form tables of features from existing VPF products. Since the current products do not normally cover the same geographic area, some data must also be simulated. Software tools are needed to generate VPF tables in all cases.

6.2 A collection of "C" routines is currently being written to manipulate VPF tables. These functions allow the user to read, write, display, delete, and copy elements or rows in VPF tables, thereby allowing DMAP to prototype an M&S VPF prototype which conforms to the basic tenets of the VPF standard and the extensions. Once software engineering is complete, DMAP will have the mechanism to merge diverse database coverage information into the M&S prototype.

6.3 In particular, VPF software tools (collectively called VPFTool), previously used to create a point coverage for the Naval Search and Rescue routine, are being refined and extended to develop these capabilities. Recent additions to VPFTool include:

- *Attribute table merging routines.* A source table row is mapped to a new attribute table, transferring any identical column entries and providing the appropriate null values for columns not found in the source row.
- *Database creation tools.* A set of functions that build the required database header, geographic extent, and library header tables using a template file, sensible default values, and a limited amount of user input, making the construction of a skeleton EVPF database structure quick and easy to accomplish.
- *Point and text feature primitive constructors.* These routines provide a method of sorting text and entity node data by geographic extent and tile, providing a means of migrating existing data to a new database. These functions also provide a way to store selected VPF data in VPF format using the additional database creation functions outlined above. No anticipated difficulties are expected for the line and area primitives.

6.4 Algorithms for constructing the initial EVPF prototype have also been developed. For example, the steps for migrating a coverage to a new database are defined as follows:

- 1) Create a set of extents, tiled or untiled, that define the new library.
- 2) Create a new attribute table in which to store the existing coverage attribute data.

- 3) Transfer the existing data. The software will map the existing attribute rows to the new table and create a table in which to insert any associated primitives that fall within the extents of the new library. If that table already exists, the primitives are appended to that table.

6.5 For displaying the prototype extended VPF, a 3-D software viewing package, PolyView version 3.1, will be used. This public domain package shall enable DMAP to display a terrain skin along with 3-D objects and have a "fly-through" capability. The relationship among the 3-D objects cannot be varied, but sequential images can be used to simulate the relative motion of objects. Documentation unfortunately extends only through version 2.0, so some difficulty is expected to be encountered.

7.0 Issues for Future Consideration

7.1 Unlimited extensions to VPF could be performed. As mentioned in an earlier section, connections between coverages has yet to be resolved.

7.2 Another issue is that of the temporal data. Many features have attribution that extends well beyond that of a "single instance in time." Forward Looking Infrared, for instance, is highly sensitive to time. Efficiently storing such information in a relational database is certainly a topic of concern which lies beyond the scope of the problem at hand.

7.3 Resolution and level of detail are additional topics of interest in M&S. VPF fixes a scale at product development time. WVS, for example, has five separate libraries corresponding to five distinct scales. A hierarchical TIN data structure has been developed to address the concept of storing terrain at various scales (see Appendix B for a brief introduction). Representing scaled data in EVPF, to the benefit of the M&S community, could very well be a separate project unto itself.

8.0 Conclusions

8.1 Results to date have been substantial and promising. The major extension to VPF, the incorporation of 3-D terrain data, has been carefully planned: The popular TIN data structure has been selected, the method of storage of TINs has been selected, and research into TIN generation from regular grids such as DTED is underway. Moreover, all current and future M&S requirements have been compiled. Software is currently being designed, and attempts at using completed software have been successful.

8.2 Anticipated difficulties are in the form of display software, and modeling 3-D objects described by the attribution of EVPF. Limited geographic extent of existing VPF products may pose a problem to EVPF prototype generation, particularly since each product has it's own unique extent.

9.0 Acknowledgments

9.1 This effort was sponsored by the Defense Mapping Agency's Terrain Modeling Program Office and the Defense Modeling and Simulation Office, under Program Element 630603832D, with Mr. Jerry Lenczowski as program manager.

10.0 References

1. Shaw, K. et al., *A Comprehensive Analysis of Navy and Marine Corps Digital Mapping, Charting, and Geodesy Requirements for Modeling and Simulation*, NRL/FR/7441--93-9435, 9 January 1995.
2. Othling, W. and L. Speir, *Analysis of Digital Topographic Data Requirements for selected Army Models/Simulations*, Contract No. DACA 76-90-0002, Delivery Order No. 6, Task 1, prepared for U.S. Army Topographic Engineering Center, Ft. Belvoir, VA, 22060, 31 January 1993.

Appendix A. Acronym List.

2-D	Two Dimensional
3-D	Three Dimensional
ARC/INFO	commercial geographic information system
DFAD	Digital Feature Analysis Data
DMAP	Digital Mapping, Charting, and Geodesy Analysis Program
DNC	Digital Nautical Chart
DTED	Digital Terrain Elevation Data
EVPF	Extended Vector Product Format
FACC	Feature and Attribute Coding Catalog
M&S	Modeling and Simulation
TIN	Triangulated Irregular Network
VMap	Vector Smart Map
VPF	Vector Product Format
VPFTool	VPF software tools
VPFView	VPF viewing software
WVS	World Vector Shoreline

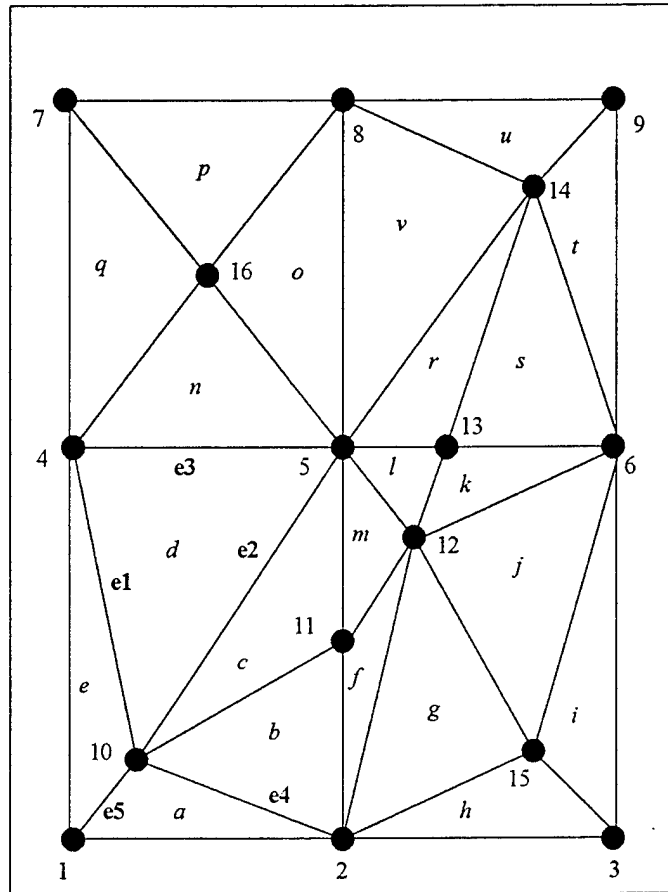
Appendix B. TIN Data Structures.

DATA STRUCTURE FOR TINs

PRELIMINARY THOUGHTS

- Storing TINs by adding a third dimension to VPF's vertices
- Storing TINs using a triangle-based data structure
- Storing TINs using a vertex-based data structure

VPF-Based Data Structure



Sample Triangular Network
 e_1, e_2, e_3, \dots edges
 1, 2, 3, ... vertices
 a, b, c, \dots triangles

Connected Node Table:

ID	x	y	z
1	x_1	y_1	z_1
2	x_2	y_2	z_2
...

Edge Table (level 3 - LFT_ID not included):

ID	start_node	end_node	right_edge	left_edge	right_face	left_face	coordinates
e ₁	4	10	e ₅	e ₃	e	d	x ₁ y ₁ z ₁ x ₂ y ₂ z ₂
...

Face Table (a face is any triangle that does not contain an edge inside - AFT_ID not included):

ID	Ring pointer
...	...
d	9
...	...

Ring Table:

ID	Face	Starting edge
...
9	d	e ₁
...

Storage Requirement = $(54N - 18B - 49)$ storage units

- N = number of TIN vertices
- B = number of TIN vertices that belong to the convex hull
- storage unit = amount of storage needed to store either a pointer or one coordinate

Basic Queries:

- Point Location: requires reading several VPF tables
- Edge Neighbor finding: needs only the edge table
- Vertex Neighbor finding: difficult to perform

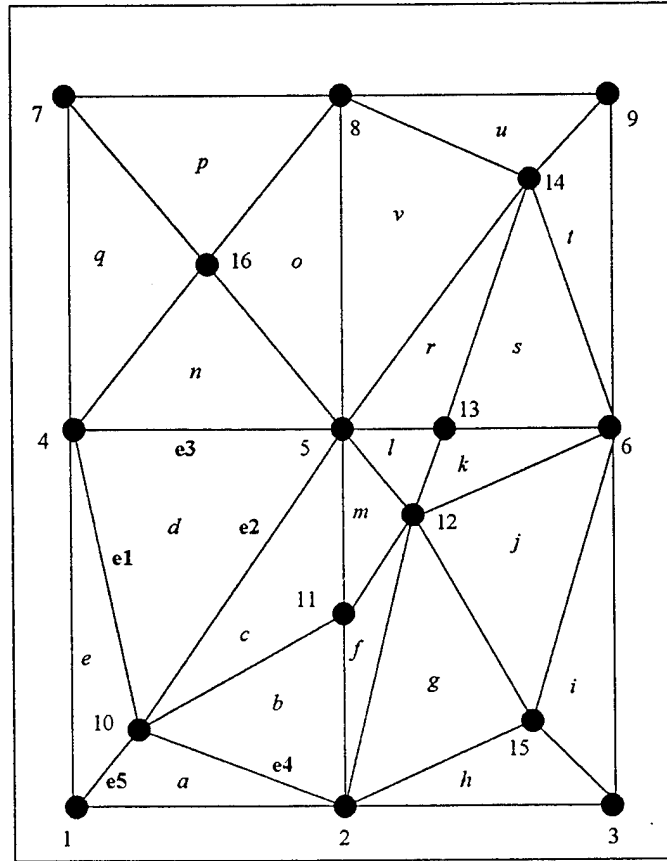
Advantages:

- Visualization software available?
- Minimum change to VPF
- Allows for area, line, and point features

Disadvantages:

- Storage requirement
- Complex data structure that was not meant for TINs

Triangle-Based Data Structure



Connected Node Table:

ID	x	y	z
1	x ₁	y ₁	z ₁
2	x ₂	y ₂	z ₂
...

Face Table (stores triangles):

ID	Vertices:			Adjacent Triangles:		
	V ₁	V ₂	V ₃	T ₁	T ₂	T ₃
a	1	2	10	null	b	e
b	2	11	10	f	c	a
...

Storage requirement = $18N - 7B - 14$ storage units

Basic Queries:

- Point Location: simpler than VPF data structure
- Edge Neighbor finding: simpler than VPF data structure
- Vertex Neighbor finding: simpler than VPF data structure

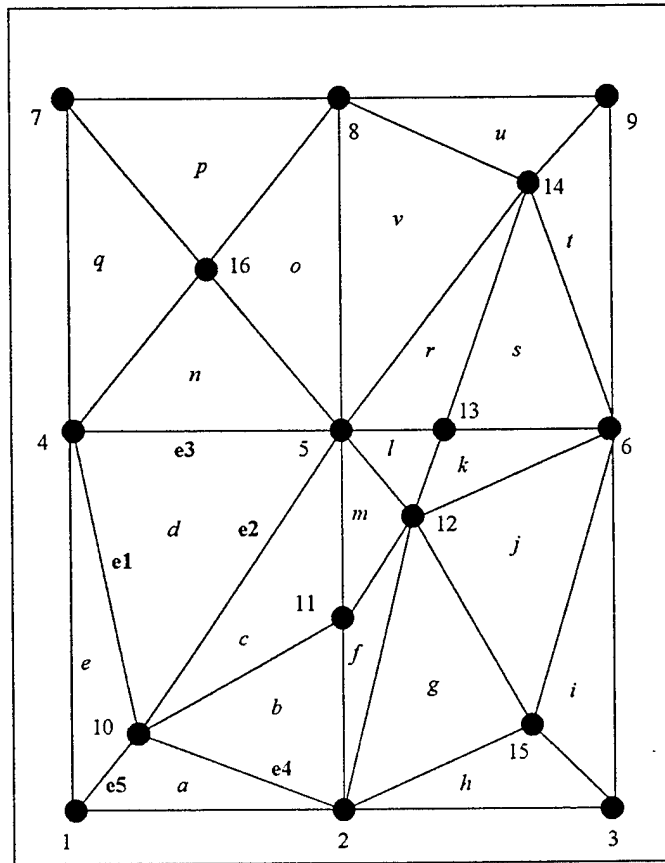
Advantages:

- Less storage than VPF (about three times less)
- Data format similar to that of ARC/INFO

Disadvantages:

- Will require substantial changes to VPF
- No edge table (but line features can easily be expressed in terms of a list of pointers to TIN vertices)

Vertex-Based Data Structure



Coordinates:

ID	x	y	z	Neighbors
1	x_1	y_1	z_1	2 10 4
2	x_2	y_2	z_2	3 15 12 11 10 1
...

Storage requirement = $10N - 2B - 6$ storage units

Basic Queries:

- Point Location: about same complexity as triangle-based data structure
- Edge Neighbor finding: complex compared to triangle-based data structure
- Vertex Neighbor finding: simple

Advantages:

- Less storage than the triangle-based data format

Disadvantages:

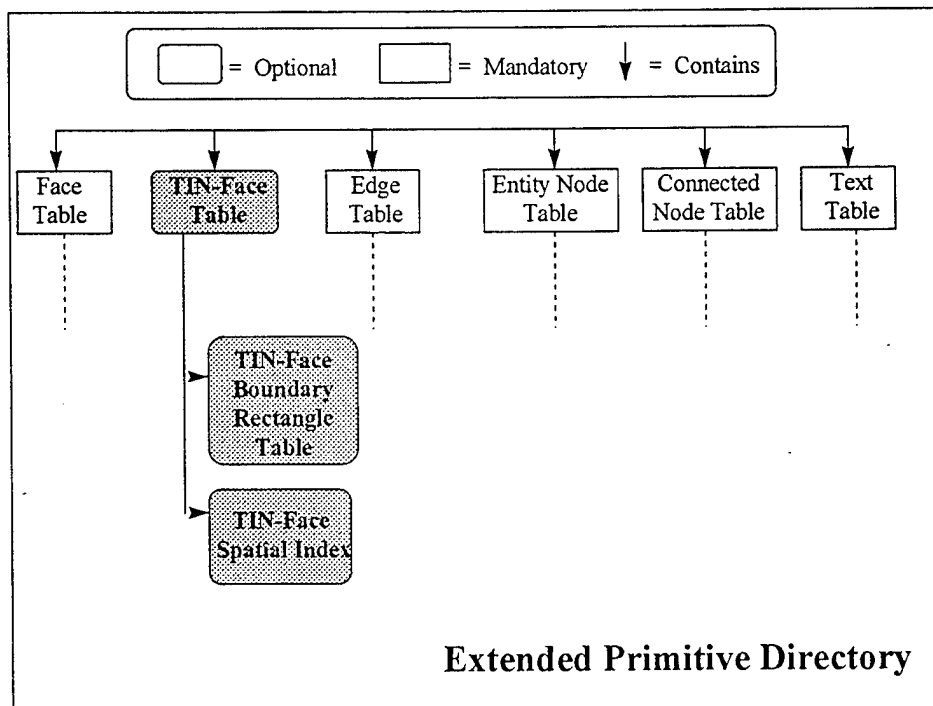
- Will require substantial changes to VPF
- Does not allow for area features
- Does not allow for line features

DATA STRUCTURE FOR TINs

Goal:

- Extend VPF to allow for the efficient storage of TIN-based elevation data
- Integrate terrain elevation data with ground surface features (point, line, and area features)

Methodology: Add an optional primitive TIN-face. A TIN-face will be stored using a triangle-based data structure



Structure of a TIN-Face Table

TIN-Face Table
Triangle Identifier
Vertex 1 Identifier
Vertex 2 Identifier
Vertex 3 Identifier
Adjacent Triangle 1 Identifier
Adjacent Triangle 2 Identifier
Adjacent Triangle 3 Identifier

HIERARCHICAL TINs

Hierarchical (multiresolution) TINs:

- Describe a terrain model at different levels of resolution.
- Each level corresponds to a particular surface elevation error. The root level is composed of all the TIN-triangles needed to reconstruct the surface with the largest error (the lowest level of resolution). The next level in the hierarchy contains TIN-triangles that when added to those of the root level yield a surface representation that has a higher resolution than that of the root level. Therefore, each level provides additional TIN-triangles that when combined with the existing ones bring the resolution of the surface to that of the corresponding level.
- Enables the compression of elevation data according to an accuracy level criterion.
- Features can be manipulated at different levels of accuracy.

Algorithms for the Generation of Hierarchical TINs:

Algorithms for the generation of hierarchical TINs can be classified into two broad categories:

- Recursive subdivision of enclosing triangles

Ternary triangulation

- + simple
- may lead to triangles with elongated shape (result in inaccuracies in numerical interpolation)

Quaternary triangulation

- + avoids the generation of elongated triangles
- may lead to discontinuous surfaces

Cartographic coherence preservation

- + preserves cartographic coherence (features - such as ridges - of the surface to be approximated are preserved)
- complex algorithm

- Retriangulation of the added points and their region of influence
 - + avoids the generation of elongated triangles
 - complex

Data Structures for Hierarchical TINs:

All hierarchical TIN implementations can use essentially the same data structures.

Level Table

Level Table
Level ID
Max Error
Num. Triangle
Num. Points
Triangle List

Triangle Table

Triangle Table		
ID		
Max Error		
Type (internal, external, boundary)		
child list		
<u>Internal</u> Vertex 1 Vertex 2 Vertex 3 Adjacent 1 Adjacent 2 Adjacent 3	<u>External</u> Parent Pointer	<u>Boundary</u> Adjacent 1 Adjacent 2 Adjacent 3

Appendix C. Feature Classes and Features.

1. AERONAUTICAL INFORMATION

Air Routes

GA005	Airspace
GA010	ATS Route Segment/Leg
GA015	Special Use Airspace
GA020	Airspace Boundary Sector
GA025	Special Use Airspace Segment
GA030	Off Route Radial/Bearing
GA035	NAVAIDS (Aeronautical)
GA045	Route (Air)
GA055	Waypoint/Reporting-Calling in Point
ZD020	Void Collection Area

2. BEACH

BA050	Beach
ZD020	Void Collection Area

3. DATA QUALITY

ZD020	Void Collection Area
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4. DEMARCATION

Boundaries/Limits/Zones (Topographic)

FA000	Administrative Boundary
FA001	Administrative Area
FA005	Access Zone
FA015	Firing Range/Gunnery Range
FA020	Armistice Line
FA030	Cease-Fire Line
FA040	Claim Line
*FA041	Contact Zone
FA050	Mandate Line/Convention Line
FA060	Defacto Boundary
FA070	Demilitarized Zone
FA090	Geophysical Prospecting Grid
FA110	International Date Line
FA165	Training Area
FA170	Zone of Occupation

Boundaries/Limits/Zones (Hydrographic)

FC021	Maritime Limit Boundary
FC031	Maritime Area

- *FC035 Pond Partition
- FC036 Restricted Area
- FC040 Traffic Separation Scheme System
- *FC041 Traffic Separation Scheme (TSS)
- FC100 Measured Distance Line
- FC130 Radar Reference Line
- FC165 Route (Maritime)
- *FC166 Deep Water Route
- *FC167 Defined Water
- *FC168 Canal Route
- FC170 Safety Fairway
- *FC177 Swept Area

Miscellaneous

- AL025 Cairn
- AL070 Fence
- AL260 Wall
- ZD020 Void Collection Area

Other

- _____ Sensitivity Areas
- _____ Low Intensity Conflict Areas
- _____ Key Tracking Areas

5. ELEVATION

- CA010 Contour Line (Land)
- CA020 Ridge Line
- CA025 Valley Bottom Line
- CA026 Breakline (*useful in TIN generation*)
- CA030 Spot Elevation
- CA035 Inland Water Elevation
- CA040 Contour Polygon (Land) (*probable attribution: irregular triangle for TIN*)

Other

- SA050 Slope Polygon
- ZD020 Void Collection Area
- _____ Berm/Barricade

6. HYDROGRAPHY

Coastal Hydrography

- BA010 Coastline/Shoreline
- BA020 Foreshore
- BA030 Island
- BA040 Water (Except Inland)
- *BA051 Dyke Crown
- _____ Surf

Ports and Harbors

BB005 Harbor
*BB006 Harbor Complex
*BB007 Channel Edge
BB010 Anchorage
*BB012 Anchor Berth
BB019 Anchor
BB020 Berth
*BB021 Mooring Trot
BB022 Basin
*BB030 Bollard
BB040 Breakwater/Groyne
*BB042 Mole
BB050 Calling-In Point
BB079 Mooring/Warping Facility
BB080 Dolphin
BB081 Shoreline Construction
BB090 Drydock
*BB100 Fish Stakes
BB105 Fishing Harbor
BB110 Fish Traps/Fish Weirs
BB111 Tunny (Tuna) Nets Area
BB115 Gridiron
BB140 Jetty
BB150 Landing Place
BB151 Landing Stairs
BB160 Mooring Ring
BB170 Offshore Loading Facility
*BB180 Oyster Bed/Mussel Bed
BB190 Pier/Wharf/Quay
BB199 Floating Dock
BB200 Pump Out Facility
BB201 Small Craft Facility
BB220 Ramp (Maritime)
BB230 Seawall
BB240 Slipway/Patent Slip
BB250 Watering Place
SU003 Port Facility

NAVAIDs

BC010 Beacon
BC020 Buoy
BC030 Leading Light(s)
BC031 Navigation Line
BC032 Radar Line
BC033 Radar Range

- BC035 Lights in Line
- BC040 Light
- BC050 Lighthouse
- BC055 Marker
- BC060 Light Sector
- BC070 Light Vessel/Lightship
- BC080 Perches/Stakes
- BC100 Leading Line
- BC101 Fog Signal

Dangers/Hazards

- BD000 Underwater-Danger/Hazard
- BD001 Mine
- BD005 Miscellaneous Underwater Feature
- BD010 Breakers
- BD020 Crib
- BD030 Discolored Water
- BD040 Eddies
- BD050 Foul Ground
- BD060 Kelp/Seaweed
- BD070 Obstruction (Nautical)
- BD071 Log Boom/Booming Ground
- BD072 Pontoon
- BD073 Oil Barrier
- BD074 Chain/Wire
- BD079 Fishing Facility
- BD080 Overfalls/Tide Rips
- BD100 Pile/Piling/Post
- BD110 Platform
- BD111 Offshore Platform Site (cleared)
- BD112 Production Installation
- BD119 Ledge
- BD120 Reef
- *BD121 Pingo
- BD130 Rock
- BD140 Snags/Stumps
- BD180 Wreck
- BD181 Hulk
- _____ Spoil/Disposal Area
- _____ Mine-Like Objects
- _____ Seamount

Depth Information

- BE010 Depth Curve
- BE015 Depth Contour
- *BE019 Depth Area
- BE020 Sounding

BE021 Drying Line, Low Water Line-LWL
 BE022 Sand Line
 BE023 Mud Line
 BE029 Bottom Return
 BE030 Track Swath
 BE040 Track Line

Bottom Features

BF010 Bottom Characteristics
 BF011 Bottom Feature
 _____ Bottom Type (acoustic)
 _____ False Acoustic Targets
 _____ Underwater Canyon
 _____ Shelf

Tide and Current Information

BG010 Current Flow
 BG011 Tideway
 BG012 Water Turbulence
 BG020 Tide Gauge
 BG030 Tide Data Point
 BG040 Current Diagram
 _____ Sound Speed Profiles

Inland Water

BH000 Inland Water
 BH010 Aqueduct
 BH015 Bog
 BH020 Canal
 BH030 Ditch
 BH040 Filtration Beds/Aeration Beds
 BH050 Fish Hatchery/Fish Farm/Marine Farm
 BH060 Flume
 BH070 Ford
 BH075 Fountain
 BH077 Hummock
 BH080 Lake/Pond
 BH090 Land Subject to Inundation
 *BH091 Flooded Area
 BH095 Marsh/Swamp
 BH100 Moat
 BH110 Penstock
 *BH115 Underground Water/Phreatic Water
 BH120 Rapids
 BH130 Reservoir
 BH135 Rice Field
 BH140 River/Stream
 BH141 River Bank

BH145 River Stream Vanishing Point
 BH150 Salt Pan
 BH155 Salt Evaporator
 BH160 Sebkha
 BH165 Spillway
 BH170 Spring/Water-Hole
 BH175 Trough
 BH180 Waterfall
 BH190 Lagoon/Reef Pool
 BH200 Miscellaneous Surface Drainage Feature
 BH210 Inland Shoreline
 BH501 River Navigation Route

Miscellaneous Inland Water

BI005 Boat Lift
 BI010 Cistern
 BI020 Dam/Weir
 BI030 Lock
 *BI039 Sluice
 BI040 Sluice gate
 BI041 Gate (Nautical)
 BI042 Caisson
 BI043 Flood Barrage
 BI050 Water Intake Tower
 *BI060 Fish Ladder
 BI070 Gauging Station

Snow/Ice

BJ020 Moraine
 BJ030 Glacier
 BJ040 Ice Cliff
 BJ060 Ice Peak/Nunatak
 BJ065 Ice Shelf
 BJ070 Pack Ice
 BJ080 Polar Ice
 BJ100 Snow Field/Ice Field
 BJ110 Tundra

Other

ZD020 Void Collection Area
 SA010 Common Open Water
 SA060 Covered Drainage

7. INDUSTRY

Extraction

AA010 Mine
 AA011 Quarry/Mine Shear Wall

AA012 Quarry
AA013 Pit
AA040 Rig/Superstructure
AA050 Well
AA051 Wellhead
AA052 Oil/Gas Field

Disposal

AB000 Disposal Site/Waste Pile
AB010 Wrecking Yard/Scrap Yard
*AB020 Burner
*AB021 Diffuser

Processing Industry

AC000 Processing Plant/Treatment Plant
AC010 Blast Furnace
AC020 Catalytic Cracker
AC030 Settling Basin/Sludge Pond
AC040 Oil/Gas Facilities
AC050 Works

Associated Industrial Structures

AF010 Chimney/Smokestack
AF020 Conveyor
AF030 Cooling Tower
AF040 Crane
*AF041 Sheerlegs (Shear Legs)
AF050 Dredge/Powershovel/Dragline
AF060 Engine Test Cell
AF070 Flare Pipe
AF080 Hopper

Agriculture

AJ010 Circular Irrigation System
*AJ020 Siphon
AJ030 Feed Lot/Stockyard/Holding Pen
AJ050 Windmill
*AJ051 Windmotor

Miscellaneous

AL140 Particle Accelerator
AL240 Tower (Non-Communication)
AL241 Tower (General)

Storage

AM010 Depot (Storage)
AM020 Grain Bin/Silo
AM030 Grain Elevator
AM060 Storage Bunker/Storage Mound
AM070 Tank
AM080 Water Tower

*AM031 Timber Yard

*AM040 Mineral Pile

Other

ZD020 Void Collection Area

8. PHYSICAL GEOGRAPHY

Exposed Surface Materials

DA005 Asphalt Lake

*DA006 Alkali Flats

DA010 Ground Surface Element

DA020 Barren Ground

*DA030 Land Area

*DA031 Land Region

SA020 Disturbed Soil

SA030 Exposed Bedrock

Landforms

DB010 Bluff/Cliff/Escarpment

DB030 Cave

DB031 Hill

DB060 Crevice/Crevasse

DB070 Cut

DB080 Depression

DB090 Embankment/Fill

DB100 Esker

DB110 Fault

DB115 Geothermal Feature

DB145 Miscellaneous Obstacle

DB150 Mountain Pass

DB160 Rock Strata/Rock Formation

DB170 Sand Dune/Sand Hills

DB176 Slope Category

DB180 Volcano

DB190 Volcanic Dike

DB200 Gully/Gorge

DB210 Potential Landslide Area

*DB211 Landslide

DB230 Fan

DB240 Karst

DB500 Bottomline of Cliff

DB501 Topline of Cliff

Other

ZD020 Void Collection Area

SA040 Permanent Snowfield

9. POPULATION

Institutional/Government

- AH010 Bastion/Rampart/Fortification
- AH020 Trench
- AH050 Fortification
- AH060 Underground Bunker
- AH070 Checkpoint
- SU001 Military Base

Residential

- AI020 Mobile Home/Mobile Home Park
- AI030 Camp

Recreational

- AK020 Amusement Park Attraction
- AK030 Amusement Park
- AK040 Athletic Field
- AK050 Tennis Court(s)
- AK060 Campground/Campsite
- *AK061 Picnic Site
- *AK070 Drive-In Theater
- *AK080 Drive-In Theater Screen
- AK090 Fairground
- AK091 Exhibition Grounds
- AK100 Golf Course
- *AK101 Golf Driving Range
- AK110 Grandstand
- AK120 Park
- *AK121 Lookout
- AK130 Race Track
- AK150 Ski Jump
- AK155 Ski Track
- AK160 Stadium/Amphitheater
- AK170 Swimming Pool
- AK180 Zoo/Safari Park

Miscellaneous

- *AL005 Animal Sanctuary
- AL012 Archeological Site
- AL015 Building
- AL018 Building Superstructure Addition
- AL019 Shed
- AL020 Built-Up Area
- AL030 Cemetery
- *AL040 Cliff Dwelling
- AL045 Complex Outline
- AL050 Display Sign

- AL073 Flagstaff/Flagpole
- *AL075 Gallery
- *AL080 Gantry
- *AL090 Grave Marker
- AL100 Hut
- AL101 Cabin
- AL105 Settlement
- *AL110 Light Standard/Light Support
- *AL116 Calvary Cross
- AL130 Monument
- AL135 Native Settlement
- *AL141 Telescope
- *AL155 Overhead Obstruction Location
- AL170 Plaza/City Square
- AL120 Missile Site
- *AL195 Ramp
- AL200 Ruins
- AL201 Historic Site/Point of Interest
- AL220 Steeple
- *AL250 Underground Dwelling

Other

- ZD020 Void Collection Area

10. TRANSPORTATION

Miscellaneous

- AL060 Dragon Teeth
- AL210 Snow Shed/Rock Shed

Railroad

- AN010 Railroad
- AN050 Railroad Siding/Railroad Spur
- AN060 Railroad Yard/Marshalling Yard
- AN075 Railroad Turntable
- AT100 Electrified Railroad Pylon

Road

- AP010 Cart Track
- AP020 Interchange
- AP030 Road
- AP040 Gate
- AP041 Barrier
- AP050 Trail
- *AP060 Drove

Associated Transportation

- AQ010 Aerial Cableway Lines/Ski Lift Lines
- AQ020 Aerial Cableway Pylon/Ski Pylon

- *AQ021 Mast
- AQ030 Boardwalk
- AQ040 Bridge/Overpass/Viaduct
- AQ045 Bridge Span
- AQ050 Bridge Superstructure
- AQ055 Bridge Tower/Bridge Pylon
- AQ056 Bridge Pier
- AQ058 Constriction/Expansion
- AQ060 Control Tower
- AQ062 Crossing
- AQ064 Causeway
- AQ065 Culvert
- AQ070 Ferry Crossing
- AQ080 Ferry Site
- AQ090 Entrance/Exit
- AQ100 Landmark Post/Distance Post
- AQ110 Mooring Mast
- AQ111 Prepared Raft or Float Bridge Site
- AQ113 Pipeline/Pipe
- AQ116 Pumping Station
- AQ118 Sharp Curve(s)
- AQ120 Steep Grade
- AQ125 Station (Miscellaneous)
- AQ130 Tunnel
- AQ135 Vehicle Stopping Area/Rest Area
- AQ140 Vehicle Storage/Parking Area
- AQ150 Flight of Steps

Aerodrome

- GB005 Airport/Airfield
- GB006 Airfield
- *GB007 Airport Area
- GB010 Airport Lighting
- GB015 Apron/Hardstand
- GB020 Arresting Gear
- GB025 Blast Barrier
- GB030 Helicopter Landing Pad
- GB035 Heliport
- GB040 Launch Pad
- GB045 Overrun/Stopway
- GB050 Revetment (Airfield)
- GB055 Runway
- GB057 Shoulder
- GB060 Runway Radar Reflector
- GB065 Seaplane Base
- GB070 Seaplane Landing/Seaplane Take-Off Area

GB075 Taxiway
 GB080 Wind Indicator
 GB160 Decontamination Pad
 GB170 INS Alignment Pad
 GB220 Air Obstruction
 GB221 Miscellaneous Air Obstruction

Other

SU002 Subway
 ZD020 Void Collection Area
 _____ Route/Distance Marker
 _____ Fueling Areas

11. UTILITY

Power Generation

AD010 Power Plant
 AD020 Solar Panels
 AD030 Substation/Transformer Yard
 AD040 Nuclear Reactor

Communications/Transmission

AT005 Cable
 AT010 Disk/Dish
 AT020 Early Warning Radar Site
 AT030 Power Transmission Line
 AT040 Power Transmission Pylon/Line
 AT041 Telpher
 AT045 Radar Transmitter
 AT050 Communication Building
 AT060 Telephone Line/Telegraph Line
 AT070 Telephone-Telegraph Pylon/Pole
 AT080 Communication Tower
 _____ Telephone Station
 _____ Communication Nodes
 _____ Poles

Other

ZD020 Void Collection Area
 _____ Condensation Line
 _____ Steam Line

12. VEGETATION

Cropland

EA010 Cropland
 EA020 Hedgerow
 EA030 Nursery
 EA031 Botanical Garden

- EA040 Orchard/Plantation
- EA050 Vineyards
- EA055 Hops
- Rangeland**
 - EB010 Grassland
 - EB015 Grass/Scrub/Brush
 - EB020 Scrub/Brush
 - EB030 Land Use/Land Cover (Vegetation)
- Woodland**
 - EC010 Bamboo/Cane
 - EC015 Forest
 - EC020 Oasis
 - EC030 Trees
 - EC040 Cleared Way/Cut Line/Firebreak
- Wetland**
 - _____ Wetlands
- Miscellaneous Features**
 - EE000 Miscellaneous Vegetation
- Other**
 - ZD020 Void Collection Area

Some general features which may also be included in one or more of the above are as follows:

Control Points

- ZB020 Benchmark
- ZB030 Boundary Monument
- ZB035 Control Point/Control Station
- ZB036 Distance Mark
- ZB040 Diagnostic Point
- ZB060 Geodetic Point

Magnetic Variation

- ZC040 Magnetic Disturbance Area
- ZC050 Isogonic Lines
- ZC051 Magnetic Pole

Miscellaneous

- ZD001 Network
- ZD003 Artifact Location
- ZD012 Geographic Information Point
- ZD015 Point of Change
- ZD020 Void Collection Area
- ZD040 Named Location
- ZD045 Text Description